TECHNICAL AND TRADE INFORMATION

EXPLANATION OF TERMS RELATING TO . . .

MECHANICAL PROPERTIES OF WELD METAL

The mechanical properties of a metal describe its suitability for any given application and provide a performance forecast. Mechanical properties are of the utmost concern in welding consumable qualification since weld deposits must often provide service characteristics equal to or better than those of the base metal. The properties considered most often (and those that are frequently cited in Welding Consumable Specification requirements) are **Strength, Hardness, Ductility and Impact Resistance.**

1. Strength:

A metal's "strength" is its capacity to withstand external forces without breaking. In a tension test, under stretch loading, a specimen reveals several features - including elastic limit, elongation, yield point, yield strength, tensile strength and reduction in area. During the test, load is increased gradually and the specimen stretches in direct proportion to the load until it reaches its **Yield Poin**t. At any point up to the yield point, if the load is relaxed, the specimen will return to its original dimensions. Beyond the yield point, the specimen continues to elongate without an increase in load. An increase in load after the yield point brings the specimen to another critical point - **Tensile Strength**, or **Ultimate Tensile Strength** - at which the specimen breaks. Yield point and tensile strength values (in psi or MPa) are obtained by dividing the load at these points by the original cross-sectional area of the specimen.

2. Hardness:

A metal's hardness is its capacity to resist surface indentation by a contacting medium. Measuring the indent size of a hardened steel ball or a diamond upon the surface of a specimen assigns value to a metal's hardness. Indent size is translated to a hardness value. Typical units of measure being
Rockwell Hardness (HR_A, HR_B & HR_C Scales), **Vickers Hardness** (HV_{20} & HV_{30} Scales) and **Brinel Hardness**.

3. Ductility:

Ductility is the characteristic of metal that allows it to withstand stretching and other deformation without breaking and to hold a new shape after external forces have been removed. Determined in a tensile test, **Percent of Elongation** is the measure of ductility. Gauge marks are made 50 mm (2 inches) apart, bounding the point at which fracture will occur, on a test specimen. The increase in gauge length, divided by the original length, x 100, equals the elongation percentage. Ductility can also be measured in a bend test.

4. Impact Resistance

This property is assessed in terms of **Impact Strength or Impact Toughness**, determined most often in a **Charpy Vee Notch (CVN) or Charpy Test**. The specimen, a beam with a notch at its centre ("V-notch" preparation is most common), is supported at both ends and struck with a pendulum on the side opposite the notch. Measuring the energy absorbed during the test, (weight of pendulum x height of pendulum upon release x height to which pendulum swings after striking specimen) gives an impact-strength value in **joules or foot-pounds**. Since steels often become more brittle (less able to absorb energy) at lower temperatures, impact tests are often carried out at a range of low temperatures.

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TERMS AND DEFINITIONS IN WELDING

A.	▲ Arc Blow	The deflection of an arc from its normal path because of magnetic forces. Normally occurs on DC current when welding carbon steel.
	▲ Arc Voltage	The voltage across the welding arc.
	▲ Arc Length	The distance from the tip of the welding electrode to the adjacent surface of the weld pool. Also known as "Arc Gap".
	▲ Arc Time	The time during which an arc is maintained in making an arc weld.
	▲ As-welded	Pertaining to the condition of weld metal, welded joints and weldments after welding, but prior to any subsequent thermal, mechanical or chemical treatments.
	▲ Autogeneous Weld	A fusion weld made without filler metal.
B.	▲ Back bead	A weld resulting from a back weld pass. Also known as "Back Filling" or "Backing Pass"
	▲ Backgouging	The removal of weld metal and base metal from the weld root side of a welded joint to allow complete fusion and complete joint penetration upon subsequent welding from that side.
	▲ Backing Strip	A material (metal, carbon, ceramic etc.) for backing up a joint during welding to help obtain a sound weld.
	▲ Backing Ring	As above, but in the form of a ring, generally used in pipe welding.
	▲ Backstep Sequence	Weld passes are made in the opposite direction to the progress of welding.
	▲ Base Metal	The metal alloy that is being welded. Also known as "Base Material" or Work Piece".
	▲ Bevel Angle	The angle formed between the prepared edges of two plates.
	▲ Build up	Layers of weld metal deposited when surfacing material to achieve a required dimension. Also known as "Buttering" and "Cladding".
	▲ Buffer Layer	Layers of weld metal on components which prevent crack formation or dilution effects in subsequent weld layers. See also "build up".
C.	▲ Consumable insert	Preplaced filler metal that is completely fused into the root of a joint and becomes part of the finished weld.

TERMS AND DEFINITIONS IN WELDING CONT.

	▲ Crater	A depression at the termination of the weld bead.
D.	▲ Deposition Efficiency	The ratio of the weight of filler metal deposited in the weld metal to the weight of filler metal melted, expressed in percent.
	▲ Deposition Rate	The weight of material deposited in a unit of time.
	▲ Depth of Fusion	Distance that fusion extends into the base metal from the surface being welded.
	▲ Dilution	A chemical composition change of the deposited weld metal due to admixture of the filler metal and base metal.
	▲ Direct Current Electrode Negative	The electrode lead and welding electrode are connected to the negative pole on the welding machine. Also known as DC - or DCEN and DC straight polarity (Negative = 1/3 Heat)
	▲ Direct Current Electrode Positive	The electrode lead and welding electrode are connected to the positive pole on the welding machine. Also known as DC+ or DCEP and DC reverse polarity. (Positive = 2/3 Heat)
E.	▲ Edge Preparation	The surface prepared on the edge of a joint for welding.
	▲ Electrode Lead	Conductor between source of current and electrode holder.
F.	▲ Flux	Fusible material for removal of oxides impurities and to create gas for shielding and slag for shape and contour.
	▲ Fusion	The melting together of filler metal and base metal or a base metal only to produce a weld.
G.	▲ Ground Lead	The electrical conductor between the arc welding current source and work piece connection. Also known as "Work Lead".
H.	▲ Hardfacing	The process of covering a surface with wear-resistant metal by welding to reduce wear.
	▲ Heat affected Zone	The region beneath or around the weld bead which has not melted, but whose mechanical properties or microstructure has been altered by the heat of welding.
I.	▲ Infra-Red Radiation	Electromagnetic energy with wavelengths from 770 to 12,000 nanometers.
	▲ Intermittent Welding	Is welding wherein continuity is broken by recurring unwelded spaces.

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TERMS AND DEFINITIONS IN WELDING CONT.

	▲ Interpass Temperature	In a multiple run weld, the lowest temperature of deposited metal before the next pass is started. Normally measured 25mm from the weld metal centre line.
L.	▲ Liquidus	The lowest temperature at which a metal or an alloy is completely liquid.
	▲ Longitudinal Sequence	The order in which weld passes of a continuous weld are made along its length.
M.	▲ Melt-Through	Is the visible root re-inforcement obtained in a one sided weld joint.
O.	▲ Open Circuit Voltage	The voltage between terminals of a power source when no current is flowing.
P.	▲ Parent Metal	Same as "Base Metal".
	▲ Peening	The mechanical working of metals by light hammering.
	▲ Penetration	The depth a weld extends into a joint from the metal surface
	▲ Post-heating	Application of heat to the weldment after welding is completed.
	▲ Preheating	Application of heat to the base metal before welding commences.
	▲ Procedure Qualification	To establish that welds made by a defined method can meet prescribed standards.
R.	▲ Residual Stress	Stress that is present in a joint member or material that is free of external forces.
	▲ Root Bead	A weld which is part or all of the root joint.
	▲ Root Bend Test	A test in which the root surface is bent around a specified radius.
	▲ Runoff / Runon Weld Tab	Is additional plate that extends beyond the end of the weld joint on which the weld is finished or started. (Also known as an End Tab)
S.	▲ Seal Weld	A weld made primarily to seal a joint for tightness against leakage.
	▲ Short Arc (short circuiting) transfer	Is metal transfer where molten metal from an electrode is deposited during repeated short circuits.
	▲ Sidewall	The surface of a joint wall included inside the preparation of a butt weld.
	▲ Side Bend Test	A test in which the side of a transverse section of the weld is bent around a specified radius.

TERMS AND DEFINITIONS IN WELDING CONT.

	▲ Slag Inclusion	Non-metallic solid material trapped in weld metal or between weld and base metal.
	▲ Spatter	Metal particles expelled during welding which do not form part of the weld.
	▲ Spray Transfer	Metal transfer where molten metal from an electrode is propelled across the arc in small droplets.
	▲ Stringer Bead	A weld bead made without weaving.
	▲ Suck-Back	A concave root surface.
T.	▲ Tack Weld	A small weld made to hold parts in proper alignment until final welds are made.
U.	▲ Underbead Crack	A crack in the heat affected zone which may or may not extend to the surface of the base metal.
	▲ Underfill	A depression on the weld face dropping below the surface of the base metal.
V.	▲ Vertical-down	Welding in a downhill direction.
	▲ Vertical-up	Welding in an uphill direction.
W.	▲ Weave Bead	A weld bead made with slow oscillation motion of the electrode, best limited in width to 2-3 times the diameter of the electrode.
	▲ Welder Certification	Written verification that a welder has produced welds meeting a prescribed standard of weld performance.
	▲ Welding Arc	A controlled electrical discharge between the electrode and the work piece that is formed and sustained by the establishment of a gaseous conductive medium, called an arc plasma.
	▲ Welding Procedure Qualification Record (WPQR)	A record of welding variables used to produce an acceptable test weld and the results of the tests conducted on that weld which qualify a welding procedure specification.
	▲ Welding Procedure Specification (WPS)	A document providing the detailed variables for a specific welding application to ensure reproduction by trained welders.
	▲ Work Lead	The conductor between source of current and the work piece or work table.
	▲ Work Piece	The job, part or component being welded.

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BASIC TYPES OF WELDED JOINTS

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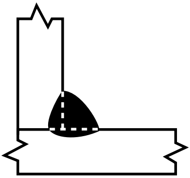
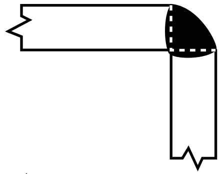
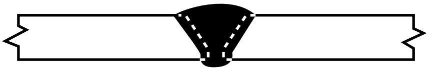
A) FILLET WELD



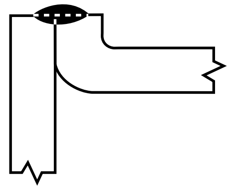
B) CORNER WELD



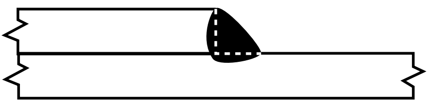
C) BUTT WELD



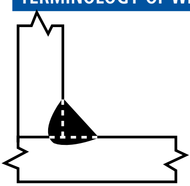
D) EDGE WELD



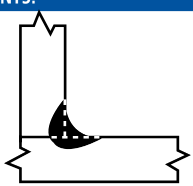
E) LAP WELD



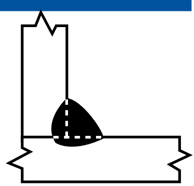
TERMINOLOGY OF WELD JOINTS:



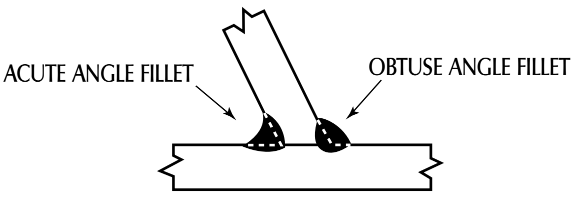
TRUE MITRE



CONCAVE

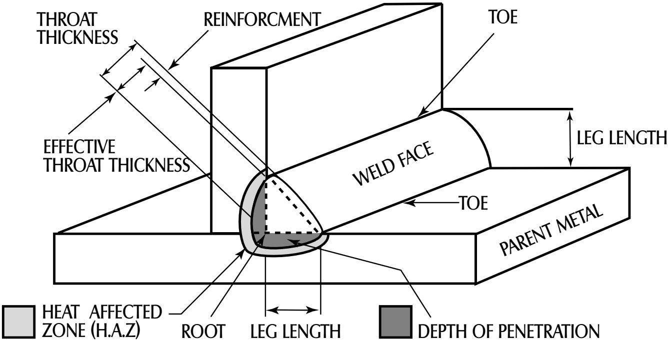


CONVEX

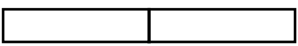


BASIC TYPES OF WELDED JOINTS CONT.

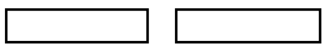
FILLET WELD DEFINITIONS:



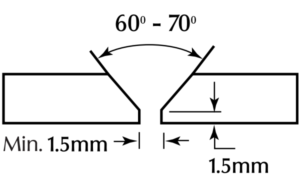
BUTT WELD - PREPARATIONS:



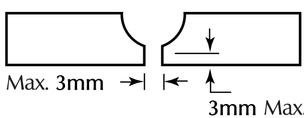
CLOSED SQUARE BUTT
Suitable for plate up to
5mm in thickness



OPEN SQUARE BUTT
>3mm ≤8mm



SINGLE VEE BUTT
>6mm ≤16mm



SINGLE U BUTT
>8mm <25mm

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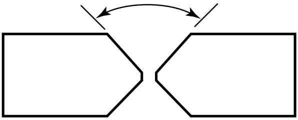
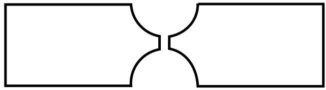
BASIC TYPES OF WELDED JOINTS CONT.

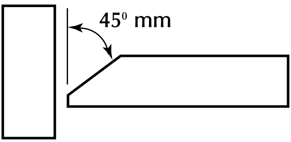
BUTT WELD - PREPARATIONS cont.:



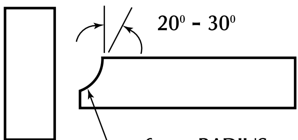
DOUBLE VEE BUTT
>16mm ≤40mm



DOUBLE U BUTT
Used on plate over
25mm thick

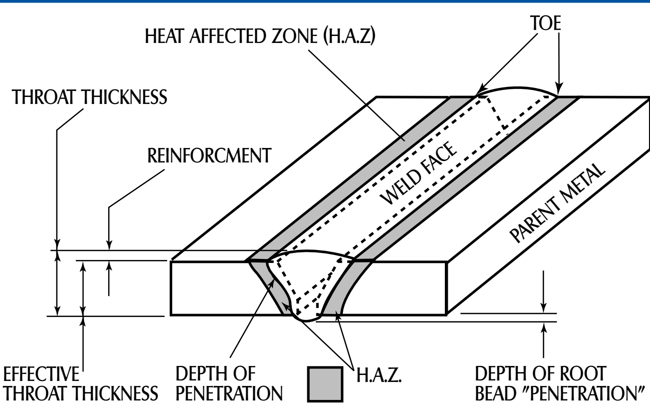


SINGLE BEVEL BUTT WELD
>6mm ≤25mm



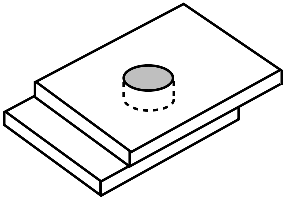
SINGLE J BEVEL BUTT WELD
>8mm 25mm

(i) BUTT WELD DEFINITIONS:

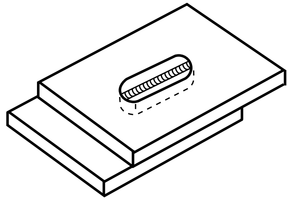


.BASIC TYPES OF WELDED JOINTS CONT.

OTHER WELDS:



PLUG WELDS



SLOT WELDS

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WELDING POSITIONS AND SYMBOLS

PLATE AND PIPE POSITIONS TO ISO AND AS/AWS STANDARDS:

- ISO STANDARD 6947
- AUSTRALIAN STANDARD AS 3545
- AMERICAN WELDING SOCIETY AWS A3.0

PLATE AND PIPE WELDING POSITIONS TO ISO:

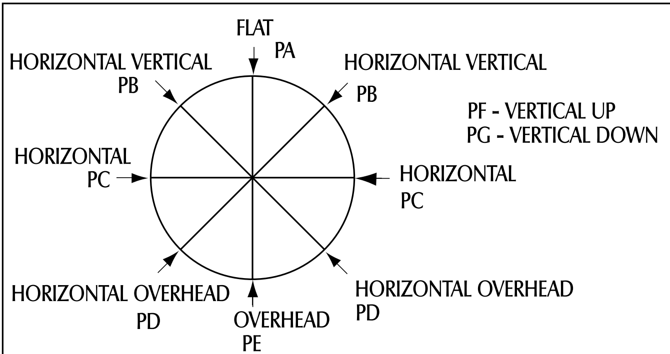
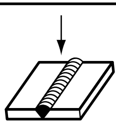
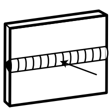
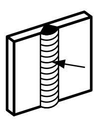
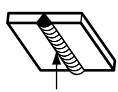
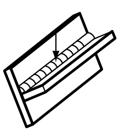
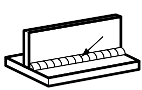
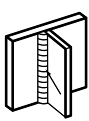
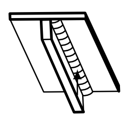
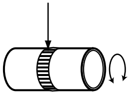
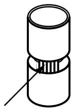
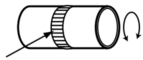
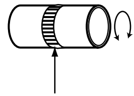
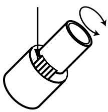
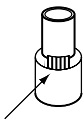
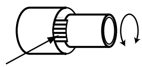
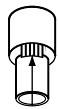


PLATE POSITIONS:

WELD	FLAT	HORIZONTAL	VERTICAL	OVERHEAD
BUTT	 1G / PA	 2G / PC	 3G / PF PG	 4G / PE
FILLET	 1F / PA	 2F / PB	 3F / PF PG	 4F/ PE

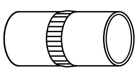
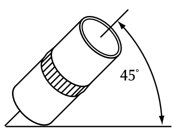
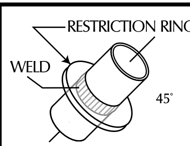
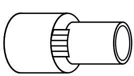
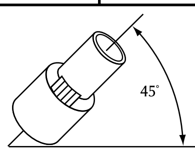
WELDING POSITIONS AND SYMBOLS CONT.

PIPE POSITIONS - ROTATED OR ROLLED:

	FLAT	HORIZONTAL	VERTICAL	OVERHEAD
BUTT	 1G / PA	 2G / PC	 3G /PF	 4G / PE
FILLET	 1F / PA	 2F /PC	 *3F/PF (AWS 2F,R)	 *4F/PE (AWS 4F,F)

* ONLY APPLIES TO AS 3545 and ISO 6947

PIPE POSITIONS - FIXED POSITION:

BUTT	 5G / PF PG	 6G /H -L045	 6GR
FILLET	 5F / PF PG	 * 6F / L45 PA	

* NOTE: ONLY APPLIES TO AS 3545 and ISO 6947

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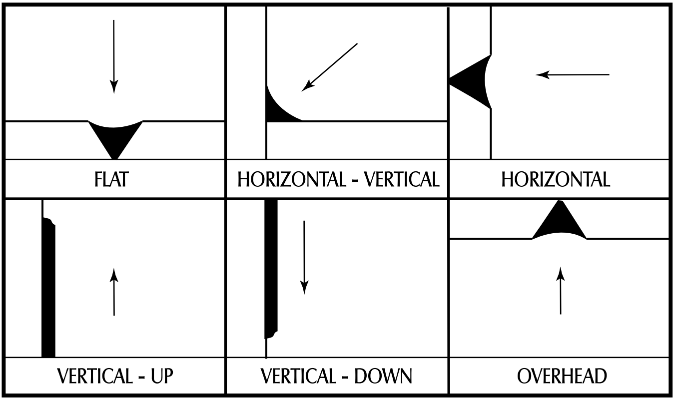
WELDING POSITIONS AND SYMBOLS CONT.

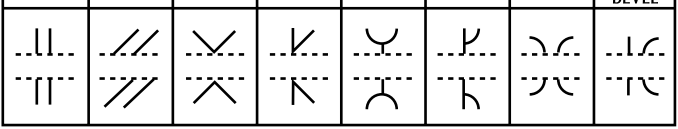
WELDING DIRECTIONS OR POSITIONS:



COMPARISON OF BASIC DRAWING (PRINTS) WELDING SYMBOLS:

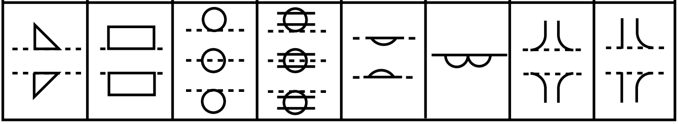
(i) AS 1101.3 /AWS A2.4
AS 1101.3 BUTT WELD / AWS A2.4 GROOVE WELD

BUTT WELD							
SQUARE	SCARF	V	BEVEL	U	J	FLARE- V	FLARE BEVEL



(ii) AS 1101.3

FILLET WELD	PLUG WELD OR SLOT WELD	SPOT WELD OR PROJECTION WELD	SEAM WELD	BACKING RUN OR BACKING WELD	SURFACING	FLANGE WELD	
						EDGE	CORNER

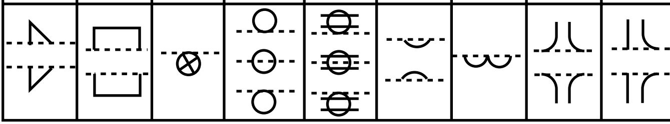


WELDING POSITIONS AND SYMBOLS CONT.

COMPARISON OF BASIC DRAWING (PRINTS) WELDING SYMBOLS cont.:

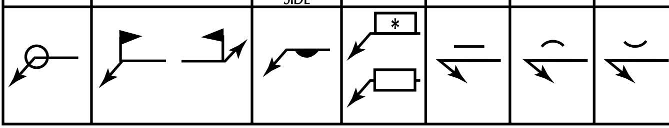
AWS A2.4

FILLET	PLUG OR SLOT	STUD	SPOT OR PROJECTION	SEAM	BACK OR BACKING	SURFACING	FLANGE	
							EDGE	CORNER



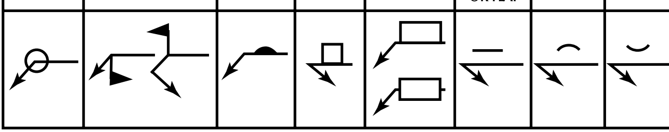
AS 1101.3

WELD ALL AROUND	SITE WELD	COMPLETE PENETRATION FROM ONE SIDE	BACKING OR SPACER MATERIAL	CONTOUR		
				FLUSH	CONVEX	CONCAVE



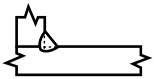
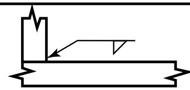
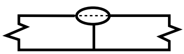
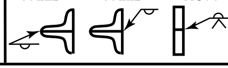
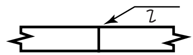
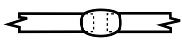
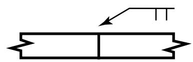
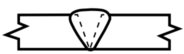
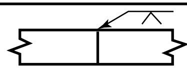
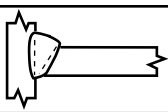
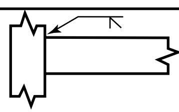
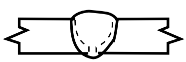
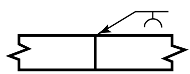
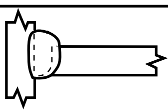
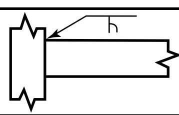
AWS A2.4

WELD ALL AROUND	SITE WELD	MELT THROUGH	CONSUM. INSERT (SQUARE)	BACKING OR SPACER (RECTANGLE)	CONTOUR		
					FLUSH OR FLAT	CONVEX	CONCAVE



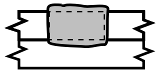
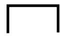
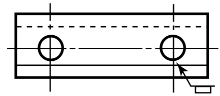
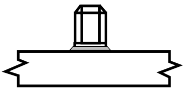
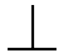
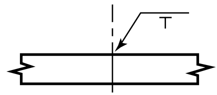
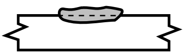
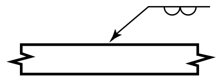
WELDING POSITIONS AND SYMBOLS CONT.

HOW WELDING SYMBOLS ARE USED:

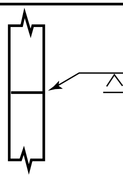
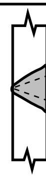
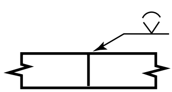
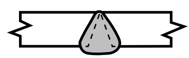
TYPE OF WELD	SKETCH OF WELD	SYMBOL	INDICATION OF DRAWING
FILLET WELD			
BEAD			EDGE WELD / SEAL WELD / BACKING RUN 
BUTT WELDS			
GENERAL BUTT	FULL PENETRATION BUTT WELD BY A WELDING PROCEDURE TO BE AGREED		
SQUARE BUTT			
SINGLE 'V' BUTT			
SINGLE BEVEL BUTT			
SINGLE 'U' BUTT			
SINGLE 'J' BUTT			

WELDING POSITIONS AND SYMBOLS CONT.

HOW WELDING SYMBOLS ARE USED cont.:

TYPE OF WELD	SKETCH OF WELD	SYMBOL	INDICATION OF DRAWING
PLUG OR SLOT			
STUD			
SURFACING			

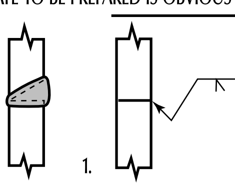
WELD FINISH

TYPE OF WELD	SYMBOL	INDICATION OF DRAWING	SKETCH OF WELD
FLUSH FINISH			
CONVEX FINISH			

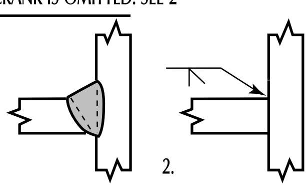
CRANKED ARROW

A. A CRANKED ARROW IS USED WITH A BEVEL OR "J" WELD SYMBOL POINTING TOWARD THE PLATE WHICH IS PREPARED. SEE 1

B. IF PLATE TO BE PREPARED IS OBVIOUS THE CRANK IS OMITTED. SEE 2



1.



2.

Email: cigweldsales@cigweld.com.au

DEFECTS IN WELDING

Types of Defects:

- EXTERNAL DEFECTS: Can be identified by a visual inspection method eg: Dye Penetrant and Magnetic Particle testing.
- INTERNAL DEFECTS: Require a Non-Destructive testing (NDT) method eg: X-Ray or Ultrasonic testing.

(i) Main Causes :

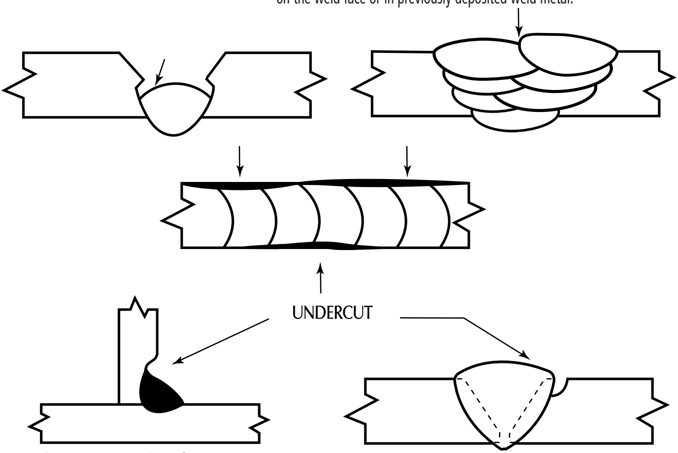
- Welding operators carelessness or lack of skill.
- Adverse working conditions (Hot - Cold).
- Poor Design or lack of preparation.

(ii) Main Defects:

- **Undercut.**
- **Slag inclusions.**
- **Porosity.**
- **Overlap or over-roll.**
- **Lack of fusion.**
- **Incomplete penetration.**
- **Weld cracking.**
- **Joint Misalignment.**

Undercut:

- Definition: A groove at the toe or root of a weld either on the weld face or in previously deposited weld metal.



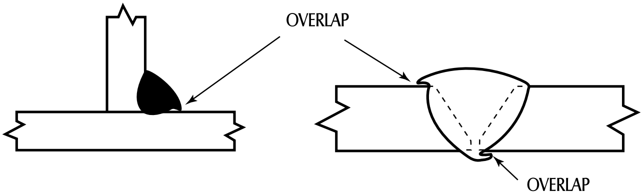
Causes:
- Excessive amperage.
- Too long an arc length .
- Excessive weaving of the electrode.
- Too fast a rate of travel.
- Angle of electrode too inclined to the joint face.

Result: A stress concentration site and a potential site for fatigue

DEFECTS IN WELDING CONT.

Overlap or over-roll:

▲ Definition: An imperfection at the toe or root of a weld caused by metal flowing onto the surface of the parent metal without fusing to it.

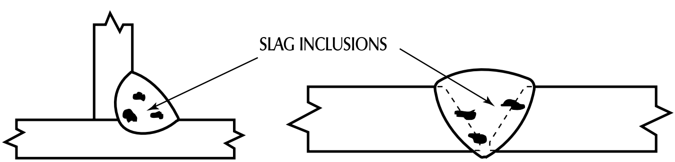


Causes:
- Incorrect rate of travel.
- Incorrect "angle of approach".
- Too large an electrode size.
- Too low an amperage.

Result: Has a similar effect as undercut and produces a stress concentration site due to the unfused weld metal.

Slag Inclusions:

▲ Definition: Refers to any non-metallic material in a completed weld joint. These inclusions can create a weak point in the weld deposit.



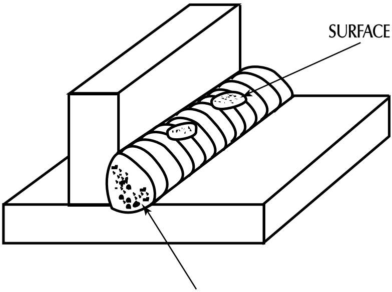
Causes:
- Failure to remove slag from previous runs.
- Insufficient amperage.
- Incorrect electrode angle or size.
- Faulty preparation.

Result: Slag inclusions reduce the cross sectional area strength of the weld and serve as a potential site for cracking.

DEFECTS IN WELDING CONT.

Porosity:

Definition: A hole or cavity found internally or externally in the weld. Porosity can originate from wet electrodes, electrode flux breaking down or from impurities on the surface of the parent metal.
Also known as "Piping", "Blow or Worm Holes"

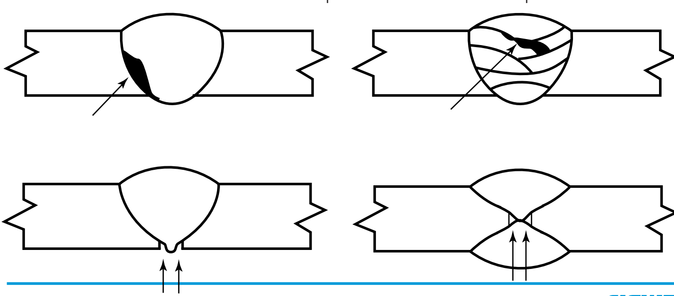


Other Causes: - Unclean parent metal surface ie. oil, dust, dirt or rust contamination.
- Incorrect electrode for parent metal.
- Inadequate gas shielding of the arc.
- Parent metals with a high percentage of sulphur and phosphorus.

Result: Severely reduces the strength of the welded joint.
Surface porosity can allow a corrosive atmosphere to attack the weld metal which may cause failure.

Lack of Fusion:

Definition: A lack of bonding between the weld metal and the parent metal or between weld metal passes.



DEFECTS IN WELDING CONT.

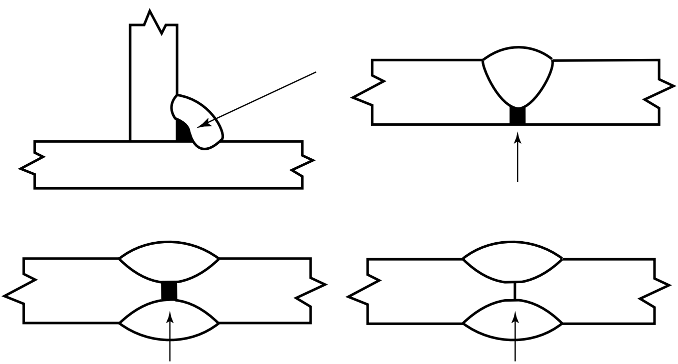
Lack of Fusion cont.:

Causes:
- Small electrodes used on cold and thick steel.
- Insufficient amperage.
- Incorrect electrode angle and manipulation.
- Rate of travel too fast, not allowing proper fusion.
- Unclean surface (mill scale, dirt, grease etc.).

Result: Weakens the welded joint and becomes a potential fatigue initiation site.

Incomplete Penetration:

Definition: A failure of the weld metal to penetrate into the root of the joint.



Causes:
- Current too low.
- Insufficient root gap.
- Too large an electrode size.

Result: Weakens the welded joint and becomes a potential fatigue initiation site.

Weld cracking:

Definition: Planar (Two Dimensional) discontinuities produced by the tearing of parent or weld metal. Weld metal cracking can occur in either the plastic condition (hot shortness) or by fracturing when cold (cold shortness).
There are many types of cracks that can occur in the base

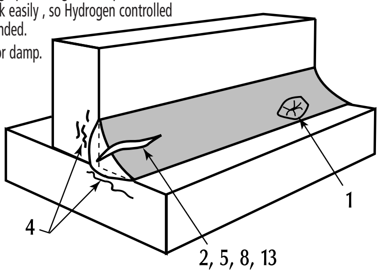
DEFECTS IN WELDING CONT.

Weld cracking cont.:

Some common types of cracking include:

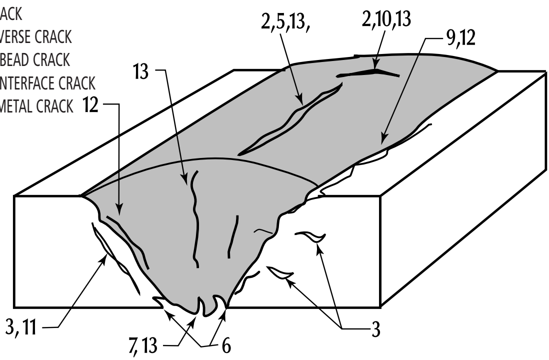
Crater Cracking:	Hot cracking mainly caused by a failure to fill up the crater depression at the end of a weld pass. Shrinkage stresses and inadequate weld metal in the crater causes crater cracking.
Underbead Cracks:	Cold cracking that is usually in the Heat-affected zone (HAZ) of the parent metal.
Longitudinal Crack:	Usually a hot cracking phenomenon. Cracking runs along the length of the weld.

Main Causes: - Incorrect welding procedures and techniques. (eg. Wrong consumable or welding current, inadequate preheat etc.)
- Weld size may be too small for the parts being welded.
- Base metal may contain a high carbon content (over 0.45%).
- Metals which contain high percentages of sulphur or phosphorus tend to crack easily , so Hydrogen controlled electrodes are recommended.
- Electrodes may be wet or damp.



CRACK TYPES:

1. CRATER CRACK
2. FACE CRACK
3. HEAT-AFFECTED ZONE CRACK
4. LAMELLAR TEAR
5. LONGITUDINAL CRACK
6. ROOT CRACK
7. ROOT SURFACE CRACK
8. THROAT CRACK
9. TOE CRACK
10. TRANSVERSE CRACK
11. UNDERBEAD CRACK
12. WELD INTERFACE CRACK
13. WELD METAL CRACK

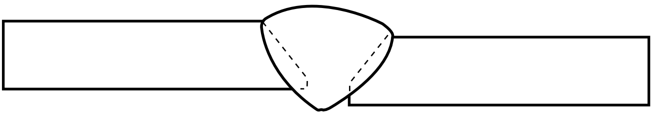


DEFECTS IN WELDING CONT.

Misalignment:

▲ Definition: Normally defined as an unnecessary or unintentional variation in the alignment of the parts being welded.

Misalignment is a common fault in prepared butt welds, and is produced when the root faces of the parent plate (or joint) are not placed in their correct position for welding.



Causes:
- Poor assembly of the parts to be welded.
- Inadequate tack welds that break or insufficient clamping that results in movement.

Result: Misalignment is a serious defect since failure to melt both edges of the root will result in stress concentration sites which in service may lead to premature fatigue failure of the joint.

DISTORTION, CAUSES AND CONTROL

Distortion:

Distortion to some degree is present in all forms of welding. In many cases it is so small that it is barely noticeable, but in other cases allowance has to be made before welding commences for the distortion that will subsequently occur.

The study of distortion is very complex and the following is a brief outline of the subject.

A) The cause of distortion - when under load metals strain or move and change shape.

- Under light loading metals remain elastic (they return to their original shape or form after the load has been removed). This is known as the "elastic range".
- Under very high load, metals may be stressed to the point where they will not return to their original shape or form and this point is known as the "yield point". (YIELD STRESS)
- As metals are heated they expand and when cooled they contract. During welding, heating and cooling of metals occurs unevenly resulting in high stresses and the metal distorts.

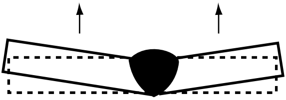
If these high stresses pass the elastic range and go over the yield point, some permanent distortion of the metals will occur. A metals yield stress is reduced at high temperatures.

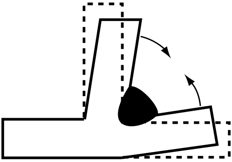
*Distortion is the result of uneven expansion and contraction of heated metals.

Distortion Types - the three main types of distortion are:-

- **Angular**
- **Longitudinal**
- **Transverse**

(i) ANGULAR DISTORTION

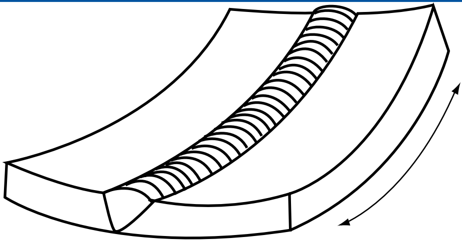




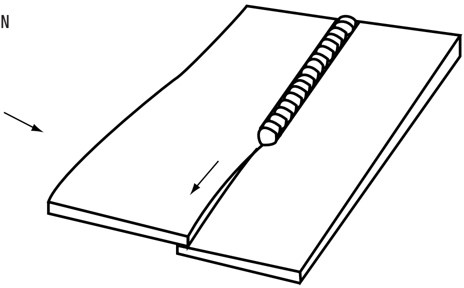
DISTORTION, CAUSE AND CONTROL CONT.

Distortion:

(ii) LONGITUDINAL DISTORTION



(iii) TRANSVERSE DISTORTION

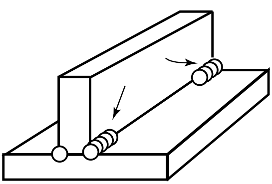


B) The **Control of distortion** can be broken up into three areas:-

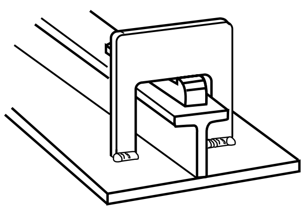
(i) Before welding
(ii) During welding
(iii) After welding

(i) The control of distortion **before** welding can be facilitated by:

- Tack Welding
- Jigs, clamps and fixtures
- Uniform pre-heating
- Pre-setting



TACK WELDS



JIGS & FIXTURES

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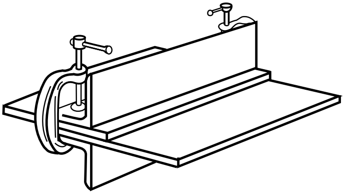
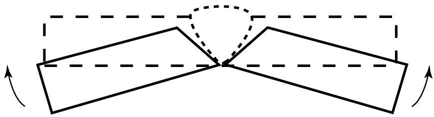
DISTORTION, CAUSES AND CONTROL CONT.

Distortion cont.:



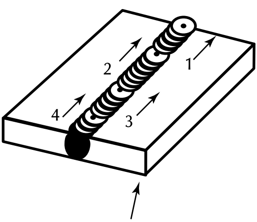
CLAMPS



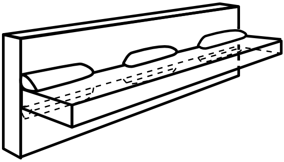
PRE-SETTING

(ii) The Control of distortion **during** welding can be facilitated by:

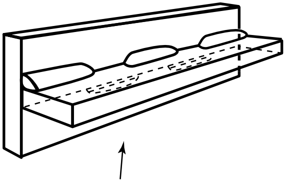
- Backstep welding
- Intermittent "Chain" welding
- Intermittent "Staggered" welding
- Balanced sequence welding
- A correct welding procedure to reduce the size of the weld beads



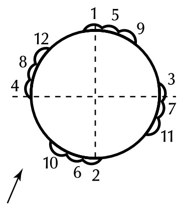
BACKSTEP WELDING



INTERMITTENT CHAIN WELDING



INTERMITTENT STAGGERED WELDING



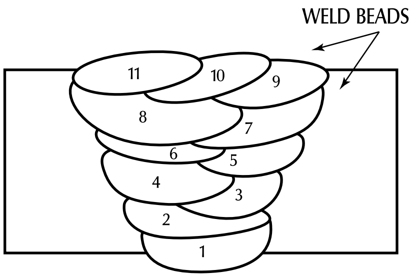
BALANCED SEQUENCE WELDING

DISTORTION, CAUSES AND CONTROL CONT.

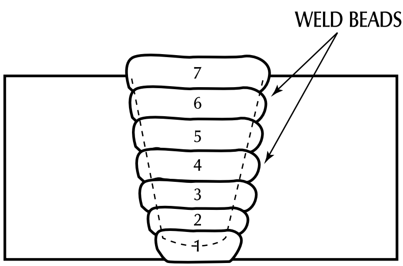
Distortion cont.:

The correct welding procedure uses a greater number of weld runs positioned to refine the grain size of the weld metal in the previous layer.

A small number of heavy runs will cause more distortion due to the greater heat input, and the contraction stresses set up by the cooling of the larger deposit of weld metal.



LESS DISTORTION



MORE DISTORTION

(iii) The control of distortion **after** welding can be facilitated by:

- Slow Cooling
- Flame straightening (also known as contra-heating)
- Annealing
- Stress Relieving
- Normalising
- Mechanical straightening

DISTORTION, CAUSES AND CONTROL CONT.

Distortion cont.:

Annealing - is a heat treatment process designed to soften metals for cold working or machining purposes. The job or finished work is normally heated in a furnace so as the metal reaches its critical range (for .025% carbon steel @ 723-820˚C) and then the work is very slowly cooled.

Stress Relieving - is the uniform heating of welded parts to a temperature below the critical range, followed by slow cooling. This process allows the yield point of the metal to be lowered allowing it to stretch or yield, so reducing the residual stresses in the work.

Normalising - is a process used to refine the grain structure of the metal so it improves its resistance to shock and fatigue.

In normalising the welded parts are heated just above the critical point (820˚C for .025% carbon steel) for approximately 1 hour per 25mm thickness and then allowed to cool in **still** air.

Mechanical Straightening includes:

- Bend Pressing
- Hammering
- Rolling

SAFETY IN WELDING

A) ARC RADIATION:

Arc radiation is a result of ULTRA-VIOLET (UV) and INFRA-RED (IR) RAYS and exposure can cause the following:-

- Skin Cancer
- Thermal Skin Burns (severe sun burn)
- ARC FLASH (Welders Flash) or EYE BURN which can result in inflammation of the cornea, cataracts or blindness.

(i) **PROTECTION REQUIRED INCLUDES**:

- An approved welding helmet with the correct filter and shade number.
- Safety glasses which will help to refract (bend away) the UV and IR rays away reducing the chances of Arc Flash.
- Always wear protective full covering clothing to shield your body from potential burns eg.
  - Overalls/flame resistant wool or cotton.
  - Leather apron and jackets.
  - Always wear leather gloves.
  - Skull cap (for overhead welding).
  - Screen the welding zone when welding in open spaces.

N.B. A welding flash can occur by indirectly viewing the arc even for a relatively short time eg.

- Unconsciously looking out the corner of the eye
- Looking away from the arc (close eyes then turn away).
- Reflections of the arc from shiny surfaces in the welding area.

B) ELECTRIC SHOCK - "PREVENTION":

- Never touch live metal parts with bare skin or wet clothing. Repair any damaged or loose connections, especially bare cables, before welding.
- Keep gloves and protective clothing dry and free of oil and grease.
- Never coil or loop welding cables around your body.
- Don't weld while standing on a wet surface or while standing in water.

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SAFETY IN WELDING CONT.

C) FUMES & GASES:

Caused by the melting, vapourisation and other reactions of the consumables, base metals and gases (where applicable) involved in the welding arc.

Some common contaminants:

Contaminant	Source
Iron fume	Vaporisation of iron from base metal and electrode coatings.
Chromium	Stainless steel, electrode coatings, platings.
Nickel	Stainless steel, nickel-clad steel.
Zinc fume	Vaporisation of zinc alloys, electrode coatings galvanised steel, zinc-primed steel.
Copper fume	Vaporisation of coatings on electrode wires, sheaths on air carbon arc gouging electrodes, copper alloys.
Vanadium, Manganese, Molybdenum	Welding rods, alloying elements in steels.
Tin	Tin-coated steel, some nonferrous alloys.
Cadmium	Plating
Lead	Fluxes, coatings on electrodes, flux in wires
Carbon Monoxide	Combustion products of gas metal arc welding, air carbon arc gouging, oxyfuel flames; exhaust from car engines.
Ozone	Gas metal arc welding, air carbon arc gouging; titanium and aluminium welding in inert gas atmospheres
Nitrogen dioxide	Gas metal arc welding; oxyfuel flame processes.
Phosgene	Welding of metal covered with chlorinated hydrocarbon solvents.

Exposure to fumes and gases can damage the lungs and respiratory system or cause asphyxiation.

SAFETY IN WELDING CONT.

Fumes and Gases:

(i) PROTECTION REQUIRED FROM FUMES AND GASES:-

- Adequate ventilation.
- Keep your head out and away from the fumes.
- Use a welding fume respirator, or an air supplied respirator (especially in confined space).
- Use a fume extraction unit/or gun.

N.B. Welding fume fever caused by breathing fumes formed by the welding of various metals can occur a few hours after exposure and can last several days.

SYMPTOMS INCLUDE:-

- Nausea
- Fever
- Chills
- Weakness
- Fatigue
- Dry nose and throat
- Metallic taste in mouth
- Joint and muscle pain

Note: If any of these symptoms are observed please seek professional medical attention.

D) HEAT, FIRE & SPARKS:

- Are caused by welding and related processes, operators are at continual risk of burns by hot and molten metal, sparks and heat radiated from the arc.
- Welding sparks can travel long distances and have been known to reach up to 15 metres away from the source of welding on the ground and even further when working in elevated positions.
- These sparks can reach combustible materials and start fires, as well as burning unprotected skin.
- Burns can result from handling hot just welded work (the most common of welding burns) and molten weld metal (spatter) falling or spitting onto exposed skin.

(i) PROTECTION REQUIRED FROM HEAT, FIRE AND SPARKS:

- Always wear protective clothing.
- Keep safety glasses on your head where they belong.
- Always mark just welded work with the word "HOT".
- Know where the nearest fire extinguisher or fire hose is and how to use them.
- Remove combustible materials away from the welding area. (at least 15 metres or 50 feet away).
- If in an elevated position, post a person on the ground as a fire-watcher.
- Never connect the earth lead to electrical circuits of pipes containing gases or flammable liquids.

SAFETY IN WELDING CONT.

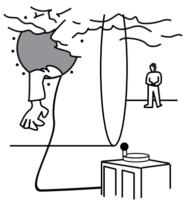
Repair or replace defective cables immediately.

Keep fire extinguishing equipment at a handy location near the job.

Never watch the arc except through filters of the correct shade.

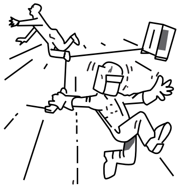
Conduct engine exhaust to outside atmosphere.

In confined spaces, adequate ventilation and constant observation are essential.

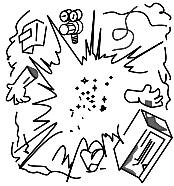


Keep primary terminals and live parts effectively covered.

Leads and cables should be kept clear of passageways.



Never strike an electrode on any gas cylinder.



Never use oxygen for venting containers.

CONSUMABLES CLASSIFICATION TABLES

AS/NZS 1553 Part 1-1995 Covered Electrodes for Welding Low Carbon Steel

AS/NZS 1553.1 classifies Manual Metal Arc Welding (MMAW / Stick) electrodes by using a series of letters and digits broken into two alpha numeric groups separated by a hyphen. eg: E4818-4H5R. NB. The second group separated by the hyphen as shown is optional. ie. 4H5R is optional.

The following layout outlines this classification system in part only. For full details CIGWELD recommend you refer to the current published version of AS/NZS 1553 Part 1. obtainable from the Standards Association of Australia or Standards New Zealand.

E 4 8 1 8 - 4 H_5 R

E = ELECTRODE

The first two digits indicate approximately 1/10th of the minimum tensile strength in MPa.

Weld Metal No:	Tensile Strength Range (MPa)	Minimum Yield Strength (MPa)	Minimum Elongation
41	430 - 550(1)	350(1)	22%
48	500 - 620(2)	420(2)	22%

The third digit = Welding Positions

4	Especially good Vertical-Down
2	Flat & H/V Fillets
1	All Positional

Optional Designators

8 = the fourth digit indicates the Flux type and Welding Current / Polarity to be used.
EG: Hydrogen Controlled Low Iron Powder A.C. & D.C.+, medium penetration.
See Table 1 for details.

R = the last letter indicates the coating is Moisture Resistant. Tested electrodes shall exhibit not > 10 mls H_2 /100g of DWM after exposure to an environment of 27°C & 80% Relative Humidity for a period of not less than 9 hours.

The fifth digit indicates the Impact energy grade number:

Impact energy grade No:	Minimum average CVN impact values
Z	Not required.
A	47J @ + 20°C
0	47J @ 0°C
2	47J @ -20°C
3	47J @ -30°C
4	**47J @ -40°C**
5	47J @ -50°C
6	47J @ -60°C

The second letter & sixth number indicates the Diffusible Hydrogen Content of Deposited Weld Metal (DWM)

H_5	≤ 5 mls H_2 /100g of DWM
H_{10}	≤ 10 mls H_2 /100g of DWM

(1) and (2) indicates that for each increase of 1% in the value of elongation over the minimum a decrease of 10 MPa in Tensile and Yield Strength is allowed to the following minimum values. EG: E41XX, Tensile: 410 MPa / Yield: 330 MPa and E48XX, Tensile: 480 MPa / Yield: 400 MPa.

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AS/NZS 1553 Part 1-1995 Covered Electrodes for Welding Low Carbon Steel cont.

AS/NZS 1553.1 Electrode Classification Summary - Table 1

Electrode Classification	Welding Positions	Type of Current and Polarity	Type of Flux Covering and Slag Type	Penetration
EXX10	F, V, OH, H	D.C. + Fluid Slag	High Cellulose	Deep
EXX11	F, V, OH, H	A.C. & D.C. + Fluid Slag	High Cellulose	Deep
EXX12	F, V, OH, H	A.C. & D.C. + or - (Viscous)	High Titania,Stiff Slag	Medium
EXX13	F, V, OH, H	A.C. & D.C. + or -	High Titania,Fluid Slag	Medium
EXX14	F, V, OH, H	A.C. & D.C. + or - Stiff Slag (Viscous)	Low Iron Powder,Titania	Low
EXX15	F, V, OH, H	D.C. + Hydrogen Controlled	Basic,	Medium
EXX16	F, V, OH, H	A.C. & D.C. + Hydrogen Controlled	Basic,	Medium
EXX18	F, V, OH, H	A.C. & D.C. + Low Iron Powder	Basic Hydrogen Controlled,	Medium
EXX19	F, V, OH, H	A.C. & D.C. + or - Potassium	Iron Oxide Titania	Medium
EXX20	F & H/V-FILLET	A.C. & D.C. + or -	High Iron Oxide	Deep
EXX24	F & H/V-FILLET	A.C. & D.C. + or - Titania	High Iron Powder,	Low
EXX27	F & H/V-FILLET	A.C. & D.C. + or - Iron Oxide	High Iron Powder & Iron Oxide	Deep
EXX28	F & H/V-FILLET	A.C. & D.C. + High Iron Powder	Basic Hydrogen Controlled,	Medium
EXX46	F, V, OH, H V-DOWN	A.C. & D.C. +	Basic, Hydrogen Controlled	Medium
EXX48	F, V, OH, H V-DOWN	A.C. & D.C. +	Basic Hydrogen Controlled, Low Iron Powder	Medium
EXX99	As Specified by the Manufacturer	As Specified by the Manufacturer	As Described by the Manufacturer	As Specified

* Legend to Abbreviations:

F = Flat
V = Vertical
H = Horizontal
OH = Overhead
H/V-FILLET = Horizontal-Vertical Fillet
V-DOWN = Vertical-Down

CONSUMABLES CLASSIFICATION TABLES

AWS A5.1-91 Carbon Steel Electrodes for Shielded Metal Arc Welding

AWS A5.1-91 classifies Shielded Metal Arc Welding (SMAW / MMAW) electrodes by using a series of letters and digits broken into two alpha numeric groups separated by a hyphen.
eg: E7018 H4R. NB. The alpha numeric group after the four digit number (or five in the case of E7018-1) is optional. ie. H4R is optional.

The following layout outlines this classification system in part only. For full details CIGWELD recommend you refer to the current published version of AWS A5.1 obtainable from the American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126, USA.

E 7 0 1 8 - 1 H_4R

E = ELECTRODE

The first two digits indicate the minimum required tensile strength in ksi.

Weld Metal No:	Minimum Tensile Strength (psi)	Minimum Yield Strength (ksi)	Minimum Elongation
60	60,000	48 (1)	22% (2)
70	70,000	58 (1)	22% (2)

The third digit = Welding Positions

4	Especially good Vertical-Down
2	Flat & H/V Fillets
1	All Positional

Optional Designators

8 = the fourth digit indicates the Flux type and Welding Current / Polarity to be used. EG: Hydrogen Controlled Low Iron Powder A.C. & D.C.+, medium penetration.
See Table 2 for details.

R = the last letter indicates the coating is Moisture Resistant. Tested electrodes as received or conditioned shall exhibit not > 0.3% (by Wt) of moisture after exposure to an environment of 80°F & 80 % relative humidity for a period of not less than 9 hours.

APPLICABLE to E7016, E7018 and E7024 type electrodes only.
This number indicates that the electrode meets the requirements for improved impact toughness. In the case of an E7024 ductility "elongation" is also improved from 17%.

Average Minimum Results	
Grade	CVN Impact Requirements.
E7016-1	20ft Lb @ -50°F (27J @ -46°C)
E7018-1	**20ft Lb @ -50°F (27J @ -46°C)**
E7024-1	20ft Lb @ 0°F (27J @ -18°C)

The second letter & sixth number indicates the diffusible hydrogen content of Deposited Weld Metal (DWM)

H_4	≤ 4 mls H_2 /100g of DWM
H_8	≤ 8 mls H_2 /100g of DWM
H_{16}	≤ 16 mls H_2 /100g of DWM

(1) Yield on E6022 electrodes is not specified and E7018M may have a range of 53-72 ksi for all diameters other than 3/32≤ (2.4mm) which is 53-77 ksi. (2) Minimum elongation for E6012, E6013, E7014 and E7024 types is 17%. Elongation on E6022 electrodes is not specified, and E7018M types are required to meet 24%.

AWS A5.1-91 Carbon Steel Electrodes for Shielded Metal Arc Welding cont.

AWS A5.1 Electrode Classification Summary - Table 2

Electrode Classification	Welding Positions	Type of Current and Polarity	Type of Flux Covering and Slag Type or "Use"	Penetration
E6010	F, V, OH, H	D.C. +	High Cellulose Sodium Thin Friable Slag	Deep
E6011	F, V, OH, H	A.C. & D.C. +	High Cellulose Potassium Thin Friable Slag	Deep
E6012	F, V, OH, H	A.C. & D.C. + or -	High Titania Sodium, Dense Slag	Medium
E6013	F, V, OH, H	A.C. & D.C. + or -	High Titania Potassium, Dense-Fluid Slag	Medium
E7014	F, V, OH, H	A.C. & D.C. + or -	Low Iron Powder, Titania Self Removing Slag	Low
E7015	F, V, OH, H	D.C. +	Low Hydrogen Sodium Basic Slag Heavy & Friable	Medium
E7016	F, V, OH, H	A.C. & D.C. +	Low Hydrogen Potassium Basic Slag Heavy & Friable	Medium
E7018	F, V, OH, H	A.C. & D.C. +	Low Hydrogen Potassium Iron Powder	Medium
E7018M	F, V, OH, H	D.C. +	Low Hydrogen Iron Powder "Military Hydrogen Controlled"	Medium
E6019	F, V, OH, H	A.C. & D.C. + or -	Iron Oxide Titania Potassium Fluid Slag	Medium
E6020	F & H/V-FILLET	A.C. & D.C. + or -	High Iron Oxide Easily Removable Slag	Medium to Deep
E6022	F & H/V-FILLET	A.C. & D.C. -	High Iron Oxide "Single-Pass Welds Only"	Deep
E7024	F & H/V-FILLET	A.C. & D.C. + or -	Iron Powder, Titania "High Deposition Efficiency"	Low
E6027	F & H/V-FILLET	A.C. & D.C. + or -	High Iron Oxide Iron Powder Heavy Honeycombed Slag	Medium
E7027	F & H/V-FILLET	A.C. & D.C. + or -	High Iron Oxide Iron Powder Heavy Honeycombed Slag	Medium
E7028	F & H/V-FILLET	A.C. & D.C. +	Low Hydrogen Potassium, Iron Powder	Medium
E7048	F, V, OH, H V-DOWN	A.C. & D.C. +	Low Hydrogen Potassium, Iron Powder	Medium

* Legend to Abbreviations: F = Flat; OH = Overhead; V = Vertical; H = Horizontal; V-DOWN = Vertical-Down; H/V-FILLET = Horizontal-Vertical Fillet

E7018M type electrodes are intended to meet most military requirements and have greater toughness, lower coating moisture content, both as-received and after exposure, and also conform to mandatory diffusible hydrogen limits for deposited weld metal.

CONSUMABLES CLASSIFICATION TABLES

AWS A5.5-96 Low Alloy Steel Covered Arc Welding Electrodes

AWS A5.5-96 classifies Shielded Metal Arc Welding (SMAW / MMAW) electrodes by using a series of letters and digits broken into two alpha numeric groups separated by a hyphen. eg: E7010-A1 or E8010-P1. NB. The alpha numeric group after the four digit number indicates chemical analysis requirements. The following layout outlines this classification system in part only. For full details CIGWELD recommend you refer to the current published version of AWS A5.5 obtainable from the American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126, USA.

Weld Metal No:	Min. Tensile Strength (psi)	Yield Strength(1) (ksi)	Weld Metal No:	Min. Tensile Strength (psi)	Yield Strength (ksi)
7010-P1	70,000	60	100	100,000	87
70	70,000	57	10018-M	100,000	88-100
70xx-B2L	75,000	57	110	110,000	97
80	80,000	67	11018M	110,000	98-110
80xx-C3	80,000	68-80	120	120,000	107
90	90,000	77	12018M	120,000	108-120
9018M	90,000	78-90	12018M1	120,000	108-120

80 = the first two digits indicate the minimum required tensile strength in ksi.

ELECTRODE

E 8 0 1 8 - C 1

The third digit = Welding Positions

- **1** All Positional
- **2** Flat & H/V Fillets
- **4** Especially good Vertical-Down

8 = the fourth digit indicates the Flux type and Welding Current / Polarity to be used. EG: Hydrogen Controlled Low Iron Powder A.C. & D.C.+, medium penetration.
See Table 3 for details.

Classification Suffixes by Major Chemical Analysis (%)						
Type	C	Mn	Ni	Cr	Mo	V
Carbon-Molybdenum Steel Electrodes						
A1	0.12	0.60-1.00	---	---	0.40-0.65	---
Chromium-Molybdenum Steel Electrodes						
B1	0.05-0.12	0.90	---	0.40-0.65	0.40-0.65	---
B2	0.05-0.12	0.90	---	1.00-1.50	0.40-0.65	---
B2L	0.05	0.90	---	1.00-1.50	0.40-0.65	---
B3	0.05-0.12	0.90	---	2.00-2.50	0.90-1.20	---
B3L	0.05	0.90	---	2.00-2.50	0.90-1.20	---
B4L	0.05	0.90	---	1.75-2.25	0.40-0.65	---
B5	0.07-0.15	0.40-0.70	---	0.40-0.60	1.00-1.25	0.05
B6	0.05-0.10	1.00	---	4.00-6.00	0.45-0.65	---
B6L	0.05	1.00	---	4.00-6.00	0.45-0.65	---
B7	0.05-0.10	1.00	---	6.00-8.00	0.45-0.65	---
B7L	0.05	1.00	---	6.00-8.00	0.45-0.65	---
B8	0.05-0.10	1.00	---	8.00-10.50	0.85-1.20	---
B8L	0.05	1.00	---	8.00-10.50	0.85-1.20	0.05
B9	0.08-0.13	1.25	---	8.00-10.50	0.85-1.20	0.15-0.30
Nickel Steel Electrodes						
C1	**0.12**	**1.25**	**2.00-2.75**	**---**	**---**	**---**
C1L	0.05	1.25	2.00-2.75	---	---	---
C2	0.12	1.25	3.00-3.75	---	---	---
C2L	0.05	1.25	3.00-3.75	---	---	---
C3	0.12	0.40-1.25	0.80-1.10	0.15	0.35	0.05
C3L	0.08	0.40-1.40	0.80-1.10	0.15	0.35	0.05
C4	0.10	1.25	1.10-2.00	---	---	---
C5L	0.05	0.40-1.00	6.00-7.25	---	---	---
Nickel-Molybdenum Steel Electrodes						
NM	0.10	0.80-1.25	0.80-1.10	0.10	0.40-0.65	0.02
Manganese- Molybdenum Steel Electrodes						
D1	0.12	1.00-1.75	0.90	---	0.25-0.45	---
D2	0.15	1.65-2.00	0.90	---	0.25-0.45	---
D3	0.12	1.00-1.80	0.90	---	0.40-0.65	---
Pipeline Electrodes						
P1	0.20	1.20	1.00	0.30	0.50	0.10
G = General and M = Military						
G*	---	1.00 min	0.50 min	0.30 min	0.20 min	0.10 min
M#	0.10	0.60-2.25	1.25-2.50	0.15-1.50	0.25-0.55	0.05
M1	0.10	0.80-1.60	3.00-3.80	0.65	0.20-0.30	0.05

Notes:
(1) Yield on E7010-P1 and E7018-W1 is required to be 60 ksi (415MPa).
(2) * G classifications require the weld deposit to exhibit only a minimum of one (1) element listed.
(3) # M classification chemical limits can vary widely in the case of Mn, Ni, Cr and Mo, refer to page 5 of AWS A5.5-96 for details. EX018-M electrodes are intended to meet most military requirements and have greater toughness, lower coating moisture content, both as-received and after exposure, and also conform to mandatory diffusible hydrogen limits for deposited weld metal.

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AWS A5.5-96 Low Alloy Steel Covered Arc Welding Electrodes cont.

AWS A5.5 Electrode Classification Summary - Table 3

Electrode Classification	Welding Positions	Type of Current and Polarity	Type of Flux Covering and Slag Type or "Use"	Penetration
E70 Series, 70,000 psi (480 MPa)				
E7010-X	F, V, OH, H	D.C. +	High Cellulose Sodium	Deep
E7011-X	F, V, OH, H	A.C. & D.C. +	High Cellulose Potassium	Deep
E7015-X	F, V, OH, H	D.C. +	Low Hydrogen Sodium	Medium
E7016-X	F, V, OH, H	A.C. & D.C. +	Low Hydrogen Potassium	Medium
E7018-X	F, V, OH, H	A.C. & D.C. +	Iron Powder, Low Hydrogen	Medium
E7020-X	F & H/V-FILLET	A.C. & D.C. + or -	High Iron Oxide	Medium to Deep
E7027-X	F & H/V-FILLET	A.C. & D.C. + or -	High Iron Oxide, Iron Powder	Medium
E80 Series, 80,000 psi (550 MPa)				
E8010-X	F, V, OH, H	D.C. +	High Cellulose Sodium	Deep
E8011-G	F, V, OH, H	A.C. & D.C. +	High Cellulose Potassium	Deep
E8013-G	F, V, OH, H	A.C. & D.C. + or -	High Titania Potassium,	Medium
E8015-X	F, V, OH, H	D.C. +	Low Hydrogen Sodium	Medium
E8016-X	F, V, OH, H	A.C. & D.C. +	Low Hydrogen Potassium	Medium
E8018-X	F, V, OH, H	A.C. & D.C. +	Low Hydrogen, Iron Powder	Medium
E90 Series, 90,000 psi (620 MPa)				
E9010-G	F, V, OH, H	D.C. +	High Cellulose Sodium	Deep
E9011-G	F, V, OH, H	A.C. & D.C. +	High Cellulose Potassium	Deep
E9013-G	F, V, OH, H	A.C. & D.C. + or -	High Titania Potassium,	Medium
E9015-X	F, V, OH, H	D.C. +	Low Hydrogen Sodium	Medium
E9016-X	F, V, OH, H	A.C. & D.C. +	Low Hydrogen Potassium	Medium
E9018-X	F, V, OH, H	A.C. & D.C. +	Low Hydrogen, Iron Powder	Medium
E9018M	F, V, OH, H	D.C. +	Low Hydrogen, Iron Powder	Medium
E100 Series, 100,000 psi (690 MPa)				
E10010-G	F, V, OH, H	D.C. +	High Cellulose Sodium	Deep
E10011-G	F, V, OH, H	A.C. & D.C. +	High Cellulose Potassium	Deep
E10013-G	F, V, OH, H	A.C. & D.C. + or -	High Titania Potassium,	Medium
E10015-X	F, V, OH, H	D.C. +	Low Hydrogen Sodium	Medium
E10016-X	F, V, OH, H	A.C. & D.C. +	Low Hydrogen Potassium	Medium
E10018-X	F, V, OH, H	A.C. & D.C. +	Low Hydrogen, Iron Powder	Medium
E10018M	F, V, OH, H	D.C. +	Low Hydrogen, Iron Powder	Medium
E110 Series, 110,000 psi (760 MPa) and E120 Series, 120,000 psi (830 MPa)				
E11010-G	F, V, OH, H	D.C. +	High Cellulose Sodium	Deep
E11011-G	F, V, OH, H	A.C. & D.C. +	High Cellulose Potassium	Deep
E11013-G	F, V, OH, H	A.C. & D.C. + or -	High Titania Potassium,	Medium
E11015-G	F, V, OH, H	D.C. +	Low Hydrogen Sodium	Medium
E11016-G	F, V, OH, H	A.C. & D.C. +	Low Hydrogen Potassium	Medium
E11018-G	F, V, OH, H	A.C. & D.C. +	Low Hydrogen, Iron Powder	Medium
E11018M	F, V, OH, H	D.C. +	Low Hydrogen, Iron Powder	Medium
E12010-G	F, V, OH, H	D.C. +	High Cellulose Sodium	Deep
E12011-G	F, V, OH, H	A.C. & D.C. +	High Cellulose Potassium	Deep
E12013-G	F, V, OH, H	A.C. & D.C. + or -	High Titania Potassium,	Medium
E12015-G	F, V, OH, H	D.C. +	Low Hydrogen Sodium	Medium
E12016-G	F, V, OH, H	A.C. & D.C. +	Low Hydrogen Potassium	Medium
E12018-G	F, V, OH, H	A.C. & D.C. +	Low Hydrogen, Iron Powder	Medium
E12016M	F, V, OH, H	A.C. & D.C. +	Low Hydrogen Potassium	Medium
E12018M1	F, V, OH, H	A.C. & D.C. +	Low Hydrogen, Iron Powder	Medium

Legend to Abbreviations: F = Flat, V = Vertical, H = Horizontal, OH = Overhead, H/V-FILLET = Horizontal-Vertical Fillet

CONSUMABLES CLASSIFICATION TABLES

AS/NZS 2717 Part 1-1996 Ferritic Steel Electrodes For Gas Metal Arc Welding

AS/NZS 2717.1 classifies Gas Metal Arc Welding (GMAW / MIG) wires by using a series of letters and digits broken into three (3) alpha numeric groups separated by hyphens. e.g.: ES4-GM-W503AH. The following table outlines this classification system in part only. For full details CIGWELD recommends that you refer to the current published version of AS/NZS 2717 Part 1. obtainable from the Standards Association of Australia or Standards New Zealand.

E S 6 - G C / M - W 5 0 3 A H

Weld metal properties.
The first two digits indicate approximately 1/10th the tensile strength of the weld metal in MPa.

Weld Metal Classification	Minimum Tensile	Minimum Yield	Minimum Elongation
W41	420 MPa	not applicable	20%
W50	**500 MPa**	**360 MPa**	**22%**
W55	550 MPa	470 MPa	19%
W62	620 MPa	540 MPa	17%
W69	690 MPa	610-700 MPa	16%
W76	760 MPa	660-740 MPa	15%
W83	830 MPa	730-840 MPa	14%

The third digit indicates Impact energy grade No:

Impact energy grade No:	Min. average CVN impacts
Z	Not required.
A	47J @ + 20°C
0	47J @ 0°C
2	47J @ -20°C
3	**47J @ -30°C**
4	47J @ -40°C
5	47J @ -50°C
6	47J @ -60°C
W559XH-Ni1	27J @ -45°C
W559XH-Ni2	27J @ -60°C
W559XH-Ni3	27J @ -73°C
W559XH-D2	27J @ -30°C
W699XH-M2	68J @ -50°C
W769XH-M3	68J @ -50°C
W839XH-M4	68J @ -50°C
W699XH-M5	68J @ -50°C

Type of external shielding.
G = Gas followed by either of these listed:
C = Carbon dioxide.
M = Mixed shielding gas eg: Argoshield 51.
I = Inert shielding gas.

Indicating the applicable heat treatment condition.
A = as-welded condition.
P = postwelded heat treatment.
H = hydrogen controlled weld metal. ≤ 15 mls of H_2 / 100gms of deposited weld metal.

E = Electrode, S = Solid Wire followed by a number or letter which defines the chemical composition of the wire.

Wire Classification	Carbon (C)	Manganese (Mn)	Silicon (Si)	Other Elements Nominal Range %
ES2	0.07	0.90-1.40	0.40-0.70	0.25Cu / 0.10Ti / 0.07Zr / 0.10Al
ES3	0.06-0.15	0.90-1.40	0.45-0.75	0.25Cu
ES4	0.07-0.15	1.00-1.50	0.60-0.85	0.25Cu
ES5	0.07-0.19	0.90-1.40	0.30-0.60	0.70Al
ES6	**0.06-0.15**	**1.40-1.85**	**0.80-1.15**	**0.25Cu**
ES7	0.07-0.15	1.50-2.00	0.50-0.80	0.25Cu
ESB2	0.07-0.12	0.40-1.2	0.40-0.70	1.25Cr / 0.50Mo / 0.17Cu
ESB2L	0.05	0.40-1.2	0.40-0.70	1.25Cr / 0.50Mo / 0.17Cu
ESB3	0.07-0.12	0.40-1.2	0.40-0.70	2.50Cr / 1.05Mo / 0.17Cu
ESB3L	0.05	0.40-1.2	0.40-0.70	2.50Cr / 1.05Mo / 0.17Cu
ES5Cr	0.10	1.00	0.90	0.20Ni / 5.25Cr / 0.55Mo / 0.37Cu
ES7Cr	0.10	1.00	0.90	0.20Ni / 7.00Cr / 0.55Mo / 0.37Cu
ES9Cr	0.10	1.00	0.90	0.20Ni / 9.25Cr / 1.02Mo / 0.37Cu
ESNi1	0.12	1.25	0.40-0.80	0.95Ni / 0.07Cr / 0.17Mo / 0.02V / 0.17Cu
ESNi2	0.12	1.25	0.40-0.80	2.37Ni / 0.17Cu
ESNi3	0.12	1.25	0.40-0.80	3.37Ni / 0.17Cu
ESD2	0.07-0.12	1.60-2.10	0.50-0.80	0.07Ni / 0.50Mo / 0.25Cu
ESM2	0.08	1.25-1.80	0.20-0.50	1.75Ni / 0.15Cr / 0.40Mo / 0.02V / 0.12Cu / 0.05ea, Ti / Zr / Al
ESM3	0.09	1.25-1.80	0.20-0.55	2.25Ni / 0.25Cr / 0.20Mo / 0.02V / 0.12Cu / 0.05ea, Ti / Zr / Al
ESM4	0.10	1.25-1.80	0.20-2.60	4.80Ni / 0.30Cr / 0.95Mo / 0.01V / 0.12Cu / 0.05ea, Ti / Zr / Al
ESM5	0.12	1.25-1.80	0.20-2.60	4.80Ni / 0.30Cr / 0.95Mo / 0.01V / 0.12Cu / 0.05ea, Ti / Zr / Al

ESMG = General, composition is agreed between the supplier & customer

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CONSUMABLES CLASSIFICATION TABLES

AWS A5.18-1993 Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding

AWS A5.18-93 classifies Gas Metal Arc Welding (GMAW / MIG) wires by using a series of letters and digits broken into two (2) alpha numeric groups separated by a hyphen. e.g.: ER70S-6 and E70C-6M

The following layout outlines this classification system in part only. For full details CIGWELD recommend you refer to the current published version of AWS A5.18 obtainable from the American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126, USA.

As Welded Mechanical Properties (Minimum)

AWS Class.	Tensile Strength psi	Tensile Strength MPa	Yield Strength psi	Yield Strength MPa	% Elong.	Charpy-V-Notch (CVN) Impact Requirements
ER70S-2	70,000	480	58,000	400	22	20ft Lb @ -20°F (27J @ -29°C)
ER70S-3	70,000	480	58,000	400	22	20ft Lb @ 0°F (27J @ -18°C)
ER70S-4	70,000	480	58,000	400	22	Not Required
ER70S-5	70,000	480	58,000	400	22	Not Required
ER70S-6	**70,000**	**480**	**58,000**	**400**	**22**	**20ft Lb @ -20°F (27J @ -29°C)**
ER70S-7	70,000	480	58,000	400	22	20ft Lb @ -20°F (27J @ -29°C)
ER70S-G	70,000	480	58,000	400	22	As agreed between supplier & purchaser
E70C-3X	70,000	480	58,000	400	22	20ft Lb @ 0°F (27J @ -18°C)
E70C-6X	70,000	480	58,000	400	22	20ft Lb @ -20°F (27J @ -29°C)
E70C-G(X)	70,000	480	58,000	400	22	As agreed between supplier & purchaser
E70C-GS (X)	70,000	480	Not Specified			Not Required

ER70S-6 H_4

E70C-6M H_4

Optional Designators

The second letter & sixth number indicates the Diffusible Hydrogen Content of Deposited Weld Metal (DWM)

H4	≤ 4 mls H2 /100g of DWM
H8	≤ 8 mls H2 /100g of DWM
H16	≤ 16 mls H2 /100g of DWM

The third letter indicates "Shielding Gas"

M = indicates "Mixed Gas" and is classified for use with Argon + 20-25% CO_2 gas.

C = indicates "Carbon Dioxide" and is classified for use with 100% CO_2 gas or the wire is self shielded.

E = Electrode, **R** = Rod, **S** = Solid Wire, **C** = Composite Metal Cored Wire, followed by a hyphen then a number or letter which defines the chemical composition of the wire.

Wire Classification	Carbon (C)	Manganese (Mn)	Silicon (Si)	Other Elements Allowable % Range
ER70S-2	0.07	0.90-1.40	0.40-0.70	0.05-0.15Ti / 0.02-0.12Zr / 0.05-0.15Al
ER70S-3	0.06-0.15	0.90-1.40	0.45-0.75	0.50Cu
ER70S-4	0.07-0.15	1.00-1.50	0.60-0.85	0.50Cu
ER70S-5	0.07-0.19	0.90-1.40	0.30-0.60	0.50Cu / 0.50-0.90 Al
ER70S-6	**0.06-0.15**	**1.40-1.85**	**0.80-1.15**	**0.50Cu**
ER70S-7	0.07-0.15	1.50-2.00	0.50-0.80	0.50Cu
ER70S-G	G = General, composition is not specified and is agreed between the supplier and the customer.			
ER70C-3X	0.12	1.75	0.90	0.50Cu
ER70C-6X	**0.12**	**1.75**	**0.90**	**0.50Cu**
ER70C-G(X)	G = General, composition is not specified and is agreed between the supplier and the customer.			
ER70C-GS(X)	G = General, Single Pass Only, composition is agreed between the supplier and the customer.			

Single values are maximum. X represents shielding gas indicators e.g. "C" indicates CO_2 shielding gas and "M" indicates mixed shielding gases in the Argon + 20-25% CO_2. (X) is optional for these classifications.

CONSUMABLES CLASSIFICATION TABLES

AS 2203 Part 1-1990 Cored Electrodes for Arc Welding Ferritic Steel Electrodes

AS 2203.1 classifies Flux Cored Arc Welding (FCAW / cored) wires by using a series of letters and digits broken into four alpha numeric groups separated by hyphens and the last group separated by a full stop.
e.g. ETP-GCp-W504A.CM1 H10.

The following layout outlines this classification system in part only. For full details CIGWELD recommend you refer to the current published version of AS 2203 Part 1. obtainable from the Standards Association of Australia.

Group 3, the first two digits indicate approximately 1/10th of the minimum tensile strength in MPa.

Weld Metal No:	Tensile Strength Range (MPa)	Min. Proof Stress at 0.2% offset (MPa)	Minimum Elongation
W40	430 - 550	310	22%
W50	**490 - 650**	**360**	**22%**
W55	550 - 690	470	19%
W62	620 - 760	540	16%
W69	690 - 830	610	15%
W76	760 - 900	680	14%
W83	830 - 970	750	13%

Group 1,

E	Electrode
T	Tubular
Welding Positions:	
P	All Positional
D	Flat & H/V Fillets
S	Single run only

Condition of Weld Metal.
A - As welded condition
P - Postweld heat treatment

E T P - G C p - W 5 0 4 A . C M 1 H_{10}

Group 4,
indicates the Weld Metal Chemistry.
See Table 4 for details.

Indicates the Diffusible Hydrogen Content of Deposited Weld Metal (DWM).

H_5	≤ 5 mls H_2 /100g of DWM
H_{10}	≤ 10 mls H_2 /100g of DWM
H_{15}	≤ 15 mls H_2 /100g of DWM

Group 2,

G = Gas Shielding:	
C	carbon dioxide CO_2
M	mixed gas
N	no external shielding gas
Welding Current:	
p	direct current positive DC+
n	direct current negative DC-
a	AC current

The third digit indicates the Impact energy grade number:

Impact energy grade No:	Minimum average CVN impact values
0	Not required.
1	47J @ + 20°C
2	47J @ 0°C
3	47J @ -20°C
4	**47J @ -40°C**
5	47J @ -60°C

AS 2203 Part 1-1990 Cored Electrodes for Arc Welding Ferritic Steel Electrodes cont.

AS 2203.1 Weld Metal Chemistry Wt% Summary - Table 4

Weld Metal No:	Carbon (C)	Manganese (Mn)	Silicon (Si)	Nickel (Ni)	Chromium (Cr)	Molybdenum (Mo)	Other Elements
Carbon Steel Cored Wires							
CM1	0.20	1.75	0.90	0.50	0.20	0.30	0.08V / 1.8Al
CM2	> 0.20	1.75	0.90	0.50	0.20	0.30	0.08V / 1.8Al
Carbon-Molybdenum Steel Cored Wires							
A1	0.12	1.25	0.80			0.40-0.65	
Chromium-Molybdenum Steel Cored Wires							
B1	0.12	1.25	0.80		0.40-0.65	0.40-0.65	
B2L	0.05	1.25	0.80		1.00-1.50	0.40-0.65	
B2	0.12	1.25	0.80		1.00-1.50	0.40-0.65	
B2C	0.10-0.15	1.25	0.80		1.00-1.50	0.40-0.65	
B3L	0.05	1.25	0.80		2.00-2.50	0.90-1.20	
B3	0.12	1.25	0.80		2.00-2.50	0.90-1.20	
B3C	0.10-0.15	1.25	0.80		2.00-2.50	0.90-1.20	
5Cr	0.10	1.50	1.00	0.40	4.00-6.00	0.45-0.65	0.50Cu
7Cr	0.10	1.50	1.00	0.40	6.00-8.00	0.45-0.65	0.50Cu
9Cr	0.10	1.50	1.00	0.40	8.00-10.50	0.85-1.20	0.50Cu
Nickel Steel Cored Wires							
Ni1	0.12	1.50	0.08	0.80-1.10	0.15	0.35	0.05V / 1.8Al
Ni2	0.12	1.50	0.08	1.75-2.75			0.05V / 1.8Al
Ni3	0.12	1.50	0.08	2.75-3.75			
Manganese-Molybdenum Steel Cored Wires							
9X.D1	0.12	1.25-2.00	0.80			0.25-0.55	
9X.D2	0.15	1.65-2.25	0.80			0.25-0.55	
9X.D3	0.12	1.00-1.75	0.80			0.40-0.65	
Other Low Alloy Steel Cored Wires							
9X.K1	0.15	0.80-1.40	0.80	0.80-1.10	0.15	0.20-0.65	0.05V
9X.K2	0.15	0.50-1.75	0.80	1.00-2.00	0.15	0.35	0.05V / 1.8Al
9X.K3	0.15	0.75-2.25	0.80	1.25-2.60	0.15	0.25-0.65	0.05V
9X.K4	0.15	1.20-2.25	0.80	1.75-2.60	0.20-0.60	0.30-0.65	0.05V
9X.K5	0.10-0.25	0.60-1.60	0.80	0.75-2.00	0.20-0.70	0.15-0.55	0.05V
9X.K6	0.15	0.50-1.50	0.80	0.40-1.10	0.15	0.15	0.05V / 1.8Al
9X.K7	0.15	1.00-1.75	0.08	2.00-2.75			
G		1.00 min.	0.80 min.	0.50 min.	0.30 min.	0.20 min.	0.10 min. / 1.8Al
9X.W	0.12	0.50-1.30	0.35-0.80	0.40-0.80	0.45-0.70		0.30-0.75Cu

Single values shown are maximum.

CONSUMABLES CLASSIFICATION TABLES

AWS A5.20-95 Carbon Steel Electrodes for Flux Cored Arc Welding

AWS A5.20-95 classifies Flux Cored Arc Welding (FCAW / cored) wires by using a series of letters and digits broken into two alpha numeric groups separated by a hyphen. eg: E70T-1 or E71T-1M J H4.

The following layout outlines this classification system in part only. For full details CIGWELD recommend you refer to the current published version of AWS A5.20 obtainable from the American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126, USA.

E 7 1 T - 1 M J H_4

E = ELECTRODE

6 or 7 = the first digit indicates the minimum tensile strength in psi x 10,000.

Weld Metal No:	Minimum Tensile Strength "psi" (MPa)
6	60,000 (415)
7	70,000 (480)

The second digit indicates the Welding Positions

0	Flat & Horizontal
1	All Positional

The second letter indicates the electrode is Flux Cored.

T = Tubular

Optional Designators

1 = the third digit group (1 to 14, or the letter/s G or GS) indicates the Welding Polarity to be used, Arc Transfer, Flux type and the No. of Weld Passes.

eg. 1 = D.C.+, spray transfer, rutile type flux for multi-pass welding.

G = "General" Classification, and means that the electrode shielding, polarity and impact properties are not specified.

S = "Single" Pass welding only.

See Table 6 for details.

M = the third letter indicates "Mixed Gas" and is classified for use with Argon + 20-25% CO_2.
If no 'M' is shown than the electrode is used with either CO_2 or the electrode is self shielded.

The second letter & sixth number indicates the Diffusible Hydrogen Content of Deposited Weld Metal (DWM)

H_4	$\leq$ 4 mls H_2 /100g of DWM
H_8	$\leq$ 8 mls H_2 /100g of DWM
H_{16}	$\leq$ 16 mls H_2 /100g of DWM

J = the fourth letter indicates that the electrode meets the following requirements of improved impact toughness, 20ft Lb @ -40°F (27J @ -40°C).

See Table 5 for details.

CONSUMABLES CLASSIFICATION TABLES

AWS A5.20-95 Carbon Steel Electrodes for Flux Cored Arc Welding cont.

Shielding Gas Types

E7XT-1 These electrodes are designed primarily for use with CO_2 shielding gas. Argon based gases may be used to improve out-of-position characteristics.

Warning: By using Argon based gas mixtures with these electrode types the following problems may occur;

1) deoxidiser levels in weld deposits may increase,
2) weld deposit hardness levels may increase,
3) weld deposit manganese and silicon levels may increase which will raise yield and tensile strength, and may degrade impact properties.

E7XT-1M These electrodes are designed primarily for use with **Argon + 20-25% CO_2** shielding gases.

Warning: Higher levels of CO_2 above those recommended, in Ar / CO_2 gases or the use of 100% CO_2 gas with these types of electrodes may result in the following;

1) deterioration of arc and out-of-position characteristics,
2) resultant weld deposits may show decreased levels of manganese and silicon which will reduce yield and tensile strength and may degrade impact properties.

As Welded Mechanical Properties - Table 5

AWS Class.	Tensile Strength ksi	Tensile Strength MPa	Yield Strength ksi	Yield Strength MPa	% Elong.	Charpy-V-Notch (CVN) Impact Requirements
T-1/1M	70	480	58	400	22	20ft Lb @ 0°F (27J @ -18°C)
T-2/2M	70	480	n.s.	n.s.	n.s.	not specified
T-3*	70	480	n.s.	n.s.	n.s.	not specified
T-4*	70	480	58	400	22	not specified
T-5/5M	70	480	58	400	22	20ft Lb @ -20°F (27J @ -29°C)
T-6*	70	480	58	400	22	20ft Lb @ -20°F (27J @ -29°C)
T-7*	70	480	58	400	22	not specified
T-8*	70	480	58	400	22	20ft Lb @ -20°F (27J @ -29°C)
T-9/9M	70	480	58	400	22	20ft Lb @ -20°F (27J @ -29°C)
T-10*	70	480	n.s.	n.s.	n.s.	not specified
T-11*	70	480	58	400	20	not specified
T-12/12M	70-90	480-620	58	400	22	20ft Lb @ -20°F (27J @ -29°C)
T-13*	60	415	n.s.	n.s.	n.s.	not specified
T-13*	70	480	n.s.	n.s.	n.s.	not specified
T-14*	70	480	n.s.	n.s.	n.s.	not specified
T-G	60	415	48	330	22	not specified
T-G	70	480	58	400	22	not specified
T-GS	60	415	n.s.	n.s.	n.s.	not specified
T-GS	70	480	n.s.	n.s.	n.s.	not specified

The above designations may be classified with the 'J' indicator provided the lower CVN Impact requirements of 20ft Lb @ -40°F (27J @ -40°C), are met for T-1/1M, T-5/5M, T-6, T-8, T-9/M and T-12/12M types.

* Self Shielded wire types.

CONSUMABLES CLASSIFICATION TABLES

AWS A5.20-95 Carbon Steel Electrodes for Flux Cored Arc Welding cont.

AWS A5.20 Electrode Classification Summary - Table 6

AWS A5.20 Class.	Polarity	Arc Transfer Type	Slag Base	No. of Weld Passes	Discernible Features and Applications
T-1 and T-1M	DC +	Spray	Rutile	Multiple	Larger diameters (2mm [5/64"] & larger) are used for flat & H/V welding only. Very smooth / quiet arc with low spatter loss, flat to slightly convex weld bead contour, full covering easy removed slag, and high deposition rates.
T-2 and T-2M	DC +	Spray	Rutile	Single	Essentially the same as T-1 / T-1M types, but with higher manganese or silicon or both. Higher levels of deoxidisers allow welding of heavily oxidised steels such as, rimmed, rusty and mill scaled steels. SINGLE pass only.
T-3*	DC +	Spray	Rutile Fluoride	Single	# High speed gasless welding in flat & H/V and 20° down inclined positions on sheet metal. Limited mech. props.
T-4*	DC +	Globular	Alumina Fluoride	Multiple	Very low Sulphur weld deposits (resistant to hot cracking) & very high deposition rates. Bridging of poor fit-up joints.
T-5 and T-5M	DC + / -	Globular	Basic	Multiple	Larger diameters (>2mm) are used for flat & H/V welding. Good mechanical properties (eg. impacts 27J @ -29°C / 20ft Lb @ -20°F) Slightly convex weld bead contour, easy removed thin slag, resistant to hot & cold cracking.
T-6*	DC +	Spray	Rutile Basic	Multiple	Good low temperature impact properties (eg. 27J @ -29°C / 20ft Lb @ -20°F). Excellent slag removal in deep groove joints. Good root run penetration. Flat & H/V only.
T-7*	DC -	Spray	Alumina Fluoride	Multiple	Dia. (>2mm) used for flat & H/V welding. High deposition rates and very low sulphur weld metal resistant to cracking.
T-8*	DC -	Spray	Alumina Fluoride	Multiple	Very good low temperature strength, notch toughness and crack resistance (eg. 27J @ -29°C / 20ft Lb @ -20°F).
T-9 and T-9M	DC +	Spray	Rutile	Multiple	Essentially the same as T-1 / T-1M types, but deposit weld metal with improved impact properties (eg. 27J @ -29°C / 20ft Lb @ -20°F). To obtain X-Ray quality, joints are to be relatively clean and free of oil, excessive oxide & mil-scale.
T-10*	DC -	small droplet Globular	---	Single	High speed gasless welding in flat & H/V and 20° vertical inclined positions on larger thickness than the T-3 class.
T-11*	DC -	Spray	---	Multiple	General purpose wire for use on material less than 20mm (3/4) unless preheat & interpass temp's are maintained.
T-12 and T-12M	DC +	Spray	Rutile	Multiple	Essentially the same as T-1 / T-1M types, but modified to increase impact properties and to meet lower manganese requirements of the ASME Boiler and Pressure Vessel code section IX, A-1 analysis group of 1.6% Mn.
T-13*	DC -	Short arc	---	Single	Root pass welding only on circumferential pipe welds.
T-14*	DC -	Spray	---	Single	# High speed all positional welding of sheet metal such as, galvanised, zinc and other coated steels ≤ 6mm (1/4).
T-G	DC + / -	not specified	N.S.	Multiple	For electrodes not covered by any present classification. The wire must meet the chemical requirements to ensure a carbon steel deposit and the specified tensile strength.
T-GS	DC + / -	not specified	N.S.	Single	For single pass electrodes not covered by any present classification. The wire must meet the specified tensile strength requirements. No other requirements are specified.

* Self shielded wire types. # Suitable only for material thickness below 6mm (1/4")

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CONSUMABLES CLASSIFICATION TABLES

AS/NZS 2576. 1996 - Classifies Welding Consumables as used for Build-up and wear resistance. The following layout outlines this classification, however for the complete classification CIGWELD recommends that users refer to the current version of the standard. The publication is available from the Standards Association of Australia or Standards New Zealand.

1560-A4

FIRST DIGIT - ALLOY GROUP

1 = Steels
2 = Chromium White Irons
3 = Tungsten Carbide Composites
4 = Nickel Alloys
5 = Copper Alloys

SECOND DIGIT - ALLOY TYPE

15XX =Tool Steel
See Table 7 for Alloy types

THIRD AND FOURTH DIGITS - DEPOSIT HARDNESS

Hardness of undiluted deposits prior to any subsequent heat treatment or work hardening expressed in Rockwell C (HRc)
e.g. XX60 = 60-65HRc

FIRST LETTER - WELDING PROCESS

Letter Indicates - Welding Process:
A = Manual Metal Arc Welding
B = Submerged Arc Welding and Flux Cored Arc Welding
C = Gas Welding

LAST DIGIT - WELDING CONSUMABLE TYPE

A1 - Tubular Electrode, no Alloy Contribution from Coating.

A4 - Low Carbon Steel Rod, Alloy additive Flux Coating.

B1 - Submerged Arc Tubular Wire, No Alloy Contribution from Flux.

B5 - Continuous Tubular Wire-gas Shielded.

B7 - Continuous Tubular Wire-self Shielded.

C1 - Filler Rod

C3 - Powder

CONSUMABLES CLASSIFICATION TABLES (TABLE 7)

Group 1 - Steels	Alloy Type	AS/NZS class.
Cobalarc Mangcraft	Austenitic manganese steel	1215-A4
Cobalarc Mang. Nickel-O		1215-B1
Cobalarc Austex	Austenitic stainless steel	1315-A4
Shieldcrome 309LT		1315-B5
Cobalarc 350	Low carbon martensitic steel	1435-A4
Stoody Super Buildup-G/O		1435-B5/7
Cobalarc Toolcraft	Tool steel	1560-A4
Cobalarc 650	High carbon martensitic steel	1855-A4
Cobalarc 750		1860-A4
Stoody 965-G/O		1855-B5/B7
Stoody 850-O		1865-B7
Group 2 - Cr White Irons	**Alloy Type**	**AS/NZS class**
Cobalarc CR70	Austenitic chromium carbide iron	2355-A4
Stoody 101 HC		2360-B5/B7
Cobalarc 9	Complex chromium carbide iron	2460-A1
Cobalarc Borochrome	Martensitic chromium carbide iron	2560-A4
Stoody Fineclad-O		2565-B7
Group 3 - Tungsten Carbide Comp.	**Alloy Type**	**AS/NZS class**
Cobalarc 4	Tungsten carbide granules in an iron rich matrix	3460-A1
Group 4 - Copper Alloys	**Alloy Type**	**AS/NZS class**
Bronzecraft AC-DC	Phosphor bronze (7-9% Sn)	6200-A2
Comweld Manganese Bronze	High tensile brass	6300-C1
Comweld Comcoat C		6300-C1
Comweld Nickel Bronze	Nickel bronze (9-13% Ni)	6400-C1
Comweld Comcoat N		6400-C1

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BOC SHIELDING GAS INFORMATION

Shielding Gases and Their Properties

The purpose of a shielding gas in the GMA or GTA welding process is to shield the weld pool and molten filler wire from atmospheric Oxygen and Nitrogen, to stabilise the arc, provide the desired depth of penetration, and in GMAW, facilitate the required form of metal transfer. These functions are affected by such factors as:

- material to be welded
- weld position
- process chosen
- weld economics
- material thickness
- type of wire
- metal transfer mode
- finish required.

The main gases used in the formulation of a shielding gas are:

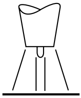
- Argon
- Carbon Dioxide
- Oxygen
- Helium
- Hydrogen.

These gases form the basis of the mixtures used in the Argoshield™ range designed to best meet the needs of the welding industry. While carbon dioxide and argon can be used in their pure form as shielding gases in most applications, a specific mixture of gases will offer improvements in welding productivity and help to reduce the total weld cost.

Argon

Argon is a chemically inert gas, heavier than air, with an ionisation potential of 15.7 eV giving easy arc starts and a stable welding arc. Argon produces a constricted arc column and has a low thermal conductivity which facilitates easy arc initiation.

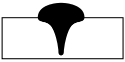
The result is a relatively narrow weld bead with deep central penetration of the weld deposit into the base metal giving the 'finger' or 'wine glass' penetration profile. In GMA welding (spray or pulse transfer mode), the main force in the arc is axial to the filler wire and accelerates the molten droplet smoothly across the arc. This allows for virtually spatter-free welding in spray transfer mode.



GMAW Argon arc column

Argon is used as a GMA welding shielding gas for many non-ferrous metals. It does not, however, provide suitable metal transfer characteristics for steel. There is a marked tendency for the filler metal not to flow out to the toes of the weld causing a very uneven weld shape. This poor weld bead shape is due to low arc energy, low heat input and rapid cooling rate and the high surface tension of liquid iron in argon atmospheres.

Argon is one of the gases available in the Argoshield™ range and is a standard GTA welding shielding gas. Argon forms 0.8% of air by volume and is produced in the air separation process in addition to oxygen and nitrogen.



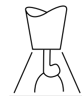
Penetration profile of Argon shielded GMA weld on Carbon steel

BOC SHIELDING GAS INFORMATION

Carbon Dioxide

Carbon dioxide, or CO_2, as it is commonly known, is not chemically inert. When energised and subjected to arc temperatures above 6000°C, its molecules dissociate at the top of the arc to form excited species of oxygen and carbon monoxide:

$2CO_2 = 2CO + O_2$

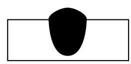


Carbon Dioxide arc column

These molecules recombine at the bottom of the arc and in so doing, release a disruptive force upward into the arc causing a stuttering, unstable arc and welding spatter. The oxygen superheats the transferring molten filler metal creating a deep penetrating, fluid weld pool and promoting the deposition of convex weld beads.

Because the CO_2 shielded arc is highly oxidising, it is useful for coping with surface contaminants such as rust, paint and primers. Carbon dioxide can be used for mild and carbon manganese steel welding, where it gives a narrow, peaked weld bead with deep penetration. The normal spray transfer of fine metal droplets does not occur in the CO_2 arc. Globular and dip transfer arc modes only are used with CO_2.

Because it is oxidising and not inert, CO_2 cannot be used to weld readily oxidisable metals such as aluminium, copper, magnesium or nickel, or for GTA welding. It is not suitable for stainless steels because of carbon pick-up which can give a 200-300% increase in carbon content in the weld metal.



Penetration profile of Carbon Dioxide on Carbon steel

In addition, because of the oxidising characteristics of CO_2 in GMA welding of steel, it is recommended that filler wires with a high manganese and silicon level or triple de-oxidised wires are used.

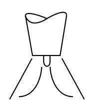
Oxygen

Although oxygen itself is not used as a shielding gas, it is a vital component in shielding gas mixtures. When used as a low percentage (i.e. 1-7%) additive to argon or argon/ CO_2 mixtures, oxygen can be very beneficial in improving arc characteristics and reducing the surface tension of the weld metal. It is an active gas which dissociates in the arc intensifying the arc plasma, thereby increasing the heat input and travel speed, and improving weld penetration and edge wetting. It promotes the spray transfer mode in GMA welding of steels to give a virtually spatter-free, high productivity process.

Helium

Helium is also inert but has a higher ionisation potential than argon, of 24.5 eV. As a result, helium arcs have a higher arc voltage than argon for a given arc length, translating into higher heat input and weld travel speeds.

The high thermal conductivity of helium produces a wide, low weld bead with good fusion and penetration. High flow rates are necessary to maintain a helium shield because the gas is lighter than air.



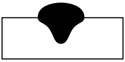
GMAW Helium arc column

BOC SHIELDING GAS INFORMATION

Helium cont.

High concentrations of helium are used in Argoshields' designed to weld thick sections of non-ferrous metals or metals where the high heat conductivity of the metal causes problems in maintaining weld pool fluidity. Welding speeds are very high with helium and its use can result in economical advantages over low cost gases, particularly in high conductivity materials.

Helium is a rare gas found in association with certain natural gas streams in low concentrations. It is costly to produce, store and transport as a liquid, because its boiling point is very low - 269°C.



Penetration profile of Helium shielded GMA weld on Carbon steel

Hydrogen

Hydrogen has a relatively low ionisation potential (13.5 eV), but a high thermal conductivity. This produces a higher arc energy for deeper penetration and weld pool fluidity. Because hydrogen is a reducing agent, its action helps to remove oxide films on the weld pool surface resulting in a cleaner weld bead.

Argon Based Mixtures

The characteristics of each gas used in a shielding gas mixture affect the way the gas will perform, including the shielding efficiency, arc stability and the shape and strength of the weld. Depending on the application, the right balance of gases in a mixture will produce a shielding gas with the optimum properties for the application and greater tolerance to voltage and current settings.

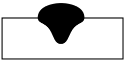
Argon is an excellent base for GMA welding shielding gas mixtures because it permits the use of spray transfer with all the commonly welded metals. However, when depositing flat or horizontal welds on steel or stainless steel, the quick freeze characteristics of an argon weld does not permit the molten metal to wet out the toes of the weld, causing undercutting at the edges of the weld bead. It is therefore necessary to add active gases to argon, such as oxygen or carbon dioxide, to increase the heat input for GMA welding of steels and stabilise the droplet size.

Argon + Oxygen Mixtures

Oxygen is added to argon to stabilise the arc, improve the weld bead profile and edge wetting and minimise the tendency to undercut ferrous welds. Discrete percentages of oxygen (i.e. 1-7%) prevent excessive losses of manganese and silicon, as well as increase the temperature of the molten metal transferred across the arc. The molten weld pool has a lower surface tension than with argon, wetting the parent metal to flatten the weld bead profile.

For stainless steels and other corrosion resistant steels (e.g. 3CR12) a mixture of 1-2% oxygen is recommended.

Above 5% oxygen, the surface of the weld bead becomes increasingly oxidised with consequent losses of manganese, silicon and chromium. Argon/oxygen welds have a flatter bead than argon or CO_2 and give awine glass penetration pattern. Argoshield™ 40 is such an argon/oxygen mixture offering virtually spatter-free beads on sheet steel in spray mode.



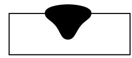
Penetration profile of Argon + Oxygen shielded GMA weld on Carbon steel

BOC SHIELDING GAS INFORMATION

Argon Based Mixtures

Argon + Carbon Dioxide Mixtures

For mild and carbon manganese steels, argon/carbon dioxide mixtures can be used with the CO_2 conventionally ranging from 2-30% by volume. Ideally 25% CO_2 should not be exceeded for best results. With increasing CO_2 content to provide more heat and broader and deeper penetration, the spray transfer mode deteriorates. Argoshield™ 52 is a high CO_2 mixture offering excellent penetration. Argon/CO_2 mixtures are successfully used with flux-cored and metal-cored wires.



Penetration profile of Argon + Oxygen shielded GMA weld on Carbon steel

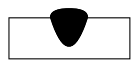
An argon/CO_2 weld shows deeper and fuller penetration than argon/carbon dioxide shielded and an argon/oxygen weld.

Argon + Oxygen + Carbon Dioxide mixtures

The further addition of Oxygen to an argon/CO_2 mixture flattens the weld bead and improves spray transfer characteristics, total heat input, weld bead profile and penetration.

Argon/oxygen/carbon dioxide mixtures allow the fullest flexibility in producing shielding gases best suited to different steel applications. The oxygen and CO_2 mixtures, such as Argoshield™ Light, are well suited to dip transfer welding of lighter section metal. In the spray transfer mode, they give an excellent arc with greater welder appeal and minimum spatter that is suitable for welding light and medium section steels.

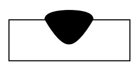
Low oxygen/high CO_2 mixtures, such as Argoshield™ Universal, are best suited to dip and spray transfer welding and display excellent weld bead profiles and penetration. They perform particularly well in all position welding of heavy steel sections. High CO_2 mixtures give spatter levels which are much lower than with carbon dioxide, but with comparable penetration and fusion performance. The addition of the oxygen reduces the droplet diameter and improves the stability of the transfer.



Penetration profile of Argon + Oxygen + Carbon Dioxide

Argon + Helium Mixtures

Argon/helium mixtures are usually used to obtain the most favourable characteristics of both gases in terms of heat input, weld speed, weld bead profile and penetration. The mixtures are normally used for heavier sections of non-ferrous metals such as aluminium, copper, magnesium and nickel. The heavier the metal thickness and the more heat conductive the metal, the greater the percentage of helium required in the mixture. Typical mixtures contain between 25% and 75% helium. Alushield Light and Alushield Heavy are argon/helium mixtures.



Penetration profile of Argon + Helium shielded weld on Carbon steel

Argon + Helium + Hydrogen

A mixture of argon/helium/hydrogen, as found in Argoshield™ 71T, produces a very hot arc making this mixture ideal for GTA welding of stainless and nickel steels. The relatively small amount of hydrogen does not cause damage to the tungsten electrode but is desirable to increase the speed of welding while offering cleaner weld beads by the reducing action of the hydrogen onthe weld pool surface oxides. Hydrogen is also known to improve the weld tolerance of variations in austenitic stainless steel castings.

SHIELDING GAS INFORMATION

Mild and Medium Tensile Steels - Gas Metal Arc and Flux Cored Arc Welding

Shielding Gas	Filler Metals GMAW		Comments	Filler Metals FCAW	Comments
Argoshield 40	Autocraft LW1	Autocraft LW1-6	Clean, smooth finish	Metal-Cor XP*	
Argoshield Light	Autocraft LW1	Autocraft LW1-6	Clean, dip & spray transfer	Metal-Cor XP* Verti-Cor XP*	
Argoshield Universal	Autocraft LW1	Autocraft LW1-6	Higher penetration	Metal-Cor XP	Optimum shielding for penetration and travel speeds
				Verti-Cor XP Verti-Cor 3XP Supre-Cor 5	Smooth even transfer spatter and fine levels. Adequate penetration.
Argoshield 52	Autocraft LW1	Autocraft LW1-6	Higher CO_2 level, excellent dip and spray	Verti-Cor XP Verti-Cor 3XP Supre-Cor 5 Verticor 3XP H4	Optimum shielding giving excellent edge fusion and penetration, low spatter and fume levels.
				Metal-Cor XP	Higher CO_2 contents with higher spatter levels.
Argoshield 54	Autocraft LW1	Autocraft LW1-6	High quality, triple mixture	Metal-Cor XP* Verti-Cor XP*	
Argoshield 100	Autocraft LW1	Autocraft LW1-6	Helium addition for higher travel speeds	Supre-Cor 5	Improved arc transfer, better fillet shapes & lower spatter levels
Welding CO_2	Autocraft LW1	Autocraft LW1-6	High penetration, low cost	Satin-Cor XP Verti-Cor ULTRA Verti-Cor ULTRA 3 Verti-Cor Ultra H4 Verti-Cor XP Supre-Cor 5 Tensi-Cor 110TXP	Optimum shielding for economy and weld metal quality. Low cost shielding giving deep penetration characteristics.

* These shielding gases are not normally recommended due to higher Mn and Si recovery in the weld metal. For single pass fillet welds the results may be acceptable.

SHIELDING GAS INFORMATION

Alloy Steels - Gas Metal Arc and Flux Cored Arc Welding

Shielding Gas	Filler Metals GMAW	Comments	Filler Metals FCAW	Comments
Argoshield 52	Autocraft Super Steel Autocraft Mn-Mo Autocraft CrMo1 Autocraft NiCrMo	Excellent penetration and usability for dip and spray transfer. Most suitable for dip transfer.	Supre-Cor 5	For alloy steels where full joint efficiency is not required
			Verti-Cor 80Ni 1 Verti-Cor 91 K2 Verti-Cor 111 K3	For alloy steels where higher joint strength is required
Stainshield	Autocraft Super Steel Autocraft Mn-Mo Autocraft CrMo1 Autocraft NiCrMo	Optimum choice for smooth transfer in spray mode, higher alloy recovery	N.R.	
Argoshield 100	Autocraft Super Steel Autocraft Mn-Mo Autocraft CrMo1 Autocraft NiCrMo	Helium addition for high travel speeds	Supre-Cor 5	Improved arc transfer, better fillet shapes & lower spatter levels. For alloy steels where full joint efficiency is not required

Stainless Steels - Gas Metal Arc and Gas Tungsten Arc Welding

Shielding Gas	Filler Metals GMAW	Comments	Filler Wires GTAW	Comments
Stainshield	Autocraft 308LSi, 316LSi, 309LSi,	Smooth, even transfer, excellent fillet shape, ideal for spray transfer	N.R.	
Stainshield Heavy	Autocraft 308LSi, 316LSi, 309LSi,	Excellent dip transfer, can also be used for spray For welding heavier section (>9mm) stainless steels.	N.R.	
Welding Argon	N.R.		Comweld 308L , 309L, 316L,	Low cost shielding for all general purpose applications. Also used as purge gas on pipe welding.

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SHIELDING GAS INFORMATION

Aluminium Alloys - Gas Metal Arc and Gas Tungsten Arc Welding

Shielding Gas	Filler Metals GMAW	Comments	Filler Wires GTAW	Comments
Welding Argon	Autocraft AL1188 Autocraft AL4043 Autocraft AL5356	Excellent shielding for general purpose applications	Comweld AL1188 Comweld AL4043 Comweld AL4047 Comweld AL5356	Excellent shielding for manual applications
Alushield Light	Autocraft AL1188 Autocraft AL4043 Autocraft AL5356	Hotter arc to give broader & deeper penetration.	Comweld AL1188 Comweld AL4043 Comweld AL4047 Comweld AL5356	Hotter arc where more penetration is required.
Alushield Heavy	Autocraft AL1188 Autocraft AL4043 Autocraft AL5356	Hottest arc, high speed broadest, deepest penetration for heavy sections.	Comweld AL1188 Comweld AL4043 Comweld AL4047 Comweld AL5356	Hottest arc for heavier sections (>6mm) and mechanised applications.

Copper Alloys - Gas Metal Arc and Gas Tungsten Arc Welding

Shielding Gas	Filler Metals GMAW	Comments	Filler Wires GTAW	Comments
Welding Argon	Autocraft Deox. Copper Autocraft Silicon Bronze	For general purpose applications	Comweld Si. Bronze	For general purpose applications
Specshield Copper	Autocraft Deox. Copper Autocraft Silicon Bronze	For improved characteristics	N.R.	
Alushield Alushield Heavy	Autocraft Deox. Copper Autocraft Silicon Bronze	Hotter arc, reduces preheat temp. requirements. Higher travel speeds.	Comweld Si. Bronze	Hotter arc for mechanised applications. Higher travel speeds.

WELDING OF STEEL

The following information is for guidance in determining the weldability of various grades of steel which have been listed under the appropriate steel standard specification or proprietary trade names. For a comprehensive treatment of the "weldability of steels" please refer to the Welding Technology Institute of Australia (WTIA) Technical Note 1.

Factors influencing weldability:

1) The effect of Carbon on Steel:

Carbon is a major alloying element in the various grades of steel; increasing the carbon content of a particular steel results in a corresponding increase in hardenability when the material is subject to thermal treatment.

From a welding point of view, the best practice is to adopt a welding procedure which minimises the risk of high hardness in the Heat Affected Zone (HAZ) of the base metal and the weld deposit.

Determination of carbon equivalent and group number of the steel:

In determining the weldability of a particular grade of steel, consideration must be given to the combined effect of alloying elements, in particular carbon and manganese. The following formula for Carbon equivalent (CE) takes account of the important alloying elements in calculating a number which grades the steel in terms of its relative weldability. Refer to the Carbon Equivalent (CE) table and respective weldability reference numbers detailed in Table 1.

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}$$

2) Determination of Combined Joint Thickness:

The concept of combined joint thickness (CJT) is required to address the expected cooling rate of adjoining sections - calculations for determining combined thickness are based on the following formula. Please refer to Diagram 1 for CJT's for a range of joint configurations.

$$T_{CJT} = t_1 + t_2 + t_3 + t_4$$

3) Welding Energy or Heat Input:

Welding energy or heat input calculations are dependent upon the practical welding variables used, in particular welding current, arc voltage and welding speed for the specific arc welding processes adopted including manual metal arc, semi-automatic and automatic welding.

Welding energy input is based on the following formula:

$$Q = \frac{I \times E}{V} \times \frac{60}{1000}$$

where
- **Q** = Welding energy or heat input (Kilojoules per millimeter, KJ/mm)
- **E** = Arc voltage (volts)
- **I** = Welding current (Amperes)
- **V** = Welding speed or travel rate (mm/min)

4) Hydrogen Controlled Consumables and Welding Process Selection:

When determining the weldability of steel, careful consideration must be given to welding consumable selection.

For the purpose of preheat determination, the welding consumable/process combination used can be broadly grouped into two major types. Those which are hydrogen controlled and those which are not hydrogen controlled:

- **Non-hydrogen controlled welding consumables:**
  This group includes cellulose, mild steel and iron powder type electrodes to Australian Standard AS/NZS 1553.1 classifications EXX10, EXX11, EXX12, EXX13, EXX14 and EXX24. For these non-hydrogen controlled electrodes care should be taken to avoid moisture pick-up from exposure to adverse atmospheric conditions (ie excessive heat, humidity etc)

- **Hydrogen controlled welding consumables:**
  Hydrogen controlled types are defined as those consumable/process combinations which produce less than 15 mls of diffusible hydrogen per 100 gms of deposited weld metal. These include hydrogen controlled manual arc electrodes of the EXX16, EXX18, EXX28 and EXX48 types to AS/NZS 1553 Parts 1 and 2. Many gas shielded metal-cored and flux-cored welding wires to AS 2203.1 and all steel gas metal-arc welding wires to AS/NZS 2717.1 satisfy the hydrogen controlled requirement provided they are used with the correct shielding gas.

  For all hydrogen controlled welding consumables, precautions must be taken in storage and handling to ensure the hydrogen status is not compromised.

  For further information on the correct storage and handling of CIGWELD welding consumables, please refer to this handbook or WTIA publication Tech Note 3 "Care and Conditioning of Welding Consumables".

General Procedure in Determining Weldability and Preheat Requirements.

1. Select the corresponding weldability reference number for the particular grade of steel.

Where a particular grade of steel is not listed, calculate the CE from the formulae given n section 1. Using Table 1 cross reference the CE calculation to determine the appropriate weldability reference number.

2. Using Diagram 1 as a guide, determine the combined joint thickness (CJT) for the specific joint being welded.
3. Using Figure 1, determine the joint weldability index from the intersection point of the two numbers from 1 & 2 above (ie the weldability reference number and the CJT number).
4. Cross reference the joint weldability index, with the expected welding energy input (in KJ/mm) on Figure 2* or 3* to calculate the appropriate preheat temperature.

*Note: if a **hydrogen controlled welding consumable** is to be used, refer to Figure 2; if a **non-hydrogen controlled welding consumable** is to be used, refer to Figure 3.

WELDING OF STEEL

The Need for Preheating of the Steel Joint:

The beneficial effects of preheating in improving the weldability of the steel joint are:

1. Preheating retards the cooling rate in the joint and is beneficial in preventing undesirable metallurgical microstructures from occurring in the heat affected zone (HAZ) of the base metal and in the weld metal of high alloy steel deposits.

2. Preheating is used to offset the thermal conductivity of the steel sections and is beneficial in reducing the level of residual stress in the joint after welding.

3. Preheat temperatures should be determined in accordance with the requirements of Figure 2 or 3 with the preheat temperature being maintained between subsequent weld passes.

4. Preheating assists in the removal of diffusible hydrogen from the weld zone ie. the weld bead and HAZ.

Tack Welding Procedure:

Best practice requires that the specified preheat is used prior to any tack welding operation regardless of the fact that tack welds will become part of the weldment.

Weldability Reference Numbers:

The Weldability Reference Numbers used in this guide relate to the carbon equivalent (CE) ranges shown in Table 1 below:

Carbon Equivalent (CE)	Weldability Reference Number	Carbon Equivalent (CE)	Weldability Reference Number
below 0.30	1	0.55 to below 0.60	7
≤ 0.30 to below 0.35	2	0.60 to below 0.65	8
0.35 to below 0.40	3	0.65 to below 0.70	9
0.40 to below 0.45	4	0.70 to below 0.75	10
0.45 to below 0.50	5	0.75 to below 0.80	11
0.50 to below 0.55	6	0.80 and above	12

Table 1

Note: Weldability Reference Numbers above 12 (ie. 12A, 12B, 12C & 13) are not related to CE.

WELDING OF STEEL

Preheat Determination:

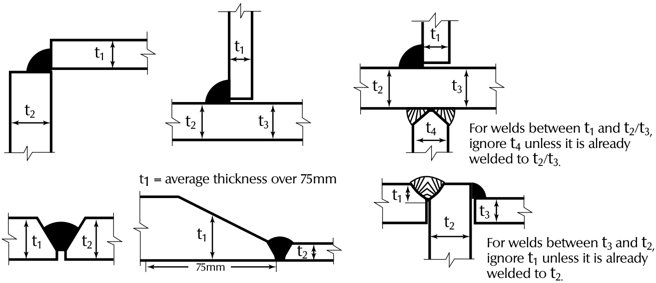

Diagram 1 - Combined Joint Thickness (CJT) calculations for welds shown in black.

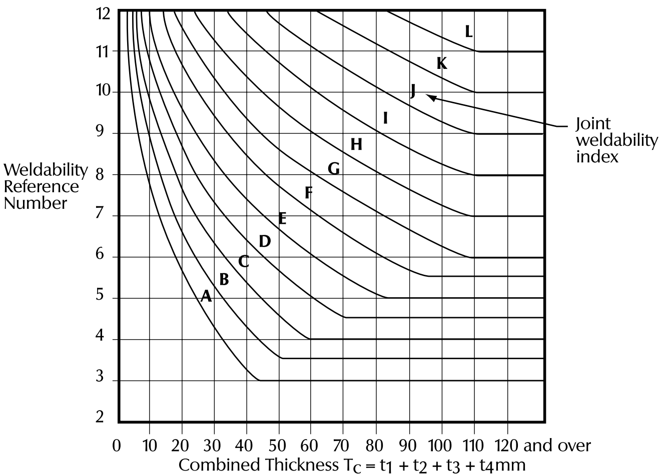

Figure 1 - Determination of joint weldability index using combined joint thickness and weldability reference number.

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WELDING OF STEEL

Preheat Determination:

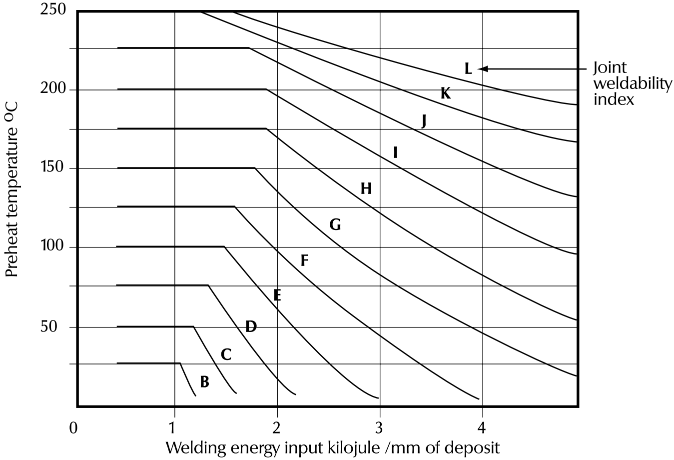

Figure 2 - Determination of preheat requirements for hydrogen controlled electrodes (EXX16, EXX18, EXX28 & EXX48) semi-automatic and automatic welding process.

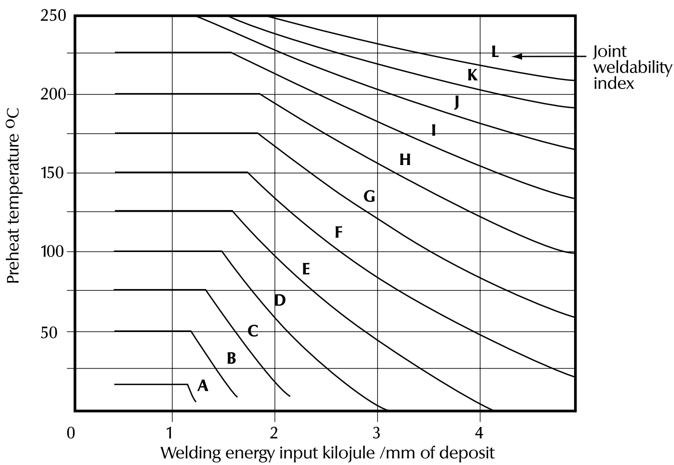

Figure 3 - Determination of preheat requirements for Manual metal-Arc Welding with other than hydrogen controlled consumables.

WELDING OF STEEL

Steel Specifications:

AS 1442 (1992) **Hot Rolled Bar and Semi Finished Product.**
AS 1443 (1993) **Cold Finished Bars Carbon Steel.**

Steel Designation	Chemical Analysis %			Weldability Reference Number
	C	Mn	Si	
1006	0.08	0.25/0.50	0.10/0.35	1
1010	0.08/0.13	0.30/0.60	0.10/0.35	1
1020	0.18/0.23	0.30/0.60	0.10/0.35	2
1030	0.28/0.34	0.60/0.90	0.10/0.35	5
1040	0.37/0.44	0.60/0.90	0.10/0.35	8
1050	0.48/0.55	0.60/0.90	0.10/0.35	10
1060	0.55/0.65	0.60/0.90	0.10/0.35	11
1070	0.65/0.75	0.60/0.90	0.10/0.35	12

Free Machine Steels.

Steel Designation	Chemical Analysis %				Weldability Reference Number
	C	Mn	S	Pb	
X1112	0.08/0.15	1.10/1.40	0.20-0.30		2A
1144	0.40/0.48	1.35/0.65	0.08-0.13		11A
X1147	0.40/0.47	0.60/1.90	0.10-0.35		11A
1214	0.15 Max	0.80/1.20	0.25-0.35		3A
12L14	0.15 Max	0.80/1.20	0.25-0.35	0.15-0.35	3A

AS 1447 (1991) **Hot Rolled Spring Steels.**

Steel Designation	Chemical Analysis %				Weldability Reference Number
	C	Mn	Si	Cr	
K1070S	0.65-0.75	0.60-0.90	0.10-0.35		12A
XK5155S	0.50-0.60	0.70-1.0	0.10-0.35	0.70-0.90	12A
XK5160S	0.55-0.65	0.70-1.0	0.10-0.35	0.70-0.90	12A
XK9261S	0.55-0.65	0.70-1.0	1.8-2.20		12A

AS 1663 (1991) **Structural Steel Hollow Sections.**

Steel Designation	Chemical Analysis %			Weldability Reference Number
	C	Mn	Si	
C250-C250LO*	0.12	0.50	0.05	1
C350-C350LO*	0.20	1.60	0.05	3
C450-C450LO*	0.20	1.60	0.35	3

* Nb + V + Ti = 0.15

WELDING OF STEEL

Steel Specifications:

Carbon Manganese Steels.

Steel Designation	Chemical Analysis % C	Chemical Analysis % Mn	Weldability Reference Number
X1315	0.12-0.18	1.40-1.70	5
X1320	0.18-0.23	1.40-1.70	5
X1325	0.23-0.28	1.40-1.70	6
X1340	0.38-0.43	1.40-1.70	10
X1345	0.43-0.48	1.40-1.70	11

AS 1444 (1986) **Fully Killed Alloy Steels.**
AS 2506 (1990) **Wrought Alloy Steels.**

Steel Designation	Chemical Analysis % C	Mn	Si	Ni	Cr	Mo	Weldability Reference Number
XK3312(EN36A)	0.10-0.16	0.35-0.60	0.10-0.35	3.0-3.75	0.70-1.0		6
4130	0.28-0.33	0.40-0.60			0.80-1.10	0.15-0.25	9
4140	0.30-0.43	0.75-1.0			0.80-1.10	0.15-0.25	12
XK4150	0.47-0.55	1.0-1.40	0.10-0.40		0.40-0.80	0.10-0.20	12
XK4340	0.37-0.44	0.55-0.90	0.10-0.35	1.55-2.0	0.65-0.95	0.20-0.35	12
4620	0.17-0.23	0.45-0.65	0.10-0.35	1.65-2.0		0.20-0.30	6
5140	0.38-0.43	0.70-0.90			0.70-0.90		11
8620	0.18-0.23	0.70-0.90	0.10-0.35	0.40-0.70	0.40-0.60	0.15-0.25	6
9050	0.45-0.55	0.90-1.20	0.60-0.90				11
XK9315	0.12-0.18	0.25-0.50	1.10-0.35	3.90-4.30	1.0-1.40	0.15-0.30	10
XK9931	0.27-0.35	0.45-0.70	0.10-0.35	2.30-2.80	0.50-0.80	0.45-0.65	12
XK9940	0.36-0.44	0.45-0.70	0.10-0.35	2.3-2.80	0.50-0.80	0.45-0.65	12

WELDING OF STEEL

Steel Specifications:

BS STEEL SPECIFICATION.

Steel Designation	Chemical Analysis %								Weldability Reference Number
	C	Mn	Si	Cr	Ni	Mo	S	P	
BS 1501 (1980)	**Steels for Fired and Unfired Pressure Vessels**								
Grade 360	0.17	0.40 - 1.20							3
Grade 400	0.22	0.50 - 130							4
Grade 430	0.25	0.60 - 1.40							5
BS EN 10028-2 (1993)	**Steels for Pressure Purposes, Non-alloy and Alloy Steels with Elevated Temperature Properties**								
Grade P235GH	0.16	0.40 - 1.20							3
Grade P265GH	0.20	0.50 - 1.40							4
Grade P295GH	0.08 - 0.20	0.90 - 1.50							5
Grade P355GH	0.10 - 0.22	1.00 - 1.70							5
BS EN 10025 (1980)	**Hot Rolled Products of Non Alloy Structural Steels**								
Grade Fe 360									3
Grade Fe 430									4
Grade Fe 430		1.60							5
BS970/PD970	**Specification Steels**								
En 25	0.27-0.35	0.10-0.35	0.50-0.70	2.30-2.50	0.50-0.80	0.40-0.70	0.050	0.050	12
En 26	0.36-0.44	0.10-0.35	0.50-0.70	2.30-2.80	0.50-0.80	0.40-0.70	0.050	0.050	12
En 36A	0.15	0.10-0.35	0.30-0.60	3.00-3.75	0.60-1.10		0.050	0.050	6
En 39B	0.12-0.18	0.10-0.35	0.50	3.80-4.50	1.00-1.40	0.15-0.35	0.050	0.050	10
En 40A	0.10-0.20	0.10-0.35	0.40-0.65	0.40	2.90-3.50	0.40-0.70	0.050	0.050	10
En 40B	0.20-0.30	0.10-0.35	0.40-0.65	0.40	2.90-3.50	0.40-0.70	0.050	0.050	12

Ferritic Creep Resistant Steels

Steel Designation	Chemical Analysis %				Weldability Reference Number
	C	Mn	Si	Pb	
Mn-Mo	0.20	1.40	-	0.45	7B
1/2Cr-1/2Mo	0.15	0.50	0.50	0.50	7B
1Cr-1/2Mo	0.12	0.50	1.10	0.50	7B
2 1/4Cr-1Mo	0.12	0.50	2.30	1.00	12B
5Cr-1/2Mo	0.12	0.50	5.00	0.60	12B

WELDING OF STEEL

Steel Specifications:

Steel Designation	Chemical Analysis % C	Mn	Si	Cr	Ni	Mo	S	Other	Weldability Reference Number
Plastic Mould Steels									
ASSAB									
Calmax	0.6	0.8	0.35	4.5		0.5		V 02	12C
BOHLER STEEL									
M200	0.40	1.50	0.40	1.90		0.20	0.070		12C
M238	0.38	1.50	0.30	2.0	1.10	0.20			12C
M310	0.43			13.5					12C
COMMONWEALTH STEEL									
P20	0.30	0.75	0.60	1.70		0.40			12C
Maxel Holder Block	0.50	1.30	0.30	0.65		0.18			12C
STEELMARK EAGLE & GLOBE									
CSM20.30	0.80	0.50	1.65		0.40			12C	
Maxel HB	0.50	0.30	0.08	0.65		0.18			12C
420 MFQ	0.35	0.1	1.0	13.0					12C
Hot Work Tool Steel									
ASSAB									
8407	0.39	0.40	1.0	5.3		1.3		V0.9	12C
8407 Supreme	0.39	0.40	1.0	5.2		1.40		V0.9	12C
QRO 90 Supreme	0.38	0.75	1.0	.6		2.25		V0.9	12C
BOHLER STEEL									
W302	0.39	0.40	1.10	5.20		1.40		V0.95	12C
W321	0.39	0.35	0.30	2.90		2.8		V0.50 Co2.90	12C
W500	0.55	0.75	0.25	1.1	1.7	0.55		V0.10	12C
COMMONWEALTH STEEL									
R15	0.55	0.70	0.30	0.65	1.40	0.35			12C
H13	0.40	0.40	1.0	5.0		1.30		V1.10	12C
STEELMARK EAGLE & GLOBE									
ADIC	0.39		1.0	5.2		1.40		V0.35	12C
NCM5	0.55	0.85		1.2	1.65	0.35		V0.15	12C

WELDING OF STEEL

Steel Specifications:

Steel Designation	Chemical Analysis %								Weldability Reference Number
	C	Mn	Si	Cr	Ni	Mo	S	Other	
Cold Work Tool Steel									
ASSAB									
XW10	1.0	0.60	0.30	5.3		1.1		V0.20	12C
XW5	2.05	0.80	0.30	12.5				W1.3	12C
XW41	1.55	0.4	0.3	11.8		0.8		V0.8	12C
DF2	0.95	1.1		0.6				W0.6 V0.1	12C
BOHLER STEEL									
K190	2.3	0.40	0.40	12.50		1.10		V4.0	12C
K600	0.45	0.40	0.25	1.30	4.0	0.25			12C
K660	0.70	2.0	0.30	1.0		1.35	0.15		12C
STEELMARK EAGLE & GLOBE									
SC23	2.0	0.20	0.30	12.0					12C
SC25	1.50	0.45	0.25	18.0		1.0		V0.35	12C
NSS6	0.70	1.90	0.30	1.0		1.35			12C
SRS	0.60	0.80	1.60	0.35		0.40		V0.15	12C

AS1302 (1991)   Steel Reinforcing Bars For Concrete

Steel Designation	Chemical Analysis %			Weldability Reference Number
	C	Mn	Si	
Grade 250R Plain Bars*	0.25			4
Grade 250S Deformed Bars*	0.25			4
Grade 400Y Deformed Bars*	0.22			3

*Grain refining and micro alloying elements = 0.15%

AS1085.1   Rail Steels

Steel Designation	Chemical Analysis %			Weldability Reference Number
	C	Mn	Si	
Grade Grade 31kg or 41kg	0.53-0.69	0.60-0.95	0.15-0.35	12
Grade 50kg or 60kg	0.66-0.82	0.70-1.00	0.15-0.50	12

WELDING OF STEEL

Steel Specifications:

AS3678 (1990) Structural Steels Hot Rolled Plates, Floor Plates and Slabs

Steel Designation	Chemical Analysis %						Weldability Reference Number
	C	Mn	Si	Ni	Cr	Mo	
Grade 200	0.15	0.60	0.25	-	-	-	1
Grade 250-250L15	0.22	1.70	0.55	-	-	-	4
Grade 300-300L-15	0.22	1.70	0.55	-	-	-	4
Grade 350-350L15	0.22	1.70	0.55	-	-	-	5
Grade 400-400L15	0.22	1.70	0.55	-	-	-	5
Grade WR350/1, L0	0.14	1.70		0.55	0.35-1.05	0.15-0.50	5A

Steels to Shipping Classification Society Rules

Steel Designation	Chemical Analysis %		Weldability Reference Number
	C	Mn	
Grade A	0.23	-	3A
Grade B	0.21	0.80 min.	3A
Grade D	0.21	0.60 min.	4A
Grade E	0.18	0.70 min.	4A
American Bureau of Shipping			
Class A	0.23	-	3A
Class B	0.21	0.80-1.10	4A
Class CS	0.16	1.00-1.35	3A
Class DS	0.16	1.00-1.35	3A
Class D	0.21	0.70-1.35	4A
Class E	0.18	0.70-1.35	4A
Det Norske Veritas			
Grade NVA	0.23	-	3A
Grade NVD	0.21	0.60 min.	4A
Grade NVE	0.18	0.70 min.	4A
Bureau Veritas			
Grade A	-	-	3A
Grade B	0.21	0.80-1.40	4A
Grade D	0.21	0.60-1.40	4A
Grade E	0.18	0.70-1.50	4A

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WELDING OF STEEL

Steel Specifications:

AS 1548 (1989) **Steel Plates for Boilers and Pressure Vessels**

Steel Designation	Chemical Analysis %							Weldability Reference Number
	C	Mn	Si	Ni	Cr	Mo	Cu	
7-430 R,N,A,T	0.20	0.50-1.60	.50	.30*	.25*	.10*	.20*	5
7-460 R,N,A,T	0.20	0.90-1.70	.60	.30*	.25*	.10*	.30*	5
5-490 N or A	0.24	0.90-1.70	.60	.30*	.25*	.10*	.20*	5
7-490 R,N,A,T	0.24	0.90-1.70	.60	.30*	.25*	.10*	.30*	6

*Total Ni + Cr + Mo + Cu = .70% max.

PIPE LINE STEELS

API 5L (1992) **Specification for Seamless Line Pipe**

Steel Designation	Chemical Analysis %		Weldability Reference Number
	C	Mn	
Grade A25 Cl I, Cl II	0.21	0.30 - 0.60	2
Grade A	0.22	0.90	3
Grade B	0.27	1.15	5
Grade X42	0.29	1.25	5
Cold-expanded -Grades X46, X52	0.29	1.25	5
Non-expanded -Grades X46, X52	0.31	1.35	5
Grades X56, X60	0.26	1.35	5

API 5L (1992) **Specification for Welded Line Pipe**

Steel Designation	Chemical Analysis %		Weldability Reference Number
	C	Mn	
Grade A25 Cl I, Cl II	0.21	0.30 - 0.60	2
Grade A	0.21	0.90	3
Grade B	0.26	1.15	4
Grade X42	0.28	1.25	5
Cold-expanded -Grades X46, X52	0.28	1.25	5
Non-expanded -Grades X46, X52	0.30	1.35	5
Grades X56, X60	0.26	1.35	5
Grade X65	0.26	1.40	5
Grade X70	0.23	1.60	5
Grade X80	0.18	1.80	5

WELDING OF STEEL

Steel Specifications:

ASTM SPECIFICATION STEELS

Steel Designation	Chemical Analysis %		Weldability Reference Number
	C	Mn	
ASTM A36M (1991) Structural Steel Plates			
To 20mm including	0.25		4
Over 20 to 40mm including	0.25	0.80 - 1.20	4
Over 40 to 65mm including	0.26	0.80 - 1.20	4
Over 65 to 100mm including	0.27	0.85 - 1.20	5
Over 100mm	0.29	0.85 - 1.20	5
ASTM 242M (1991) High Strength Low Alloy Structural Steel			
Type 1	0.15	1.00	5
ASTM 283M (1992) Low and Intermediate Tensile Strength Carbon Steel Plates			
Grade A	0.14	0.90	2
Grade B	0.17	0.90	3
Grade C	0.24	0.90	4
Grade D	0.27	0.90	4
ASTM 284M (1990) Low and Intermediate Tensile Strength Carbon - Silicon Steel Plates			
Grade C:			
25mm and under	0.24	0.90	3
Over 25 to 50 mm, including	0.27	0.90	4
Over 50 to 100mm, including	0.29	0.90	4
Over 100 to 200mm, including	0.33	0.90	5
Over 200 to 300mm, including	0.36	0.90	6
Grade D:			
25mm and under	0.24	0.90	3
Over 25 to 50 mm, including	0.27	0.90	4
Over 50 to 100mm, including	0.29	0.90	4
Over 100 to 200mm, including	0.33	0.90	5
ASTM 285M (1990) Pressure Vessel Plates, Carbon Steel			
Grade A	0.17	0.90	2
Grade B	0.22	0.90	3
Grade C	0.28	0.90	4

WELDING OF STEEL

Steel Specifications:

ASTM SPECIFICATION STEELS.

Steel Designation	Chemical Analysis %		Weldability Reference Number
	C	Mn	
ASTM A516M (1990) Pressure Vessel Plates, Carbon Steel			
Grade 415			
12.5mm and under	0.21	0.60 - 0.90	3
Over 12.5 to 50mm including	0.23	0.85 - 1.20	4
Over 50 to 100mm including	0.25	0.85 - 1.20	5
Over 100 to 200mm including	0.27	0.85 - 1.20	5
Over 200	0.27	0.85 - 1.20	5
Grade 450			
12.5mm and under	0.24	0.85 - 1.20	4
Over 12.5 to 50mm including	0.26	0.85 - 1.20	5
Over 50 to 100mm including	0.28	0.85 - 1.20	5
Over 100 to 200mm including	0.29	0.85 - 1.20	5
Over 200	0.29	0.85 - 1.20	5
Grade 485			
12.5mm and under	0.27	0.85 - 1.20	5
Over 12.5 to 50mm including	0.28	0.85 - 1.20	5
Over 50 to 100mm including	0.30	0.85 - 1.20	6
Over 100 to 200mm including	0.31	0.85 - 1.20	6
Over 200mm	0.31	0.85 - 1.20	6
ASTM A537M (1991) Pressure Vessel Plates, Heat Treated, Carbon-Manganese-Silicon Steel			
40mm and under	0.24	0.70 - 1.35	5
Over 40mm	0.24	1.00 - 1.60	6
ASTM A569M (1991) Carbon Steel (0.15% max) Hot-Rolled Sheet and Strip			
Commercial quality	0.15	0.60	1
ASTM A572M (1992) High Strength Low Alloy Niobium Vanadium Steels			
Grade 290	0.21	1.35	5
Grade 345	0.23	1.35	5
Grade 415	0.26	1.35	6
Grade 450:			
13mm and under	0.26	1.35	6
over 13mm to 32mm	0.23	1.65	6

WELDING OF STEEL

Steel Specifications:

ASTM SPECIFICATION STEELS.

Steel Designation	Chemical Analysis % C	Chemical Analysis % Mn	Weldability Reference Number
ASTM A607 (1992) Steel Sheet and Strip, High Strength, Low Alloy, Hot Rolled and Cold Rolled			
Grade 415:			
Class 1, Grade 45	0.22	1.35	4
Class 1, Grade 50	0.23	1.35	5
Class 1, Grade 55	0.25	1.35	5
Class 1, Grade 60	0.26	1.50	6
Class 1, Grade 65	0.26	1.50	6
Class 1, Grade 70	0.26	1.65	6
Class 2, Grades 50,55	0.15	1.35	3
Class 2, Grades 60, 65	0.15	1.50	4
Class 2, Grade 70	0.15	1.65	4
ASTM A662M (1990) Pressure Vessel Plates, Carbon Manganese Steel for Moderate and Lower Temperature Service			
Grade A	0.14	0.90 - 1.35	3
Grade B	0.19	0.85 - 1.50	4
Grade C	0.20	1.00 - 1.60	5
ASTM A737M (1987) Pressure Vessel Plates, High Strength Low Alloy Steels			
Grade B	0.20	1.15 - 1.50	5
Grade C	0.22	1.15 - 1.50	5

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WELDING OF STEEL

Steel Specifications:

QUENCHED AND TEMPERED STEELS.

Structural and Abrasion Resistant Grades.

Properties	Steel Designation	Typical Chemical Analysis* (%)								Weldability Reference Number
		C	Mn	Si	Cr	Ni	Mo	S	Other	
BISALLOY Q & T STEELS (Australia).										
Yield Stress:										
500MPa 600MPa 620-690MPa	Bisalloy 60 Bisalloy 70 Bisalloy 80/80PV	0.16-0.18	1.10-1.40	0.20	0.20-0.90	---	0.20	0.003	B: 0.001 Ti: 0.02	13
Hardness:										
320-360HB 360-400HB	Bisplate 320 Bisplate 360	0.18	1.15	0.40	0.85	---	0.20	---	B: 0.002 Ti: 0.03	13
400-460HB	Bisplate 400	0.28	0.50	0.35	0.96	---	0.15	---	B: 0.002 Ti: 0.04	13
IMPORTED Q & T STEELS (JAPAN & USA).										
Yield Stress:										
550MPa 690MPa	HY80 HY100	0.14	0.30	0.25	1.60	2.8	0.40			13
690MPa	USST1	0.16	0.85	0.30	0.57	0.90	0.50		B: 0.004 V: 0.04 Cu: 0.30	13
690MPa	USST1 Type A	0.18	0.90	0.30	0.55		0.20	---	B: 0.001 V: 0.04	13
450MPa	Welten 60	0.11	1.22	0.45	0.17				V: 0.04	13
690MPa	Welten 80C	0.10	0.85	0.22	0.80		0.45		B: 0.001 V: 0.04 Cu: 0.28	13
690MPa	Welten 80E	0.18	0.90	0.23	0.40				B: 0.001 V: 0.03 Cu: 0.25	13
Hardness:										
320HB min	Welten AR 320	0.18	1.10	0.25	0.70		0.35		B: 0.002 V: 0.04 Cu: 0.35	13
360HB min	Welten AR 360C	0.18	1.10	0.25	0.90		0.35		B: 0.002 V: 0.04 Cu: 0.35	13
477HB min	Welten AR 500	0.30	1.20	0.40	0.60		0.10		B: 0.003 Cu: 0.28	13

* Dependent on plate thickness.

WELDING OF STEEL

Quenched & Tempered Steels:

Preheat recommendations for Q & T Steels - Table 2.

Q & T Steel Grade	< 13mm	> 13mm < 25mm	>25mm < 50mm	> 50mm
MINIMUM PREHEAT TEMPERATURE (°C) (assuming high joint restraint)				
High Strength Structural Grades.				
450 MPa minimum Yield Stress	10	25	75	100
620 MPa minimum Yield Stress	50	100	125	150
680 MPa minimum Yield Stress	50	100	125	150
Abrasion Resistant Grades.				
320 HB	50	100	125	100
360 HB	50	100	125	150
500 HB	100	150	150	---
MAXIMUM INTERPASS TEMPERATURE (°C)				
All Grades	150	175	200	220
MAXIMUM ARC HEAT INPUT (Kj / mm)				
All Grades	2.5	3.5	4.5	5.0

Filler Metal Selection Guide for Bisalloy Q & T Steels - Table 3.

Steel Designation	Weld Strength Category*	Manual Metal Arc Welding (MMAW)	Gas Metal Arc Welding # (GMAW)	Flux Cored Arc Welding # (FCAW)
Bisalloy 60	MS LS M H	Alloycraft 90 Ferrocraft 61/ 7016 NR	Autocraft Mn-Mo Autocraft LW1-6 NR	Verti-Cor 91 K2 Supre-Cor 5 / Verti-Cor 80Ni 1 NR
Bisalloy 70	MS LS M H	Alloycraft 110 Ferrocraft 61/ 7016 NR	Autocraft NiCrMo Autocraft Mn-Mo / Autocraft LW1-6 NR	Tensi-Cor 110TXP Supre-Cor 5 / Verti-Cor 80Ni 1 NR
Bisalloy 80	MS LS M H	Alloycraft 110 Ferrocraft 61/ 7016 NR	Autocraft NiCrMo Autocraft LW1-6 / Autocraft Mn-Mo NR	Tensi-Cor 110TXP Verti-Cor 111 K3 Supre-Cor 5 / Verti-Cor 80Ni 1 NR
Bisplate 320, 360, 400, 500	MS LS M H	NR Ferrocraft 61/ 7016 Cobalarc 350, 650	NR Autocraft LW1-6 Cobalarc 350, 650	NR Supre-Cor 5 / Verti-Cor 80Ni 1 Cobalarc 350, 650

* Weld Strength Category Definitions: MS - Matching Strength; M H - Matching Hardness; LS - Lower Strength; NR - Not Recommended

Use only recommended shielding gases, please refer to product data in this handbook.

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WELDING OF STEEL

Welding Recommendations:

Weldability Reference No:

1 & 2	Readily weldable with mild steel electrodes of the AS/NZS 1553.1: E41XX or E48XX, or AWS A5.1: E60XX or 70XX classifications (such as Satincraft 13, Ferrocraft 12XP, Ferrocraft 21 or Weldcraft). Gas Metal Arc (GMAW or MIG/MAG) welding or Flux Cored Arc welding (FCAW) with an appropriate CIGWELD welding consumable such as Autocraft LW1-6 or Verti-Cor 'series' wires can be carried out with out any precautions. No preheat is normally required.
2A*	The welding of these steels is normally not recommended because the high sulphur or lead content can often lead to hot shortness during welding. For non critical applications, best results are achieved using basic coated electrodes such as Ferrocraft 7016, Ferrocraft 61 or Ferrocraft 16TXP
3 & 4	Readily welded using mild steel electrodes as per recommendation 1 & 2. GMAW or FCAW processes can be used depending on specific welding details including equipment availability, welding location, material thickness and positional welding requirements etc. Refer to GMAW product data for Autocraft LW1-6 and FCAW product data for Verti-Cor XP / Ultra / Ultra 3 and 3XP in the front of this handbook. For Combined Joint Thicknesses (CJT, refer Diagram 1) of ≥50mm, the best practice is to select a hydrogen controlled welding process / consumable combination and a correspondingly lower preheat temperature.
3A* & 4A*	Check specific Shipping Society approval requirements of the consumable. This group of steels are readily welded using mild steel electrodes of the AS/NZS 1553.1: E41XX-2 or E48XX-2 classifications. Also readily weldable with the GMAW process and Autocraft LW1-6 welding wire or other "W503" GMAW welding wires. The FCAW process can also be used with Verti-Cor Ultra 3 / 3XP or other "W503" FCAW wires.
5 & 6	For intermediate strength and low alloy high strength steel, select a welding consumable producing near matching weld deposit analysis and/or mechanical properties. The best practice is to select a hydrogen controlled electrode or welding wire of a comparable strength grade to that of the steel being welded and use the recommended preheat.
5A*	To achieve matching 'weathering' of the parent steel, a welding consumable containing Nickel and Copper alloy additions must be used. If colour match is not an issue refer to 5.
7, 8 & 9	Follow the recommendations prescribed in 5 & 6. The use a hydrogen controlled welding process / consumable combinations is considered more important as the carbon equivalent and hardenability of the steel increases. The weld deposit strength level should at least equal that of the grade of steel being welded. These steels are hardenable and the use of correct preheat and interpass temperatures and slow cooling after welding are important for success. To avoid hydrogen cracking, the welding consumable should be used, stored and reconditioned in accordance with the manufacturer's recommendations. For CIGWELD welding consumables please refer to Recommended Storage, Care and Conditioning of CIGWELD Electrodes, Welding Wires and Rods **in this handbook**.
7B*	These Chromium-Molybdenum and Molybdenum type steels are usually welded with near matching welding consumables such as Alloycraft 80-B2 electrodes, Autocraft Mn-Mo / CrMo1 GMAW welding wires or Comweld CrMo1 GTAW rods etc. This is carried out to achieve comparable creep strength and corrosion resistance to the parent steel. Low hydrogen welding conditions are essential as are the correct preheat and interpass temperatures, retarded cooling and a post weld heat treatment.

*Note A , B & C suffixes indicate constraints or conditions not adequately covered by the CE formula (eg high S, Pb etc)

WELDING OF STEEL

Welding Recommendations:

Weldability Reference No:

10 & 11 Use hydrogen controlled welding process / consumable combinations which best match the chemical composition and/or strength level of the parent steel.

To avoid hydrogen cracking, the welding consumable should be used, stored and reconditioned in accordance with the manufacturer's recommendations. For CIGWELD welding consumables please refer to Recommended Storage, Care and Conditioning of CIGWELD Electrodes, Welding Wires and Rods **in this handbook**.

Preheat temperature should be determined using the procedure described on page 69 of this guide. The use of 'dry' welding consumables is essential for the successful welding of these steels, as is slow cooling after welding. Post Weld Heat Treatment (PWHT) is also considered good welding practice.

11A Following on from recommendation 2A the welding of high carbon, sulphur bearing steel is not recommended except for non critical applications. Use hydrogen controlled process / consumable combinations. Welding consumables must be dry immediately prior to use, please refer to Recommended Storage, Care and Conditioning of CIGWELD Electrodes, Welding Wires and Rods **in this handbook**.

12 Use hydrogen controlled welding process / consumable combinations, including such consumables as Ferrocraft 61 and Ferrocraft 7016 electrodes or Suprecor 5 flux cored wire for lower strength welding and Alloycraft 110 electrode or Tensi-Cor 110 TXP flux cored wire for higher strength joints. The choice of higher or lower consumable strength levels will depend on the specifics of the application. These steels are normally supplied in the hardened and tempered condition which requires strict control of preheat, interpass temperature, post weld cooling and PWHT. To achieve optimum results please refer to the steel supplier for specific technical information, in particular heat treatment recommendations.

12A* For the welding of high alloy spring steels in the hardened and tempered condition:

Use hydrogen controlled process / consumable combinations including such consumables as Ferrocraft 61, Ferrocraft 7016 or Supre-Cor 5 in a thoroughly dry condition. Preheat steel sections to be joined to 250-300°C and maintain an interpass temperature of 250-300°C throughout welding. After welding slowly cool the joint in lime or wrap in a thermal blanket.

Alternatively where preheat must be reduced to the minimum, use Weldall electrodes with approximately 100°C less preheat and interpass temperature (ie 150 - 200°C) and slowly cool as previously described.

12B* These Chromium-Molybdenum type steels are usually welded with near matching welding consumables such as Alloycraft 90-B3 electrodes, Autocraft CrMo2 GMAW welding wire or Comweld CrMo2 GTAW rods etc. This is done to achieve comparable creep strength and corrosion resistance to the parent steel. Low hydrogen welding conditions are essential as are the correct preheat and interpass temperatures, retarded cooling and a post weld heat treatment.

12C* The welding of tool steels in the heat treated (hardened and tempered) condition should be avoided where possible. Comprehensive repair and maintenance applications using ferritic steel, low hydrogen consumables such as Ferrocraft 18-Ni electrodes or Supre-Cor 5 flux cored wire should only be attempted on mould and tool steels in the annealed condition. Minor repair work on heat treated tool steels can be carried out using "reconditioned" Weldall electrodes and appropriate preheat and interpass temperatures, retarded cooling and a post weld heat treatment (PWHT) to reduce residual stresses. Please refer to the steel manufacturer for specific welding recommendations.

*Note A , B & C suffixes indicate constraints or conditions not adequately covered by the CE formula (eg high S, Pb etc)

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WELDING OF STEEL

Welding Recommendations:

Weldability Reference No:

13 **Welding Quenched and Tempered (Q & T) steels:**

1. Use only hydrogen controlled welding process / consumable combination, where the welding consumable has been used, stored and re-conditioned in accordance with the manufacturer's instructions. Refer to Recommended Storage, Care and Conditioning of CIGWELD Electrodes, Welding Wires and Rods **in this handbook**.
2. Welding consumable selection is dependant on the particular grade of steel being welded and the specific service requirements of the weldment.
3. For full strength weld joints select a welding consumable of matching (or near matching) weld metal mechanical properties. See Table 3 on Page 81 for CIGWELD welding consumable recommendations.
4. For lower strength welds select hydrogen controlled welding consumables having lower weld metal tensile properties and alloy content. See Table 3 on Page 81 for CIGWELD welding consumable recommendations.
5. Recommended preheat and interpass temperatures and maximum heat input data for structural and abrasion resistant Q & T steel grades are detailed in Table 2. If they are not adhered to closely the strength or integrity of the joint may be compromised.
6. Lower strength welding consumables are invariably used to join abrasion resistant Q & T steels because of their very high tensile properties. For butt welds subject to surface abrasion, a capping pass deposited with a welding consumable of matching hardness to the base steel is sometimes used.

WELDING OF STEEL

Consumables Prequalified to AS/NZS 1554.1: 1995

Manual Metal Arc Welding Consumables:	AS/NZS Standard	LRS/DNV Approval	Applicable Steel Types*
GP6012	E4112-0	2	1 & 2
Ferrocraft 12XP	E4112-0	2Y	"
Satincraft 13	E4113-0	2	"
Ferrocraft 11	E4111-2	3	3, 4, 5 & 6
PipeArc 6010P	E4110-2	3	"
Weldcraft	E4113-2	3	"
Ferrocraft 21	E4814-2	3	3, 4, 5, 6, 7A & 7B
Ferrocraft 22	E4824-0	2Y	"
Ferrocraft 16TXP	E4816-2 H_{10}	3YH	"
Ferrocraft 55U	E4816-2 H_{10}	3YH	"
Ferrocraft 61	E4818-3 H_{10}	3YH	"
Ferrocraft 7016	E4816-3 H_{10}	3YH	"
Gas Metal & Flux Cored ARC Welding Consumables:	**AS/NZS Standard**	**LRS/DNV Approval**	**Applicable Steel Types***
Autocraft LW1	ES4-GC/M-W503AH	3YMS	All Types
Autocraft LWI-6	ES6-GC/M-W503AH	3YS	"
Verti-Cor Ultra	ETP-GCp-W502A. CM1 H_{10}	2YSH	1, 2 & 4
Verti-Cor Ultra H4	ETP-GCp-W502A. CM1 H_{10}	2YSH	1, 2 & 4
Satin-Cor XP	ETD-GCp-W502A. CM1 H_{10}	2YSH	"
Verti-Cor XP	ETD-GMp-W502A. CM1 H_{10}	2YSH	"
Verti-Cor Ultra 3	ETP-GCp-W503A. CM1 H_{10}	3YSH	All Types
Metal-Cor XP	ETD-GMn/p-W503A. CM1 H_5	3YSH	"
Verti-Cor 3XP	ETP-GMp-W503A. CM1 H_{10}	3YSH	"
Verti-Cor 3XP H4	ETP-GMp-W503A. CM2 H_5	3YSH	"
Supre-Cor 5	ETP-GMn-W505A. CM1 H_5	3YSH	"

* See applicable steel types on next page.

APPLICABLE STEEL TYPES - PREQUALIFIED TO AS/NZS 1554.1: 1995

Steel type	AS 1163	AS 1397	AS 1450	AS 1548	AS 1594	AS 1595	AS 2074	AS 3678/ AS 3679.2	AS 3679.1	NZS 3415
1	C250	G250 G300	C200 H200 C250 H250	7-430 7-460	Hd1 Hd2 Hd3 Hd4 Hd200 Hd250 Hd300 Hd300/1 A1006 A1010 A1016	All grades	C2 C3 C7A-1	200 250 300 A1006 XK1016	250 300	Fe 430A
2	C250 L0			7-430L0 7-460L0					250 L0 300 L0	Fe 430C
3				7-430L20 7-430L40 7-430L50 7-460L20 7-460L40 7-460L50				250 L15 300 L15	250 L15 300 L15	Fe 430D
4	C350	G350	C350 H350	5-490 7-490	Hd350 Hd400 HW350		C1 C4-1 C4-2 C7A-2	350 WR350/1 400	WR350/1 WR350/2 350	Fe 510A Fe 510B
5	C350 L0			7-490L0	XF300 XF400			WR350/1 L0	WR350/1 L0 WR350/2 L0 350 L0	Fe 510C
6				5-490L20 5-490L40 5-490L50 7-490L20 7-490L40 7-490L50				350 L15 400 L15	WR350/2 L15 350 L15	Fe 510D
7A	C450	G450	C450							
7B	C450L0									

WELDING OF STEEL

Consumables for Welding Structural, Stainless and Engineering Steels:

Applicable Steel Grades	Manual Metal Arc	Gas Metal Arc	Gas Tungsten Arc	Flux Cored Arc
AS3678 (AS 1204) Grades 200, 250, 300 and LO & L15 Grades AS 1548 Grad 7-430R	Ferrocraft 11 (P) Weldcraft (P)	Autocraft LW1 (P) Autocraft LW1-6 (P)	Comweld High Test (P)	Verti-Cor XP (P) Satin-Cor XP (P) Metal-Cor XP (P) Verti-Cor Ultra (P) Satin-Cor HD70
AS3678 (AS 1204) Grades 350, 400 and LO & L 15 Grades AS 1548 Grades 7-460R, 5-490 and L20 Grades	Ferrocraft 21 (P) Ferrocraft 22 (P) Ferrocraft 61 (P)	Autocraft LW1 (P) Autocraft LW1-6 (P)	Comweld Super steel Supre-Cor XP (P)	Verti-Cor 3 XP (P) Metal-Cor XP (P) Verti-Cor Ultra 3 (P)
AS2074 Grades C4, C5, C6, C7, L1A, L1B ASTM A106 All Grades	Ferrocraft 61 Ferrocraft 7016	Autocraft LW1 Autocraft LW1-6	Comweld Super steel	Supre-Cor 5
AS1548 L40 ASTM A333 Grades 3 & 7				Supre-Cor 5 Verti-Cor 80Ni 1
AS1442 S5, K5, K9 AS2074 Grade L3A AS2056 EN33 ASTM Grades: A148 80-40, 80-50 A302B, C & D A420 WPL9 A437 Class 2	Alloycraft 80-C1	Autocraft Mn-Mo		Verti-Cor 80Ni 1
ASTM A2170-WC6 ASTM A335-P11 ASTM A387-G11, 12 AS2074 Grades L5B, L5D, L5F	Alloycraft 80-B2	Autocraft CrMo1	Comweld CrMo1	
ASTM A217-WC9 ASTM A335-P22 ASTM A387-G22 AS2074 Grades L5C, L5D, L5F	Alloycraft 90-B3		Comweld CrMo2	
AS3597 - 500 ASTM A537 C1.2 ASTM A572 Grades 60, 65 ASTM A852 eg. Bisalloy 60 AS2074 Grade L6	Alloycraft 90			Verti-Cor 91 K2

(P) These products are prequalified to AS/NZS 1554.1 for welding the steels listed.

WELDING OF STEEL

Consumables for Welding Structural, Stainless and Engineering Steels cont.

Applicable Steel Grades	Manual Metal Arc	Gas Metal Arc	Gas Tungsten Arc	Flux Cored Arc
AS 3597-600 & 700 ASTM A533 Type A ASTM A514 A517 eg. Bisalloy, Welten 70 & 80 AS2074 Grade L6A	Alloycraft 110	Autocraft NiCrMo		Tensi-Cor 110T XP Verti-Cor 111K-3
AS2074 Grades H1A, H1B (Hadfield Manganese) (Austenitic Manganese) ASTM A128 All Grades	Cobalarc Mangcraft (build up)	Autocraft 309LSi	Comweld 309L	Shieldcrome 309LT / LTD
AISI Grades 201, 202 301, 301, 304, 304L, 305 AS2074 Grade H5A	Satincrome 308L-17	Autocraft 308LSi	Comweld 308L	Shieldcrome 308LT
AISI Grades 316L, 316, 316TI AS2074 Grades H6B, H6C	Satincrome 316L-17 Satincrome 318-17	Autocraft 316LSi	Comweld 316L	Shieldcrome 316LT
AISI Grade 309 AS2074 Grades H8A, H8B	Satincrome 309Mo-17	Autocraft 309LSi	Comweld 309L	Shieldcrome 309LT / LTD
Joining 3CR12 & 5CR12. Joining dissimilar steels eg. stainless steel to structural steel	Satincrome 309Mo-17 Cobalarc Austex	Autocraft 309LSi	Comweld 309L	Shieldcrome 309LT / LTD
ASTM A288 Grade 5 ASTM A434 Grades BB, BC ASTM A513 Grades 4130, 8630 Hardened to 230-270 HB	Alloycraft 110	Autocraft NiCrMo		Tensi-Cor 110T XP Verti-Cor 111K-3
AS1444 Grade XK4140 ASTM A288 Grades 6, 7, 8 ASTM A434 Grades BB, BC, BD ASTM A513 Grades 4130, 8630 Hardened to 330-370HB AS2074 Grade L6C	Cobalarc 350			Cobalarc 350-G Cobalarc 350-0

WELDING OF STAINLESS STEEL

Introduction.

This section is designed to provide the reader with a technical overview for welding the major types of stainless steels available today.

Types of Stainless Steels:

Stainless steels are an important grade of structural material used worldwide for a multitude of applications based on their corrosion resistance, heat resistance, aesthetic appeal, low temperature properties, high strength and/or ease of cleaning and sterilising.

The main types of weldable stainless steels available include:

- Austenitic stainless steels (AISI 200 and 300 series / UNS S20000 and S30000 series) which are easy to weld and by far the most popular type - accounting for over 70% of the stainless steel sold around the world.
- Ferritic stainless steels (AISI 400 series / UNS S40000 series) which are weldable particularly in thin sections and commonly used for elevated temperature applications.
- Martensitic stainless steels (AISI 400 series / UNS S40000 series) which are difficult to weld and commonly used for wear resistant applications.
- Duplex stainless steels (UNS S30000 series) which are weldable with precautions and used for corrosion resistant applications as an alternative to 300 series austenitic stainless steels.

WELDING TECHNIQUE

The technique of welding stainless steels does not differ greatly from that of the welding of mild steel, but as the material being handled is very expensive, and exacting conditions of service are usually involved, extra precautions and attention to detail at all stages of fabrication is desirable. In principle, all stainless steel for high-class work should be welded with a short arc.

Any techniques which aim at increasing the penetration, speed of travel or the use of wide weaving techniques are to be discouraged. Usually the lowest convenient current should be used. Weaving should be not wider than twice the diameter of the electrode for base material and electrodes of like composition, and even less for plate of dissimilar composition.

The edges of the preparation should be free from scale. Clamps and jigs are advisable when welding sheets thinner than 3 mm (1/8 in) while cooling blocks are helpful with sheets 1.6mm to 2.5 mm (1/16 in to 3/32 in) thick. Tack welds, particularly on thin sheets, should be placed much closer together than is the usual practice for mild steel. This procedure is necessary as the thermal conductivity of these alloy steels is less and the coefficient of expansion is considerably greater than that of mild steel.

NOTES ON TECHNIQUE:

1. Ensure that the surface of the material in the weld area is clean and free from foreign matter.
2. Use the edge preparation shown in Table 1 over the page.
3. Tack at regular intervals, at about half the pitch used for mild steel.
4. Maintain a short arc during welding, to avoid loss of alloying materials during transfer across the arc.

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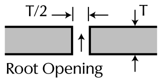
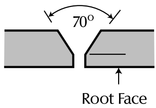
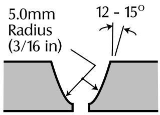
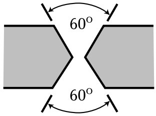
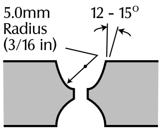
WELDING OF STAINLESS STEEL

NOTES ON TECHNIQUE cont.:

5. Use stringer passes rather than wide weaves.
6. To minimise distortion, employ back step or block sequences when welding.
7. Thoroughly remove slag from welds between passes.
8. When welding double V or U joints, balance the welding on each side, to minimise distortion.
9. Never use emery wheels or buffs for grinding or polishing stainless if they have previously been used for mild steel.
10. Do not use excessive welding current. Because of the high electrical resistance and low thermal conductivity, the currents used with stainless steel electrodes are somewhat lower than those used for mild steel.

TABLE 1. EDGE PREPARATION FOR MANUAL METAL ARC WELDING:

Thickness (mm)	Edge Preparation	Notes
Up to 1.5 (1/16″)		Square butt joint - not gap.
1.5 - 5.0 (1/16″ - 3/16″)		Square butt joint - gap equal to half thickness.
5.0 - 13.0 (3/16″ - 1/2″)		Single V preparation - 1.5 mm (1/16 ″) landing, 1.5 mm (1/16 ″) gap.
13.0 - 20.0 (1/2″ - 3/4″)		Single U preparation - 3 mm (1/8″) landing, 3 mm (1/8″) gap.
Over 20 (3/4″)		Double V preparation - 1.5mm (1/16″) max. landing, 1.5 mm (1/16″) gap.
		Double U preparation - 3 mm (1/8″) landing, 1.5 mm (1/16″) to 3mm (1/8″) gap.

WELDING OF STAINLESS STEEL

Austenitic Stainless Steels

Austenitic stainless steels are easily welded with all standard arc welding processes, without preheat and using matching or near matching welding consumables. Because of their high thermal expansion and low thermal conductivity compared to carbon steel they will distort more during and after welding. This can be minimised by more frequent tacking prior to welding, balanced and back step welding methods and the use of lower welding current and heat input parameters. Low carbon austenitic stainless steels are commonly used because they are less susceptible to sensitisation (or carbide precipitation) during welding or high temperature service which can result in intergranular corrosion in a caustic environment. Matching low carbon welding consumables (designated with an "L") are also commonly used to de-sensitise the weld deposit, in the same way as the parent metal, and eliminate the risk of intergranular corrosion of the welded joint.

The common welding consumable types used for welding the many austenitic stainless steel grades are shown in the following table.

Austenitic Stainless Steel Grades - Welding Consumable Selection Guide.

Stainless Steel Grade			Welding consumable type		
AISI No:	UNS No:	Werkstoffe No:	1st Choice	2nd Choice	3rd Choice
201	S20100	---	308 / 308L	316L	347
202	S20200	1.4371	308 / 308L	316L	347
205	S20500	---	308 / 308L	316L	347
209	S20910	1.4565	308 / 308L	316L	347
301	S30100	1.4310	308 / 308L	316L	347
302	S30200	---	308 / 308L	316L	347
303	S30300	1.4305	312 (Weldall)	309L / 309Mo	308 / 308L
303Se	S30323		312 (Weldall)	309L / 309Mo	308 / 308L
304	S30400	1.4301	308 / 308L	316L	347
304L	S30403	1.4306	308 / 308L	316L	347
304H	S30409	1.4948	308H	308L	316L
304N	S30451	---	308L / 308	316L	347
304LN	S30453	1.4311	308L / 308	316L	347
305	S30500	1.4303	308 / 308L	316L	347
308	S30800	---	308 / 308L	316L	347
309	S30900	1.4828	309 / 309L / 309Mo	312 (Weldall)	---
309S	S30908	1.4833	309L / 309Mo	312 (Weldall)	---
310	S31000	1.4841	310	312 (Weldall)	---
310S	S31008	1.4845	310	312 (Weldall)	---
314	S31400	---	310	318	309L / 309Mo
316	S31600	1.4401	316 / 316L	318	309L / 309Mo
316L	S31603	1.4404	316L / 316	318L	309L / 309Mo
316H	S31609	1.4919	316H	316L / 318	309L / 309Mo
316N	S31651	---	316L / 316	318	309L / 309Mo
316LN	S31653	1.4406	316L / 316	318	309L / 309Mo
317	S31700	1.4429	317 / 317L	318	316L
317L	S31703	1.4438	317L	318	316L
321	S32100	1.4541	347	318	308 / 308L
321H	S32109	1.4941	347	318	308 / 308L
347	S34700	1.4550	347	318	308 / 308L
347H	S34709	---	347	318	308 / 308L
348	S34800	---	347	318	308 / 308L
384	S38400	---	309L / 309Mo	312 (Weldall)	---

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WELDING OF STAINLESS STEEL

Ferritic Stainless Steels:

Ferritic stainless steels can be welded under strict precautions using all standard arc welding processes. They can be joined with welding consumables which match or near match the base metal or with austenitic welding consumables, for example Satincrome 308L-17 & 316L-17 electrodes or Autocraft 308LSi & 316LSi GMAW wires. During welding, ferritic stainless steel grades can suffer a loss of ductility due to grain growth, martensite formation and carbide precipitation. To achieve good welds, in thicker sections, it is often necessary to preheat the work to ≈100-120°C and minimise the heat input during welding. To dissolve or modify carbides in the Heat Affected Zone (HAZ) and reduce welding stresses, post-weld heat treatment to 750-850°C for 30-60 minutes is necessary. This heat treatment will improve the ductility, toughness and corrosion resistance of the Heat Affected Zone.

Ferritic Stainless Steel Grades - Welding Consumable Selection Guide.

Stainless Steel Grade			Welding consumable type		
AISI No:	UNS No:	Werkstoffe No:	1st Choice	2nd Choice	3rd Choice
405	S40500	1.4002	430	309L / 309Mo	308
409	S40900	1.4512	309L / 309Mo	312 (Weldall)	---
429	S42900	1.4001	430	308 / 308L	309L / 309Mo
430	S43000	1.4016	430	308 / 308L	309L / 309Mo
430F	S43020	1.4104	430	308 / 308L	309L / 309Mo
430FSe	S43023	---	430	308 / 308L	309L / 309Mo
434	S43400	1.4113	430	308 / 308L	309L / 309Mo
436	S43500	---	430	308 / 308L	309L / 309Mo
442	S44200	---	316L	318	309L / 309Mo
444	S44400	1.4521	316L	318	309L / 309Mo
446	S44600	1.4762	308 / 308L	309L / 309Mo	310
3Cr12#	---	---	309L / 309Mo	316L	308L

- 3Cr12 is a trademark of Bluescope Steel.

Martensitic Stainless Steels:

Martensitic stainless steels are difficult to weld successfully due to the formation of hard and brittle martensite in the Heat Affected Zone (HAZ) of the joint. To reduce the affects of martensite formation, adequate control over pre-heat, interpass temperatures and heat input are essential. Depending on the carbon content of the particular martensitic steel, preheat temperatures of between 100 - 300°C are commonly recommended to avoid cracking. Interpass temperature also plays an important role in reducing the risk of cracking. In multipass welding, an interpass temperature between the martensite start and finish temperatures (Ms and Mf) will minimise crack sensitivity by allowing each subsequent weld pass to be tempered. Post Weld-Heat Treatment (PWHT) is also carried out to improve mechanical properties and reduce welding stresses. For complicated joint configurations PWHT is commenced once the fully welded joint has cooled to just under the martensite start temperature (≈130 -150°C). This is done to ensure the complete transformation of austenite to martensite before PWHT.

WELDING OF STAINLESS STEEL

Martensitic Stainless Steel Grades - Welding Consumable Selection Guide.

Stainless Steel Grade			Welding consumable type		
AISI No:	UNS No:	Werkstoffe No:	1st Choice	2nd Choice	3rd Choice
403	S40300	1.4000	410	309L / 309Mo	310
410	S41000	1.4006	410	309L / 309Mo	310
414	S41400	---	410	309L / 309Mo	310
415	S41500	1.4313	410	309L / 309Mo	310
416	S41600	---	410	309L / 309Mo	310
416Se	S41623	---	410	309L / 309Mo	310
420	S42000	---	410	309L / 309Mo	310
431	S43100	1.4057	430	308L / 308	309
440A	S44002	---	312 (Weldall)	309L / 309Mo	---
440B	S44003	---	312 (Weldall)	309L / 309Mo	---
440C	S44004	---	312 (Weldall)	309L / 309Mo	---

Duplex Stainless Steels:

Duplex stainless steels consist of two microstructure phases, ferrite and austenite and are also referred to as Ferritic-Austenitic stainless steels. A typical duplex microstructure consists of approximately 50% ferrite and 50% austenite.

Duplex stainless steels are readily welded with precautions using all common arc welding processes. Careful attention must be given to heat input and consumable selection to prevent the formation of excessive ferrite levels in both the base metal and weld metal , which can reduce joint toughness and corrosion resistance.

The main grades of duplex stainless steels used in industry today are listed below. These alloys can be classified into two (2) main groups:

Duplex Stainless Steels = S32900 (329), S39205 (2205) and S39230 (2304)

Super Duplex Stainless Steels = S39553, S39275 (2507) and S39276 (Zeron 100).

Welding Consumables for duplex stainless steels contain Nitrogen (a strong austenite stabiliser) as an alloying element, which helps to achieve the correct balance of austenite and ferrite in the weld deposit microstructure. In addition to welding consumable selection, careful attention must also be given to heat input and interpass temperature to promote the desired balance of ferrite and austenite in the weld and surrounding heat affected zone (HAZ) of the base material.

If the base metal and weld metal ferrite levels are controlled to 25-50% (FN 30-70) then a good combination of strength, toughness and corrosion resistance will be achieved in the welded joint.

Heat Input:

When the weld pool solidifies, the weld metal consists of 100% ferrite which begins to transform to austenite upon cooling. If the correct heat input is used the resultant cooling rate will promote the formation of an even distribution of the ferrite and austenite (≈50:50) in the weld deposit and Heat Affected Zone (HAZ).

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WELDING OF STAINLESS STEEL

Duplex Stainless Steels cont.:

Generally heat input should be limited to between 0.6 - 2.6 kJ/mm. When a welding process with less than 0.6kJ/mm heat input is used (as in automatic GMAW), preheating up to 150°C maximum may be required to reduce the cooling rate and increase austenite in the weld and the HAZ.

$$\text{Heat Input (kJ/mm)} = \frac{\text{Volts x Amps x 60}}{\text{Travel Speed (mm/min) x 1000}}$$

Interpass Temperature Control:

Interpass temperature should be limited to between 75-150°C.

Preheat:

On thicknesses below 6mm no preheat is required. For heavier sections or for welds under high restraint preheat may be used to minimise the risk of weld cracking. When a welding process with less than 0.6kJ/mm heat input is used, preheating to between 50-200°C is helpful in reducing the cooling rate and increasing austenite in the weld and the HAZ. If the air temperature is below 15°C preheat of ≈ 50°C should be used.

Correct Welding Consumables and Shielding Gas:

Always use the correct welding electrode, wire or rod (refer to the welding consumable selection guide shown below). For GTAW (TIG) welding do not weld without a filler rod unless using the correct nitrogen content shielding gas. Always use an inert (nitrogen containing) backing gas when completing root runs. Consult your local gas supplier for detailed information.

Duplex Stainless Steel Grades - Welding Consumable Selection Guide.

Duplex stainless steel grade				
Name or No:	UNS No:	Werkstoffe No:	ASTM Specification No:	Welding Consumable Type
329	S32900	1.4460	A240, A789, A790	329
2RE60	S31500	1.4841	A789, A790, A815	2209
2205 Bohler A903	S31803* **S39205**	1.4462	A182, A240, A276, A789, A790, A815	2209
2304	S32304* **S39230**	1.4362	A789, A790	2209
Ferralium# 255	S32550* **S39553**	1.4507	A240, A789, A790	2507
2507	S32750* **S39275**	1.4410	A789, A790	2507
Zeron# 100	S32760* **S39276**	1.4501	A182, A276, A790, A815	2507

* - old UNS number, replaced by the number beneath in bold.
\# - Ferralium is a trademark of Langley Alloys Ltd. Zeron is a trademark of Weir Material Services Ltd.

WELDING OF STAINLESS STEEL

Duplex Stainless Steels cont.:

ASTM Specification No:	Description of Product Types:
A182	Fittings, Valves, Flanges and other items for high temperature service
A240	Plate, strip and sheet for pressure vessels and pressure equipment
A276	Bars and extruded shapes
A789	Tubing, welded and seamless for general work
A790	Pipe, welded and seamless
A815	Pipe fittings, welded and seamless

Schaeffler and De Long Diagrams:

The alloying elements used in stainless steel base metals and welding consumables have a significant influence on the resultant microstructure. Anton Schaeffler was the first person to carry out a detailed study of the relationship between the composition and microstructure of stainless steel weld metals. The results of this research are summarised in the Schaeffler diagram shown in Diagram 1 which predicts the microstructure of freely cooled All Weld Metal (AWM) stainless steel deposit s as a function of Chromium and Nickel Equivalents.
Chromium and Nickel Equivalents for the Schaeffler diagram are calculated as follows:

- **Chromium Equivalent = %Cr + %Mo + 1.5 x %Si + 0.5 x %Nb**
- **Nickel Equivalent = %Ni + 30 x %C + 0.5 x %Mn**

Once the Chromium and Nickel equivalent have been calculated the Schaeffler diagram can be used to estimate the microstructural phases present. It should be noted that the Schaeffler diagram is not applicable to the Heat affected Zone (HAZ) of the welded joint nor is it usable for weld deposits which have been heat treated after welding.

The De Long Diagram shown in Diagram 2 is a later development of the central part of the Schaeffler diagram. The De Long diagram works in a similar way to the Schaeffler diagram, however it incorporates nitrogen in the calculation of the Nickel Equivalent which is particularly important for the gas shielded welding processes such as Gas Metal Arc and Gas Tungsten Arc Welding where gas shielding can significantly influence nitrogen pickup in the weld deposit. The De Long diagram also classifies ferrite content as a Ferrite Number (FN) rather than as a percentage.

Once the Chromium and Nickel Equivalents are calculated they can be plotted on the Schaeffler or De Long diagrams to determine the microstructural phases present in the weld deposit. The crack free, austenite - ferrite microstructure of CIGWELD Satincrome 309Mo-17 manual arc electrode is shown as Point D in Diagram 1, calculated from typical AWM chemical analysis. In predicting the microstructural phases present in the weld deposit the Schaeffler diagram is also a guide to potential joint problems such as hot cracking, sigma phase embrittlement, martensitic cracking and brittle grain coarsening. See the shaded regions on the Schaeffler diagram for details.

The Schaeffler diagram is commonly used to predict weld deposit microstructures for the joining of dissimilar metals, given the chemical analyses of both base metals and the welding consumable AWM deposit. For example, the resultant weld deposit microstructure from joining mild steel to 316 austenitic stainless steel using Satincrome 309Mo-17 is shown in Diagram 1.
By explanation:

Point A on the Schaeffler diagram	=	microstructure of mild steel base metal.
Point B on the Schaeffler diagram	=	microstructure of 316 stainless steel base metal.
Point C on the Schaeffler diagram	=	weld deposit microstructure for joining mild steel to 316 stainless steel without a filler metal.
Point D on Schaeffler diagram	=	microstructure of AWM deposit with Satincrome 309Mo-17.
Point E on Schaeffler diagram	=	microstructure of weld deposit assuming 30% dilution using the manual metal arc welding process.

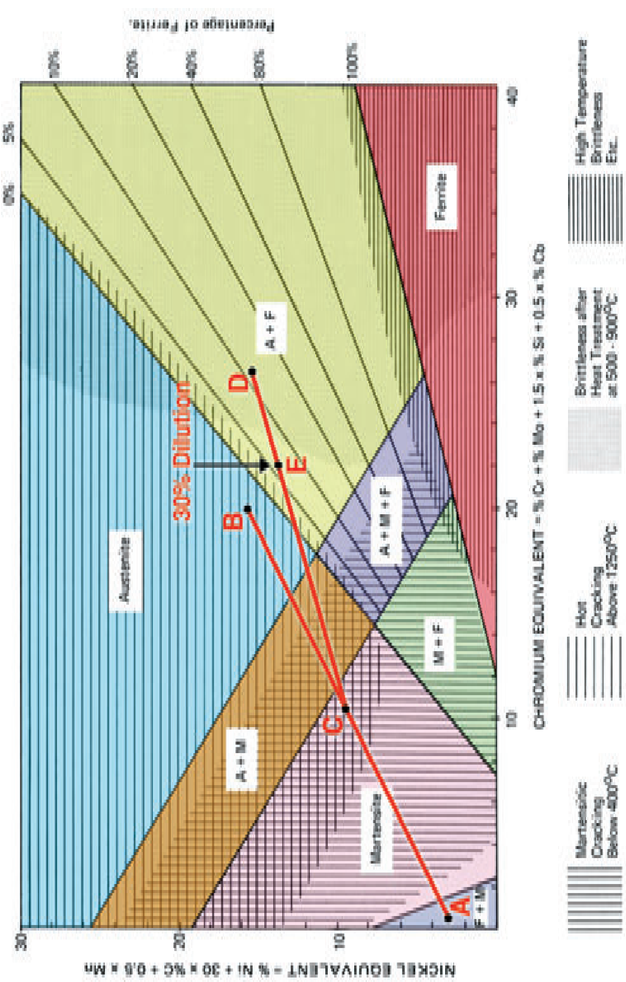

Diagram 1. Schaeffler Diagram. Showing approximate regions of potential weld problems depending on composition and phase balance.

WELDING OF STAINLESS STEEL

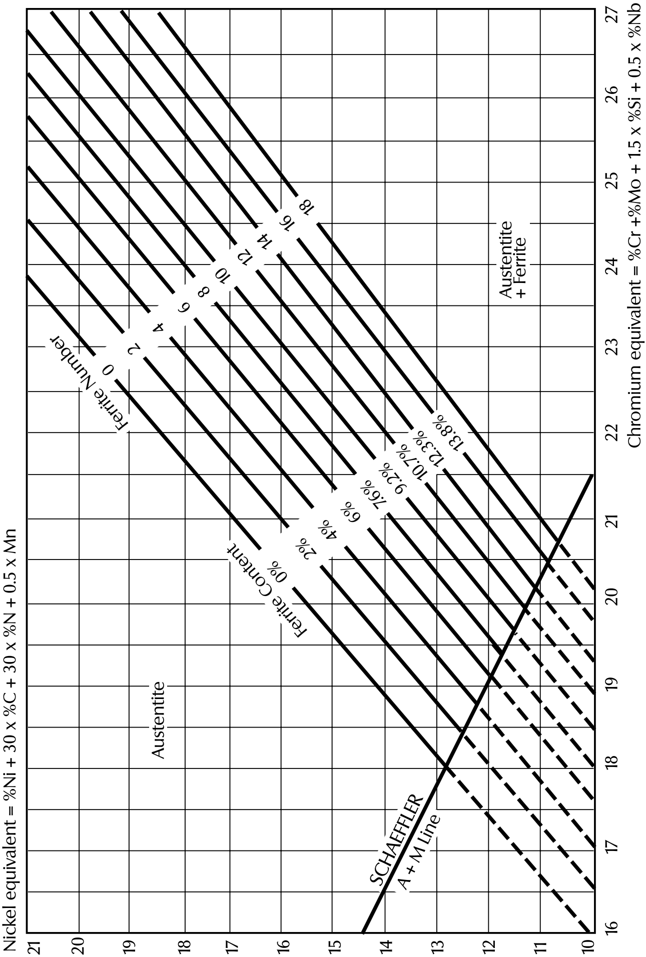

Diagram 2. **De Long Diagram.**

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WELDING OF STAINLESS STEEL

Definition of Dilution:

Dilution is the degree to which the base metal(s) contributes to the resultant weld deposit. It is normally expressed as the percentage of melted parent metal in the total weld metal.

i.e. 30% dilution = 30 parts of base material per 100 parts of weld deposit.

The dilution for any given process will always be the same irrespective of the parent metals involved but may be influenced by preheating. It is often assumed that the parent metals each contribute equal parts in the resultant weld.

i.e. 30% dilution = 15% contribution from **parent metal 1**, + 15% contribution from **parent metal 2**, see Figure 1 below.

Dilution can be approximately calculated using a geometric approach involving the cross-section of the weld.

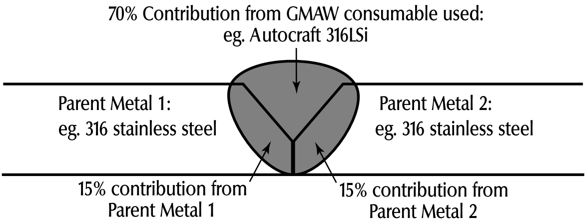

Figure 1. Example of 30% dilution in a stainless steel butt weld using the GMAW process with Autocraft 316LSi welding wire.

Calculating Dilution:

Dilution can be calculated using the following formula. For the purpose of this example Nickel content will be used since the transfer of nickel from the filler metal to the weld metal is virtually 100%.

$$x = \frac{F - W}{F - P} \times 100$$

x = Percentage Dilution (%)
F = Percentage nickel in the filler metal
W = Percentage nickel in the weld metal
P = Percentage nickel in the parent metal

Therefore, if for example F = 13%, W = 12.7% and P = 12%

$$x = \frac{13 - 12.7}{13 - 12} \times 100 = 0.3 \times 100 = 30\% \text{ dilution}$$

The following values are a guide to typical dilution levels expected in a butt weld:

Welding Process Used	**Dilution %**
Manual metal arc welding	20-30
Gas Metal Arc Welding & Gas Tungsten Arc Welding	20-40
Submerged-arc welding	30-40

WELDING OF ALUMINIUM

1) "Atmospheric Conditions" Affect on Weld Quality:

Many fabricators experience welding problems at different times of the year. Moisture (H_2O) is a prime source of hydrogen. At arc temperatures, water breaks down releasing hydrogen atoms that cause porosity in weldmetal. Shielding gas supplies are controlled to very low moisture content (-57°C dew point or lower). Likewise, the atmospheric conditions in a fabricating facility need to be controlled to prevent moisture condensation from forming on the aluminium welding wire or base metal.

Aluminium which is allowed to repeatedly come into contact with water will eventually form a hydrated oxide (AlOH) coating. Moisture from condensation present on either the welding wire or the base metal can cause two problems during welding:

- Porosity caused by hydrogen generated from the breakdown of water or from the breakdown of hydrated oxide (AlOH) present on the metal surfaces.
- Entrapment of the actual oxide (AlOH), present on the metal surfaces, in the weld metal.

Terms:

Relative Humidity -
The ratio of the quantity of water vapour present in the atmosphere to the quantity which would saturate the air at the existing temperature. Relative humidity is expressed as a percentage number and needs to be monitored in the welding area. Dip tanks, cleaning stations, etc. affect relative humidity.

Dew Point - The temperature at which condensation of water vapour in the air takes place. Moisture will condense on metal surfaces when their temperature is equal to or below the dew point. For each relative humidity percentage, there is a corresponding dew point.

Air Temperature -
The temperature of the air in the welding area at any given time.

Base Metal or Aluminium Welding Wire Temperature -
The temperature of the welding wire or base metal at any given time.

General:

In an aluminium welding shop, the uniformity of air and metal temperatures is important especially when the relative humidity is high. Aluminium welding wires and the base metal should be allowed to stabilise to the weld area temperature. The aluminium welding wire should not be opened in the welding area for 24 hours after entry from a cooler storage area. The base metal should be cleaned and brushed with a clean stainless steel brush prior to welding. CIGWELD recommends mild alkaline solutions and commercial degreasers that do not evolve toxic fumes during welding. Welders should wipe joint edges with a clean cloth dipped in a volatile petroleum based solvent. All surfaces must be thoroughly dried after cleaning.

WELDING OF ALUMINIUM

Dew Point Conditions Versus Relative Humidity (RH):

(T_{air} - T_{metal})° - Temperature of the air minus the temperature of the metal shown in °C and °F.

The chart below shows the relative humidity at which detrimental water condensation will form for a number of given differential temperatures.

* **Example -** If the relative humidity in the weld area is 70%, the base metal and aluminium welding wire must be no colder than 5°C below the air temperature to prevent moisture condensation.

(T_{air} - T_{metal})°		RH	(T_{air} - T_{metal})°		RH
°C	(°F)	%	°C	(°F)	%
0	(0)	100	12	(21.6)	44
1	(1.8)	93	13	(23.4)	41
2	(3.6)	87	14	(25.2)	38
3	(5.4)	81	15	(27.0)	36
4	(7.2)	75	16	(28.8)	34
5*	(9.0*)	70*	18	(32.4)	30
6	(10.8)	66	20	(36.0)	26
7	(12.6)	61	22	(39.6)	23
8	(14.4)	57	24	(43.2)	21
9	(16.2)	53	26	(46.8)	18
10	(18.0)	50	28	(50.4)	16
11	(19.8)	48	30	(54.0)	14

2) Aluminium Storage & Preparation for Welding:

One of the most frequently asked questions in the process of welding aluminium is "Should the base metal be cleaned before welding?" To answer this question correctly, one must first determine the finished welded product requirements. If consistent, porosity free, high strength, high quality welds are desired, then the base metal must be thoroughly cleaned using a properly designed and executed procedure. Welding wire quality is a subject of constant concern among designers, engineers, and welders, however, base metal preparation and cleanliness if of equal or even greater importance and is often ignored.

Producers of aluminium sheet, plate, rod, bar, and other fabricated shapes generally ship their products with a protective coating of oil or other hydrocarbon to protect the surface. Depending on storage conditions and storage time, aluminium products are covered with oil, ink, grease, dirt, moisture, and a variable layer of hydrated oxide. These contaminants contain hydrogen and are broken down by the arc during welding, releasing atomic hydrogen which is absorbed by the molten aluminium in the weld puddle. During solidification, this hydrogen comes out of solution and coalesces into bubbles in the aluminium which we see as porosity.

The general melting temperature of aluminium alloys is around 650°C (1200°F) while the melting temperature of aluminium oxides is 2040°C (3700°F). Aluminium oxide is not melted during the welding process and if it is present to an excessive degree, it can easily cause lack of fusion and oxide inclusion type defects.

WELDING OF ALUMINIUM

With this in mind, CIGWELD suggest the following guidelines for the proper storage, joint preparation, cleaning, and welding of aluminium be adhered to:

Storage and Handling:

Base Metal:

- Position base metal vertically and space apart to provide for air circulation and minimise condensation contact points.
- Store inside, preferably in a heated room with as constant a temperature as possible. Humidity control is also desirable, if it can be achieved.

Aluminium Welding Wires:

- Store in a heated room with uniform temperature control and, if possible, with humidity control as well.
- Hold the Aluminium Welding Wire in the welding area for 24 hours before unpacking to allow its temperature to equalise with that of the surrounding area.
- Store unpacked material in a heated cabinet.
- Use dust covers on all welding equipment.

Joint Preparation:

Oxy-fuel Gas Cutting:

- Not recommended for aluminium because it leaves a large heat affected zone with harmful eutectic melting and heavy oxide films.

Carbon Arc Cutting, Bevelling, and Gouging:

- Not widely recommended or used for the same reasons as gas cutting. If it is used, it requires heavy mechanical surface removal before welding.

Plasma Arc Cutting, Bevelling, and Gouging:

- This process is commercially used but has some limitations and must be carefully controlled. If it is used, it requires the power source to be set on DCEN along with the use of a small orifice to gain high velocity and concentrated heat. Heat affected zones will be crack prone particularly for 2XXX, 6XXX, and 7XXX series alloys and will require 3mm or more of mechanical surface removal before welding. Series 1XXX, 3XXX, and 5XXX alloys are not as crack prone and can generally be welded as cut by this process.

Mechanical Machining:

- Drilling, gouging, filing, milling, or router-type cutting produce the best surface for welding. Lubricants or coolants must not be used and tools should be sharp to avoid metal smearing.

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WELDING OF ALUMINIUM

Joint Preparation cont.:

Sawing:

- Blade speed:
  - Circular high-speed steel (8,000 fpm)
  - Circular carbide (12,000 fpm)
  - Band saw (5,000 fpm)

- Tooth shape and spacing:
  - Circular (std. Spacing, high rake angle)
  - Band (3 to 4 teeth per inch)

- Lubricants or coolants must not be used and band saw surfaces should be removed by filing prior to welding.

Grinding:

- Wheel grinding is not recommended since it smears the surface of aluminium and can deposit organic binders from the wheel during grinding.
- Disc grinding can be used with grit size, 30 to 50 preferred, and speeds of 4,000 to 6,000 fpm. Only flexible discs should be used and grinding pressures should be moderate to prevent surface heating or smearing of the aluminium. Lubricants or coolants must not be used.

Base Metal Cleaning:

Moisture:

- Minute traces of moisture on aluminium can produce severe weld porosity. Both the welding wire and the base metal should be brought into the welding area 24 hours in advance to allow all material temperatures to equalise. A dew point test should be done prior to welding. If pre-heating must be used, heat no higher that 65°C (150°F) and remember that oxy-fuel flames produce water as a by-product of combustion.

Lubricants:

- Before oxides can be removed from aluminium, the base metal must be degreased. This is best done with a solvent. Toluene is the best general solvent for this purpose. Acetone is a poor solvent for oils and greases and is less effective than toluene. Chlorinated solvents are also good degreasers but are not recommended for this application because they present environmental problems and their vapours can decompose into toxic or poisonous gases in the presence of heat. Weld joints should be washed with solvent prior to assembly and wiped dry using clean cloth such as cheese cloth. Shop rags should not be used since they contain soaps and other organic compounds from the washing and conditioning processes used to treat them. Do not use compressed air to blow off or dry solvent cleaned areas since it often contains moisture and oil.

WELDING OF ALUMINIUM

Base Metal Cleaning cont.:

Oxides:

- Wire Brushing:
  Oxide removal must be done after degreasing and is best done with a stainless steel wire brush. Wire brushes must be frequently cleaned with the same solvent as the base metal. Wire brushing can be done by hand or with a power brush. If power is used, keep rpm's and pressures low to avoid heating and smearing the surface metal. Compressed air power brushes should exhaust their air to the rear, not forward towards the brush where the compressed air can contaminate the base metal.

- Chemical Cleaning:
  Chemical cleaning deoxidises and etches the aluminium. These cleaners contain acids and can present problems in handling and disposal. If they are used, the base metal must be thoroughly rinsed and dried and should be milled or wire brushed prior to welding.

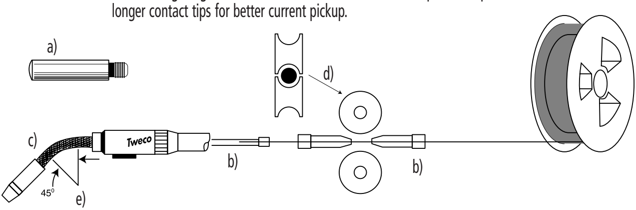
- Etch Cleaning:
  This process uses a hot sodium hydroxide etch and nitric acid rinse. It effectively removes heavy oxides, rough machined, sawn or smeared surfaces and hydrocarbons. However, the process leaves a porous surface containing hydrated oxides that absorb moisture during storage faster than an as-fabricated mill surface. This surface should be milled or wire brushed prior to welding.

3) Feedability of Aluminium Welding Wire:

Performance of GMAW equipment used for welding aluminium significantly affects welding wire feedability. Arcing or burn-backs are often the result of deficiencies in accessory equipment. Such deficiencies can be attributed to improper combinations of accessories, poor care or lack of preventive maintenance. Correcting these deficiencies often improves welding wire feedability markedly. Shown below are important accessory components, each of which is CIGWELD's' recommended equipment for aluminium GMA Welding.

Hints on Feedability:

a) always use the correct size contact tip, or for heavy current work use a tip size 10-15% larger. eg. diameter of the wire 1.2mm = 1.3mm tip. Where possible use longer contact tips for better current pickup.



b) always use where possible, nylon, conduits and inlet and outlet guides. Clean brass inlet and outlet guides are 2nd choice.

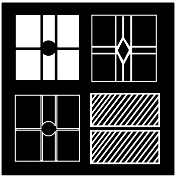
WELDING OF ALUMINIUM

3) Feedability of Aluminium Welding Wire cont.:

Hints on Feedability:

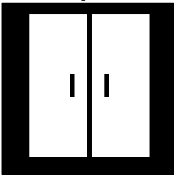
c) use a copper jump liner in the conductor tube (goose neck).
d) always use U-Groove drive rolls.
e) where possible use 45° or straight barrelled conductor tube.
f) keep MIG guns as short as possible (3 metre) when using push type wire feeders.
g) use push pull MIG guns & equipment when welding over longer distances.

Drive Rolls:



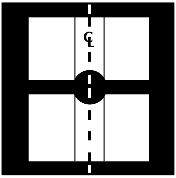
Always use U-Groove drive rolls. Other types distort or shave wire causing more burn backs. Ensure that the U-groove drive roll edges are chamfered, not sharp...The white coloured picture shows the correct drive roll type.

Dust Covers and Wire Storage:



Using dust covers and periodically cleaning the dust and dirt from the liner increases service life. Proper storage is also important in reducing contamination. CIGWELD recommends that aluminium welding wires be stored in a controlled atmosphere below thirty percent relative humidity (30%RH), preferably a temperature and humidity controlled cabinet. Packages containing aluminium welding wire should never be in unheated buildings. Aluminium welding wire should never be left on equipment overnight unless protective means are added to the welding machine, such as fully enclosed temperature controlled wire feeders (resistance heater inside the feeder), temperature and humidity controlled workshops, etc.

Proper Alignment of Drive Rolls:



Centre line, misaligned drive rolls will distort the welding wire and cause serious feedability problems. Check your wire feeder for drive roll alignment after each size change of feed rolls. CIGWELD can supply U-groove rollers for most of the TRANSMIG range.

Drive Roll Pressure:

In addition to proper U-type drive roll contours, correct drive roll pressure must be maintained. Excessive drive roll pressure distorts the welding wire increasing frictional drag through the liner and contact tip.

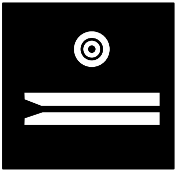
The correct drive pressure can normally be obtained by following these steps;

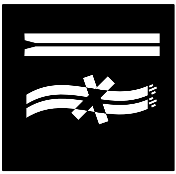
a) lower the pressure roller down onto the aluminium wire, making sure that all pressure has been backed off.
b) pull the trigger of the MIG gun and slowly wind the pressure roller down until the welding wire starts to feed through the entire length of the MIG gun.
c) once the welding wire has passed through the contact tip, wind the pressure roller down another 1 - 2 turns.

WELDING OF ALUMINIUM

3) Feedability of Aluminium Welding Wire cont.:

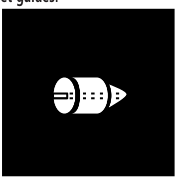
Contact Tips:





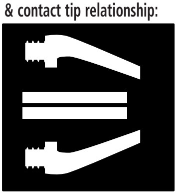
Correct I.D. of the contact tip is of paramount importance. If there is too much clearance between the welding wire and the contact tip, arcing will occur. Continuous arcing causes a build up of particles on the I.D. surface of the tip which increases drag forces and produces burn-backs due to unsteady feed. ▲ Changing contact tips when unsteady feeding is noted eg. pulsing or spiralling of the welding wire, also improves overall performance. ▲ Always use the correct size contact tip, or for heavy current work use a tip size 10-15% larger. eg. diameter of the wire 1.2mm = 1.3mm. Where possible use longer contact tips for better current pickup.
▲ Do not use bent, damaged or crimped contact tips.
▲ Never redrill the I.D. of a genuine Tweco tip as this will soften the tip and cause poor current pick up and severely reduce the tips working life.

Inlet and outlet guides:



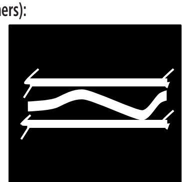
Where possible use, nylon inlet and outlet guides.
New, clean brass inlet and outlet guides may be used on aluminium wires but are 2nd choice.

Proper nozzle & contact tip relationship:



The contact tip should be recessed from the edge of the gas shielding nozzle by approximately 1.6mm for lower amperage and voltage settings and up to 5mm for higher settings.

Conduits (liners):

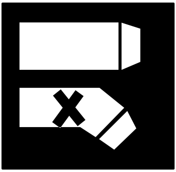


Properly sized flexible conduits with nylon, or plastic liners improves the feeding of aluminium welding wire through long distances by avoiding abrasion of the welding wire. Smooth feeding is also assured by non-metallic connection fittings. Clear total length of the conduit after a burn back.

WELDING OF ALUMINIUM

3) Feedability of Aluminium Welding Wire cont.:

Conductor Tubes:



Conductor Tubes (goose necks) are a critical component for successful aluminium welding. CIGWELD recommends the use of either 45° or Straight barrelled conductor tubes. The straighter the tube the better the wire feed. 60° conductor tubes are not recommended. It is advisable to use a copper jump liner throughout the length of the conductor tube, which will aid in current pick up. The copper jump liner replaces the nylon liner between the end of the handle and the gas diffuser.

Water and Inert Gas Leaks:

Check for water and inert gas leaks as these can be a major cause of porosity. Do not interchange water and inert gas lines. Never use old oxy / acetylene hoses for inlet gas lines.

Achieving High Quality Welds:

Although welding equipment is sturdy, the abuses of day-to-day work makes regular maintenance a necessity. Faulty or improperly maintained welding equipment can result in poor welding work. Nevertheless, with proper selection of welding parameters, correct equipment and accessories, an effective program of preventive maintenance and the purchase of CIGWELD aluminium welding wires, high quality welds are attainable.

4) Smoke Testing Aluminium Welding Wire for Surface Contamination:

What Contributes to Weld Porosity?

Weld porosity results from the entrapment of hydrogen gas. This gas entrapment results in lower weld strength and ductility by reducing the cross sectional area of sound metal and by acting as stress risers which cause premature failure. Several variables can produce gas porosity, one of which is the surface condition of the aluminium filler wire. The qualities relating to the surface characteristics of the filler wire include:

1. The removal of surface oxides (hydrated oxides).
2. The absence of any water or water vapour.
3. The removal of hydrogen-containing compounds (hydrocarbons).

Of these three surface conditions, the most common cause of weld porosity is the presence of hydrocarbons. Examples of these compounds include residual wire drawing lubricants, mill dirt or even fingerprints. One relatively quick and inexpensive method of testing aluminium welding wire for freedom from residual hydrocarbons is by means of a "Smoke Test".

What is a Smoke Test?

The "Smoke Test" is a qualitative test performed by heating a sample of wire using an electrical resistance heating machine. While conducting the test, the wire is visually examined for the presence of smoke, caused by the burning of any surface contamination. Minute amounts of contamination, even a fingerprint, will result in smoke.

WELDING OF ALUMINIUM

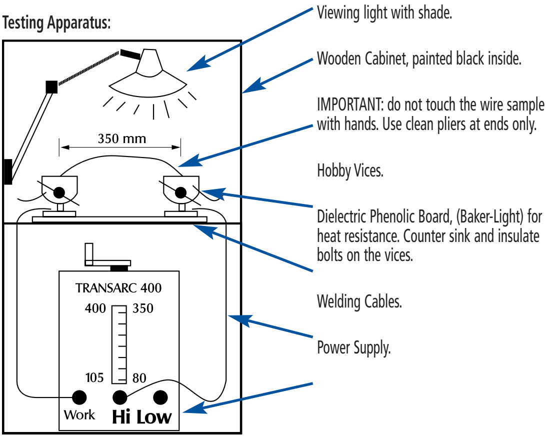
The schematic shows a typical smoke tester machine. Just about any commercial welding power source will suffice. The weld cables are connected to two hobby vices. The wire sample completes the circuit. A light with a dark viewing background is recommended to aid in observing any smoke as the test is performed. Care must be taken in selecting and placing the sample in the vice grips so that the wire does not come in contact with any contamination, including human hands.

4) Smoke Testing Aluminium Welding Wire for Surface Contamination:

CAUTION: Do not touch the wire after testing since it becomes extremely hot.

Typical amperages settings based upon the alloy and diameter of the sample to be tested are listed below. The amperage is chosen to control the melt rate of the sample and allow adequate time to detect the presence of any smoke. The amperage should be sufficient to melt the sample in 3 to 5 seconds.

Smoke Testing Apparatus:



Suggested Amperage Settings By Alloy Series

Sizes (mm)	1XXX 2319	4XXX, C355 A356 & A357	5XXX
0.8	45	40	40
0.9	50	50	50
1.0	60	60	60
1.2	90	90	70
1.6	140	120	120
2.4	225	225	225

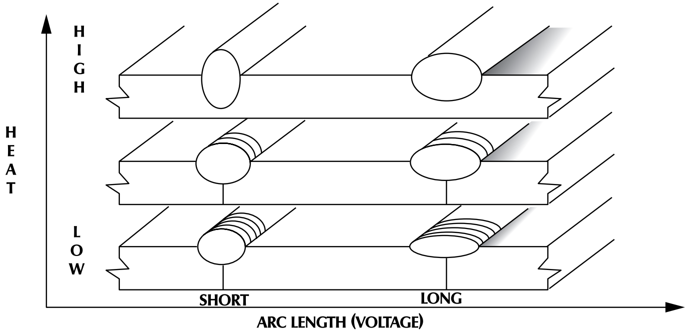
What Can I Interpret From the Smoke Test?

A direct correlation exists between smoke test results and weld porosity. Zero smoke should indicate minimal weld porosity. A small amount of smoke will indicate some evidence of weld porosity generated by contamination. A large amount of smoke will indicate severe contamination and the filler wire should be further examined before continuing production welding.

WELDING OF ALUMINIUM

5) Arc Length & Heat (volts x amps) the Affect on Weld Bead Characteristics:

The visual characteristics and mechanical properties of aluminium welds are controlled by weld bead penetration and shape. A number of variables affect the end properties of the weld bead and they can be controlled by the welder. Presented here is a description of those variables and how they can be used to achieve the desired end results.

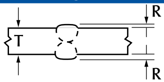


Note: **Because 5XXX series alloys conduct heat significantly less than 4XXX series alloys, shorter arc lengths are required for desired penetration.**

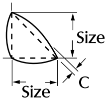
Characteristics	Short Arc	Long Arc
Penetration	Deep	Shallow
Weld Width	Narrow	Wide
Weld Height	High	Flatter
Molten Pool Surface	Depressed	Flat
Spatter	Less	More
Arc Noise	Crackling	Humming
Porosity - Surface	More	Less
Characteristics	**High Heat**	**Low Heat**
Penetration	Deep	Shallow
Surface	Smooth	Rippled
Smut (soot)	More	Less
Porosity - Root	Less	More
Recommendations		
Root Pass	Shorter Arc	-
Finish Pass	-	Longer Arc
5XXX Alloys	Shorter Arc Lower Arc Voltage Higher Amperage	- - -
4XXX Alloys	-	Longer Arc Higher Arc Voltage Lower Amperage

WELDING OF ALUMINIUM

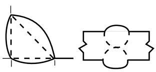
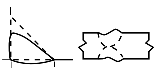
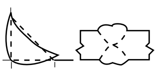
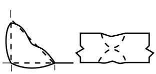
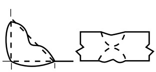
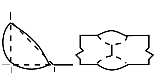
5) Arc Length & Heat (volts x amps) the Affect on Weld Bead Characteristics cont.



	T	R (max)
CONVEXITY CONTROL SPECIFICATION (USA only)	up to 10mm	2.4mm
	10mm to 20mm	3.2mm
	20mm +	5.0mm



	C (max)
CONVEXITY CONTROL SPECIFICATION (USA only)	.07 x face width, plus 1.5mm

	Problem	Solution
	**Excessive Convexity** Reduced fatigue strength	Increase arc length[1] Increase torch angle
	**Insufficient Throat or Leg** Reduced mechanical properties	Change torch angle Change torch position[2] Decrease arc length[1]
	**Insufficient Throat** Reduced mechanical properties	Reduce cooling rate Increase wire feed speed Decrease travel speed Decrease arc length[1]
	**Undercut** Reduced mechanical properties	Change torch position to compensate for: - Dissimilar section sizes - Dissimilar thermal conductivity
	**Overlap** Severe reduction in fatigue strength	Increase welding heat Decrease traverse speed
	**Incomplete penetration** Reduced weld strength and increased sensitivity to crack propagation	Increase heat Decrease arc length[1] Decrease traverse speed Decrease torch forehand angle

Notes:
1) Remember, when changing arc length, arc voltage is changed which also requires a change in arc amperage if constant heat is to be maintained. Watts (heat) = volts x amps
2) For example, the thermal conductivity of 5083 is 32% less than 6061 because of higher magnesium content. This requires more heat input into the 6061 alloy.

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WELDING OF ALUMINIUM

6) Aluminium Welding Problems, Causes and Corrections:

Problem	Causes	Corrections
Porosity	Turbulence of weld pool	Increase welding current to stabilise transfer of metal droplets.
	Hydrogen from hydrated oxide film or oil on wire, base metal, drive rolls & liner.	Keep wire covered. Store wire in a low humidity chamber at a constant temperature. Clean base metal of oil and oxide immediately prior to welding.
	Wet or contaminated shielding gas or inadequate flow. Fast cooling rate of weld pool.	Reject bottles above -57°C dew point. Increase flow rate. Shield from air currents. Use higher welding current and/or a slower speed. Preheat base metal.
Weld Cracking	Improper choice of aluminium welding wire or rod.	Select welding wires with lower melting and solidification temperatures, refer to "W" category of the "Aluminium Alloy Selection Chart".
	Critical chemistry range.	Avoid weld pool chemistry of 0.5 to 2.0% silicon and 1.0 to 3.0% magnesium. Avoid MgSi eutectic problems (5xxx welded with 4xxx).
	Inadequate edge preparation or spacing.	Reduce base metal dilution of weld through increased bevel angle and spacing.
	Incorrect weld technique.	Clamp to minimise stress. Narrow heat zone by increased traverse speed. Produce Convex rather than Concave bead. Minimise super heated molten metal, to control grain size. Proper weld size - not too small. Preheat base metal.
Burn-back or irregular wire feed	Fast run-in wire feed.	Slow run-in wire feed for CV power supply to reduce current surge and arcing in contact tip.
	Insufficient wire feed.	Increase wire feed for CC dropper power supply and reduce arc voltage on CV power supply.
	Electrode too soft, kinked or not level layer wound.	Talk to your local CIGWELD or THERMADYNE Branch Office.
	Flexible conduit too long or kinked.	Cut down or Replace.
	Worn or dirty liner or conduit.	Replace.
	Spatter on end of or eroded interior of the Gas Nozzle.	Replace gas nozzle.
	Aluminium fillings in liner or conductor tube and contact tip, resulting in arcing	Align drive rolls, align the centerline of the drive rolls with the outlet guide, use "U" grooved feed rollers, use only enough feed pressure to prevent slippage.
	Arcing in the Contact Tip	Match contact tip size to wire (or 10-15% above).

WELDING OF ALUMINIUM

6) Aluminium Welding Problems, Causes and Corrections:

Problem	Causes	Corrections
Poor arc starting	Improper grounding.	Reconnect ground (earth).
	Anodic coating.	Remove anodic coating.
	No shielding gas.	Pre-purge gas shield.
	Wrong polarity.	Change polarity.
Dirty welds	Inadequate gas coverage.	Increase gas flow. Shield arc from drafts. Hold gas nozzle closer to work. Replace damaged gas nozzle. Centre contact tip in gas nozzle. Decrease gun angle. Check gun and leads for air or water leaks.
	Dirty filler wire.	Keep aluminium wire covered when spool is mounted on machine.
	Dirty parent material.	Degrease with toluene, varsol or mineral spirits, etc. to remove oil or grease from joint area. Stainless steel brush to remove other foreign matter from joint area.
	Heavy oxide film or water stain on parent material.	Clean joint area with disc sander, heavy stainless steel brushing or etch.
Unstable arc	Poor electrical connections.	Check electrical connections.
	Dirt in joint area.	Remove all oil, grease, cutting compounds, paints and caulking from joint areas.
	Arc blow.	Do not weld in area of strong magnetic field. Arrange ground clamp to neutralise magnetic field.

6) Aluminium Welding Problems, Causes and Corrections: Cont.

Weld bead excessively wide	Welding current too high. Arc travel speed too low. Too long an arc.	Change welding parameters.
Inadequate penetration and incomplete fusion in welds	Insufficient welding current.	Increase weld current.
	Arc travel speed too high.	Reduce arc travel speed.
	Too long an arc.	Decrease arc length through increased wire feed speed.
	Dirty parent metal.	Degrease with toluene, varsol or mineral spirits, etc to remove oil or grease from joint area. Stainless steel brush to remove other foreign matter from joint area.
	Inadequate joint spacing or edge preparation.	Redesign joint.
	Oxide on base metal.	Clean joint area with disc sander, heavy stainless steel brushing or etch.
	Insufficient depth or improper shape of the back-gouge.	Increase depth of back gouge, U-type preferred over V-type.
	Fillet or vee grooves - torch oscillation with CV power supply.	Weld with straight stringer passes without torch manipulation. Switch to CC dropper power supply.
Mismatch of colour after anodising	Improper alloy selection.	Match colour selection in "Aluminium Alloy Selection Chart". Avoid 4xxx and 6xxx match; use 5xxx filler wire with 5xxx and 6xxx base alloys.

ALUMINIUM ALLOY SELECTION CHART

Base Alloys		1070, 1080 1060, 1350	1100	2014, 2036	2219	3303, ALCLAD 3003	3004	ALCLAD 3004	5005, 5050	5052, 5652
Characteristics		WSDCTM	WSDCTM	WSDCTM	WSDCTM	WSDCTM	WSDCTM	WSDCTM	WSDCTM	WSDCTM
	Filler Alloys									
319.0, 333.0, 354.0, 355.0, C355.0, 380.0	2319	-	-	BAAAAA	BAAAAA	-	-	-	-	-
	4043	BAAAAA	BAAAAA	CCBCAA	CCBCAA	BBAAAA	BBAAAA	BBAAAA	BBAAAA	AAAAAA
	4145	AABAAA	AABAAA	ABCBAA	ABCBAA	AABAAA	AABAAA	AABAAA	AABAAA	-
413.0, 443.0, 444.0, 356.0, A356.0, A357.0, 359.0	4043	AAAAAA	AAAAAA	BBAAAA	BBAAAA	AAAAAA	AAAAAA	AAAAAA	AAAAAA	ABAAAA
	4145	AABBA	AABBA	AABAA	AABAA	AABBA	-	-	-	-
	A356.0	-	-	-	-	-	-	-	-	-
	A357.0	-	-	-	-	-	-	-	-	-
	5356	-	-	-	-	-	-	-	-	BABB-A
7005, 7021, 7039, 7046, 7146, 710.0, 7110.0	4043	AACAA	AACAA	BBAAA	BBAAA	ABCAA	ADCBA	ADCBA	ABCBA	BDCBA
	4145	-	-	ABAA	AABAA	-	-	-	-	-
	5183	BABA-A	BABA-A	-	-	BABA-A	BABA-A	BABA-A	BABA-A	AABA-A
	5356	BAAA-A	BAAA-A	-	-	BAAA-A	BBAA-A	BBAA-A	BAAA-A	ABAA-A
	5554	-	-	-	-	-	CCAAAA	CCAAAA	CAAAAA	BCAAAA
	5556	BABA-A	BABA-A	-	-	BABA-A	BABA-A	BABA-A	BABA-A	AABA-A
	5654	-	-	-	-	-	CCAA-B	CCAA-B	CAAA-A	BCAA-A
6061, 6070	4043	AACAA	-ACAA	BBAAA	BBAAA	ABCAA	ADCAA	ADCAA	ABCAA	ADCAA
	4145	AADBA	AADBA	AABAA	AABAA	AADBA	BCDBA	BCDBA	ABDBA	-
	4643*	-	-	-	-	-	-	-	-	-
	5183	BAB--A	BAB--A	-	-	BAB--A	BAB--A	BAB--A	BAB--A	BABC-B
	5356	BAA--A	BAA--A	-	-	BAA--A	BBA--A	BBA--A	BAA--A	BBAC-A
	5554	-	-	-	-	-	-	-	-	CCABAB
	5556	BAB--A	BAB--A	-	-	BAB--A	BAB--A	BAB--A	BAB--A	BABC-B
	5654	-	-	-	-	-	-	-	-	CCAB-A
6005, 6063, 6101, 6151, 6201, 6351, 6951	4043	AACAA	AACAA	BBAAA	BBAAA	ABCAA	ADCAA	ADCAA	ABCAA	ADCAA
	4145	AADBA	AADBA	AABAA	AABAA	AADBA	BCDBA	BCDBA	ABDBA	-
	4643*	-	-	-	-	-	-	-	-	-
	5183	BAB--A	BAB--A	-	-	BAB--A	BAB--A	BAB--A	BAB--A	BABC-B
	5356	BAA--A	BAA--A	-	-	BAA--A	BBA--A	BBA--A	BAA--A	BBAC-A
	5554	-	-	-	-	-	-	-	-	CCABAB
	5556	BAB--A	BAB--A	-	-	BAB--A	BAB--A	BAB--A	BAB--A	BABC-B
	5654	-	-	-	-	-	-	-	-	CCAB-A
5454	4043	ABCCA	ABCCA	-	AAAAA	ABCCA	ADCCA	ADCCA	ABCCA	ADCCA
	5183	BABB-A	BABB-A	-	-	BABB-A	BABB-A	BABB-A	BABB-A	AAAB-A
	5356	BAAB-A	BAAB-A	-	-	BAAB-A	BBAB-A	BBAB-A	BAAB-A	ABAB-A
	5554	CAAAAA	CAAAAA	-	-	CAAAAA	CCAAAA	CCAAAA	CAAAAA	CCAAAA
	5556	BABB-A	BABB-A	-	-	BABB-A	BABB-A	BABB-A	BABB-A	AABB-A
	5654	-	-	-	-	-	-	-	-	BCAB-B
511.0, 512.0, 513.0, 514.0, 535.0, 5154, 5254	4043	ABCC	ABCC	-	AAAA	ABCC	ADCC	ADCC	ABCC	ADCC
	5183	BABB-A	BABB-A	-	-	BABB-A	BABB-A	BABB-A	BABB-A	AABB-B
	5356	BAAB-A	BAAB-A	-	-	BAAB-A	BBAB-A	BBAB-A	BAAB-A	ABAB-A
	5554	CAAA-A	CAAA-A	-	-	CAAA-A	CCAA-A	CCAA-A	CAAA-A	CCAA-B
	5556	BABB-A	BABB-A	-	-	BABB-A	BABB-A	BABB-A	BABB-A	AABB-B
	5654	CAAA-B	CAAA-B	-	-	CAAA-B	CCAA-B	CCAA-B	CAAA-B	BCAA-A
5086, 5056	4043	ABCB	ABCB	-	AAAA	ABCB	ACCB	ACCB	ABCB	-
	5183	AABA-A	AABA-A	-	-	AABA-A	AABA-A	AABA-A	AABA-A	AABA-A
	5356	AAAA-A	AAAA-A	-	-	AAAA-A	ABAA-A	ABAA-A	AAAA-A	ABAA-A
	5554	-	-	-	-	-	-	-	-	CCAA-A
	5556	AABA-A	AABA-A	-	-	AABA-A	AABA-A	AABA-A	AABA-A	AABA-A
	5654	-	-	-	-	-	-	-	-	BCAA-B
5083, 5456	4043	ABCB	ABCB	-	AAAA	ABCB	ACCB	ACCB	ABCB	-
	5183	AABA-A	AABA-A	-	-	AABA-A	AABA-A	AABA-A	AABA-A	AABA-A
	5356	AAAA-A	AAAA-A	-	-	AAAA-A	ABAA-A	ABAA-A	AAAA-A	ABAA-A
	5554	-	-	-	-	-	-	-	-	CCAA-A
	5556	AABA-A	AABA-A	-	-	AABA-A	AABA-A	AABA-A	AABA-A	AABA-A
	5654	-	-	-	-	-	-	-	-	BCAA-B
5052, 5652	4043	ABCAA	ABCAA	AAAAA	AAAAA	ABCAA	ABCAA	ACCAA	ABCAA	ADCBA
	5183	BAB--A	BAB--A	-	-	BAB--A	BAB--A	BAB--A	BAB--A	AABC-B
	5356	BAA--A	BAA--A	-	-	BAA--A	BAA--A	BBA--A	BAA--A	ABAC-A
	5554	-	-	-	-	-	-	-	-	CCAAAB
	5556	BAB--A	BAB--A	-	-	BAB--A	BAB--A	BAB--A	BAB--A	AABC-B
	5654	-	-	-	-	-	-	-	-	BCAB-A
5005, 5050	1100	CBAAAA	CBAAAA	-	-	CCAAAA	-	-	B-AAAA	-
	4043	AACAA	AACAA	BBAAA	BBAAA	ABCAA	ABCAA	ABCAA	ABDAA	-
	4145	BADBA	BADBA	AABAA	AABAA	BBDBA	-	-	-	-
	5183	CAB--B	CAB--B	-	-	CABC-B	BAB--A	BABB-A	BAC--B	-
	5356	CAB--B	CAB--B	-	-	CABC-B	BAA--A	BAAB-A	BAB--B	-
	5556	CAB--B	CAB--B	-	-	CABC-B	BAB--A	BABB-A	BAC--B	-
ALCLAD 3004	1100	DBAAAA	DBAAAA	-	-	CCAAAA	-	-	-	-
	4043	AACAA	AACAA	BBAAA	BBAAA	ABCAA	ADDAA	ADDAA	-	-
	4145	BADBA	BADBA	AADAA	AABAA	BBDBA	-	-	-	-
	5183	CABC-B	CABC-B	-	-	CABC-A	BACC-A	BACC-A	-	-
	5356	CABC-B	CABC-B	-	-	CABC-A	BBBC-A	BBBC-A	-	-
	5554	-	-	-	-	-	CCABAA	CCABAA	-	-
	5556	CABC-B	CABC-B	-	-	CABC-A	BACC-A	BACC-A	-	-
3004	1100	DBAAAA	DBAAAA	-	-	CCAAAA	-	-	-	-
	4043	AACAA	AACAA	BBAAA	BBAAA	ABCAA	ABDAA	-	-	-
	4145	BADBA	BADBA	AABAA	AABAA	BBDBA	-	-	-	-
	5183	CAB--B	CAB--B	-	-	C-BC-A	BACC-A	-	-	-
	5356	CAB--B	CAB--B	-	-	CABC-A	BBBC-A	-	-	-
	5554	-	-	-	-	-	CCABAA	-	-	-
	5556	CAB--B	CAB--B	-	-	C-BC-A	BACC-A	-	-	-
3003 ALCLAD 3003	1100	BBAAAA	BBAAAA	-	-	BBAAAA	-	-	-	-
	4043	AABAA	AABAA	BAAAA	BAAAA	AABAA	-	-	-	-
	4145	AACBA	AACBA	AABAA	AABAA	AACBA	-	-	-	-
2219	2319	-	-	BAAAAA	AAAAAA	-	-	-	-	-
	4043	BAAAA	BAAAA	BCBCA	BCBCA	-	-	-	-	-
	4145	AABAA	AABAA	ABCBA	ABCBA	-	-	-	-	-
2214, 2036	2319	-	-	CAAAAA	-	-	-	-	-	-
	4043	BAAAA	BAAAA	BCBCA	-	-	-	-	-	-
	4145	AABAA	AABAA	ABCBA	-	-	-	-	-	-
1100	1100	BBAAAA	BBAAA	-	-	-	-	-	-	-
	4043	AABAA	AABAA	-	-	-	-	-	-	-
	5356	-	-	-	-	-	-	-	-	-
1060, 1350, 1070, 1080	1100	BBAAAB	-	-	-	-	-	-	-	-
	1188	CCAAAA	-	-	-	-	-	-	-	-
	4043	AABAA	-	-	-	-	-	-	-	-

ALUMINIUM ALLOY SELECTION CHART CONT.

Base Alloys		5083, 5456	5086, 5056	511.0, 512.0 513.0, 514.0 535.0 5154, 5254	5454	6005, 6063, 6101, 6151, 6201, 6351, 6951	6061, 6070	7005, 7021, 7039, 7046, 7146, 710.0, 711.0	413.0, 443.0 444.0,356.0 359.0 A356.0, A357.0	319.0, 333.0 354.0, 355.0 C355.0,380.0
Characteristics		WSDCTM	WSDCTM	WSDCTM	WSDCTM	WSDCTM	WSDCTM	WSDCTM	WSDCTM	WSDCTM
	Filler Alloys									
319.0, 333.0, 354.0, 355.0, C355.0, 380.0	2319	-	-	-	-	-	-	-	-	BAAAAA
	4043	AAAA-A	AAAA-A	AAAA-A	AAAAAA	BBAAAA	BBAAAA	BBAAAA	BBAAAA	-
	4149	-	-	-	-	AABAAA	AABAAA	AABAAA	AABAAA	ABBBAA
413.0, 443.0, 444.0, 356.0, A356.0, A357.0, 359.0	4043	ABBA-A	ABBA-A	ABBA-A	ABBAAA	ABAAAA	ABAAAA	ABBAAA	ABAAAA	-
	4145	-	-	-	-	AABBA	AABBA	AABBA	AABBAB	-
	A356.0	-	-	-	-	-	-	-	AAAAAA	-
	A357.0	-	-	-	-	-	-	-	AAAAAA	-
	5356	AAAA-A	AAAA-A	AAAB-A	AAAB-A	-	-	AAAA-B	-	-
7005, 7021, 7039, 7046, 7146, 710.0 7110.0	4043	-	-	-	-	ADCBA	ADCBA	BDCBA	-	-
	4145	-	-	-	-	-	-	-	-	-
	5183	AABA-A	AABA-A	AABA-A	AABA-A	AABA-A	AABA-A	AABA-A	-	-
	5356	ABAA-A	ABAA-A	ABAA-A	ABAA-A	ABAA-A	ABAA-A	ABAA-A	-	-
	5554	-	-	BCAA-A	BCAAAA	BCAAAA	BCAAAA	BCAAAA	-	-
	5556	AABA-A	AABA-A	AABA-A	AABA-A	AABA-A	AABA-A	AABA-A	-	-
	5654	-	-	BCAA-A	BCAA-A	BCAA-A	BCAA-A	BCAA-A	-	-
6061, 6070	4043	ADCA	ADCA	ADCA	ADCBA	ACBAA	ACBAA	-	-	-
	4145	-	-	-	-	-	-	-	-	-
	4643*	-	-	-	-	ACBAA	ACBAA	-	-	-
	5183	AABA-A	AABA-A	BABC-B	BABC-A	BAAC-A	BAAC-A	-	-	-
	5356	ABAA-A	ABAA-A	BBAC-A	BBAC-A	BAAC-A	BBAC-A	-	-	-
	5554	BCAA-A	BCAA-A	CCAB-B	CCAAAA	CBABBA	CBABBB	-	-	-
	5556	AABA-A	AABA-A	BABC-B	BABC-B	BAAC-A	BAAC-B	-	-	-
	5654	BCAA-B	BCAA-B	CCAB-A	CCAB-B	CBAB-B	CBAB-B	-	-	-
6005 6063 6101 6151 6201 6351 6951	4043	ABCA	ABCA	ABCA	ABCBA	ACBAA	-	-	-	-
	4145	-	-	-	-	-				
	4643*	-	-	-	-	ACBAA				
	5183	AABA-A	AABA-A	BABC-A	BABC-A	BAAC-A				
	5356	AAAA-A	AAAA-A	BAAC-A	BAAC-A	BAAC-A				
	5554	BAAA-A	BAAA-A	CAAB-A	CAAAAA	CBABBA				
	5556	AABA-A	AABA-A	BABC-A	BABC-A	BAAC-A				
	5654	BAAA-B	BAAA-B	CAAB-B	CAAB-B	CBAB-B				
5454	4043	-	-	-	-	-				
	5183	AABB-A	AABB-A	AABB-A	AABB-A	-				
	5356	ABAB-A	ABAB-A	ABAB-A	ABAB-A	-				
	5554	BCAA-A	BCAA-A	BCAA-A	BCAAAA	-				
	5556	AABB-A	AABB-A	AABB-A	AABB-A	-				
	5654	-	-	BCAA-B	BCAB-B	-				
511.0 512.0 513.0 514.0 535.0 5154, 5254	4043	-	-	-	-	-				
	5183	AABA-A	AABA-A	AABB-B	-	-				
	5356	ABAA-A	ABAA-A	ABAB-A	-	-				
	5554	BCAA-A	BCAA-A	BCAA-B	-	-				
	5556	AABA-A	AABA-A	AABB-B	-	-				
	5654	BCAA-B	BCAA-B	BCAA-A	-	-				
5086 5056	4043	-	-	-	-	-				
	5183	AABA-A	AABA-A	-	-	-				
	5356	ABAA-A	ABAA-A	-	-	-				
	5554	-	-	-	-	-				
	5556	AABA-A	AABA-A	-	-	-				
	5654	-	-	-	-	-				
5083 5456	4043	-	-	-	-	-				
	5183	AABA-A	-	-	-	-				
	5356	A-AA-A	-	-	-	-				
	5554	-	-	-	-	-				
	5556	AABA-A	-	-	-	-				
	5654	-	-	-	-	-				

*4643 gives higher strength in thick 6xxx series welds after post weld solution heat treatment and aging. 4047 can be used in lieu of 4043 for thin section sheet due to the lower melting point of 4047.

LEGEND

Symbol Characteristic

W Ease of welding (relative freedom from weld cracking).

S Strength of welded joint ("as welded" condition). (Rating applies particularly to fillet welds. All rods and electrodes rated will develop presently specified minimum strengths for butt welds.)

D Ductility. (Rating is based upon the free bend elongation of the weld.)

C Corrosion resistance in continuous or alternate immersion in fresh or salt water.

T Recommended for service at sustained temperatures above 150°F (65.5°C).

M Colour match after anodising.

*A,B,C and D are relative ratings in decreasing order of merit. The ratings have relative meaning only within a given block.

NOTE: Combinations having no rating are not usually recommended. Ratings do not apply to these alloys when heat-treated after welding.

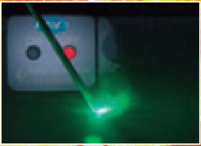
ALUMINIUM ALLOY SELECTION CHART

How to Use:

1. Select base alloys to be joined (one from the side column, the other from the top row).
2. Find the block where the column and row intersect.
3. This block contains horizontal rows of letters (A,B,C or D) representative of the alloy directly across from them in the filler alloy box at the end of each row. The letters in each line give the A-to-D rating of the characteristics listed at the top of each column -
W, S, D. C, T and M (see Legend at right for explanation of each letter).
4. Analyse the weld characteristics afforded by each filler alloy. You will find that you can 'trade off' one characteristic for another until you find the filler that best meets your needs.

Example:
When joining base alloys 3003 and 1100, find the intersecting block. Now, note that filler alloy 1100 provides excellent ductility (D), corrosion resistance (C), performance at elevated temperatures (T) and colour match after anodising (M), with good ease of welding (W) and strength (S). However, if ease of welding and shear strength are UTMOST in importance, and ductility and colour match can be sacrificed slightly, filler alloy 4043 can be used advantageously.

Superior Integrated VRD technology



When it comes to safety in welding, the answer is VRD.

When it comes to VRD . . .
. . . the answer is CIGWELD.

WELDING OF ALUMINIUM

1) Aluminium Base Metals

Aluminium Alloys can be broken up in to the following groups:

Group A - Cast Alloys
Group B - Wrought Alloys

Group A - Cast Alloy System

SERIES No.	MAJOR ALLOY ELEMENTS
100	99% Pure
*200	Copper
*300	Copper & Silicon
400	Silicon
500	Magnesium
*600	Magnesium & Silicon
*700	Zinc
800	Tin

Group B - Wrought Alloy System

SERIES No.	MAJOR ALLOY ELEMENTS
1000	99% Pure
*2000	Copper
3000	Manganese
4000	Silicon
5000	Magnesium
*6000	Magnesium & Silicon
*7000	Zinc

* NB: These alloys are heat-treatable.
Cast aluminium alloys generally contain a higher percentage of alloying elements than wrought alloys.

The higher additions of alloys greatly improve casting qualities, but make machining and working more difficult.

The Different Groups (Features)

▲ 100/1000 Series: contain 99% AL or greater (iron and silicon are the major impurities).

- excellent surface finish, high thermal and electrical conductivity and excellent corrosion resistance.
- excellent weldability.
- uses: electrical conductors, architectural items and containers.

▲ 200/2000 Series: contain copper as a major alloying element.

- limited corrosion resistance, a high strength to weight ratio and superior machinability.
- very poor weldability.
- uses: forgings, heavy duty structural work.

▲ 300 Series: containing copper and silicon have almost replaced the original 200/2000 series due to better casting characteristics, the other features are the same.

▲ 3000 Series contains manganese which provides approximately 20% more strength than the 100/1000 series. This series has good ductility and retains workability.

- good weldability.
- uses: cooking utensils, sheets and panels which are used on storage tanks.

WELDING OF ALUMINIUM

The Different Groups (Features) cont.

- 400/4000 Series: contains silicon as the major alloying element which aids in the metals fluidity and improves strength and machinability. The silicon lowers the melting point and makes the 400 alloys one of the best for casting.

  - good to excellent weldability.
  - uses: welding wires, castings, decorative gate castings and sheet.

- 500/5000 Series: contains magnesium as the major alloying element. The alloys in the group are widely used due to their excellent mechanical properties, high corrosion resistance and excellent anodising characteristics.

  - 500 series are difficult to cast.
  - good to excellent weldability.
  - uses: sheet, plate, angles etc, widely used in the shipping and marine industries, and also in general fabrication.

- 600/6000 Series: contain silicon and magnesium making these alloys heat treatable, which allows the mechanical properties to be improved considerably by heat treatment after forming.

  - high resistance to corrosion and ease of machining, plus high strength.
  - good weldability.
  - uses: transportation equipment, engineering structures, bridges etc.

- 700/7000 Series: contains zinc which helps to give these alloys very good impact resistance, high strength and excellent ductility.

  - not recommended for welding.
  - uses: aircraft structures and mobile equipment.

- 800 Series: tin is the principal alloy in the group, its chief purpose being to improve anti-friction characteristics in bearing alloys. These alloys have a high resistance to corrosion by engine oils.

  - poor weldability.

GTAW Welding Consumables for Aluminium and Aluminium Alloys:

The CIGWELD/Comweld range

* Comweld AL1100
* Comweld AL4043
* Comweld AL4047
* Comweld AL5356

- see product information in the front of this Pocket Guide or the CIGWELD Welding Consumables Technical Reference Manual.

WELDING OF ALUMINIUM

Filler Metals to AS 1167.2/AWS A5.10

ALUMINIUM ALLOYS		CONSUMABLE (Filler Rod) TYPE		
CAST	WROUGHT	AS1167.2	AWSA5.10	CIGWELD PRODUCT
AP150	1100	R1100	R1100	Comweld AL1100 (Pure Aluminium)
AP170	1200	R1100	R1100	Comweld AL1100 (Pure Aluminium)
AP185	3003	R1100	R1100	Comweld AL1100 (Pure Aluminium)
	3203	R1100	R1100	Comweld AL1100 (Pure Aluminium)
AP403	3004	R4043	R4043	Comweld AL4043 (Aluminium 5% Silicon)
AP601	5005	R4043	R4043	Comweld AL4043 (Aluminium 5% Silicon)
BP601	5050A	R4043	R4043	Comweld AL4043 (Aluminium 5% Silicon)
CP601	6061	R4043	R4043	Comweld AL4043 (Aluminium 5% Silicon)
AS601	6063	R4043	R4043	Comweld AL4043 (Aluminium 5% Silicon)
AP603	6351	R4043	R4043	Comweld AL4043 (Aluminium 5% Silicon)
AP501	5052	R5356	R5356	Comweld AL5356 (Aluminium 5% Magnesium)
AP701	5083	R5356	R5356	Comweld AL5356 (Aluminium 5% Magnesium)
AP703	5086	R5356	R5356	Comweld AL5356 (Aluminium 5% Magnesium)
	5154A	R5356	R5356	Comweld AL5356 (Aluminium 5% Magnesium)
	5251	R5356	R5356	Comweld AL5356 (Aluminium 5% Magnesium)
	5454	R5356	R5356	Comweld AL5356 (Aluminium 5% Magnesium)
	7005	R5356	R5356	Comweld AL5356 (Aluminium 5% Magnesium)
BP401		R4047	R4047	Comweld AL4047 (Aluminium 10% Silicon)
CP401		R4047	R4047	Comweld AL4047 (Aluminium 10% Silicon)
AP303		R4047	R4047	Comweld AL4047 (Aluminium 10% Silicon)
AS303		R4047	R4047	Comweld AL4047 (Aluminium 10% Silicon)
AP309		R4047	R4047	Comweld AL4047 (Aluminium 10% Silicon)

AWS A5.10-92 Specification for Bare Aluminium and Aluminium Welding Electrodes and Rods.

2) Tungsten Electrodes

Pure, Zirconiated, and Ceriated are the recommended tungsten welding electrodes for use in A.C. welding. Thoriated welding electrodes are generally reserved for D.C. welding of products such as low alloy steels and stainless steels. Thoriated tungsten will handle a higher current than pure tungsten, although it does not retain the balled shape required for A.C. welding of aluminium.

Pure Tungsten Electrodes:

Pure Tungsten welding electrodes are not often recommended or used for A.C. welding on aluminium and magnesium alloys as Zirconiated, and Ceriated electrodes have gained popularity in recent years. Pure Tungsten electrodes contain a minimum of 99.5% tungsten, with no alloying elements intentionally added. By using high purity tungsten, current carrying capability is diminished, although it maintains a clean, balled end which provides good arc stability.

WELDING OF ALUMINIUM

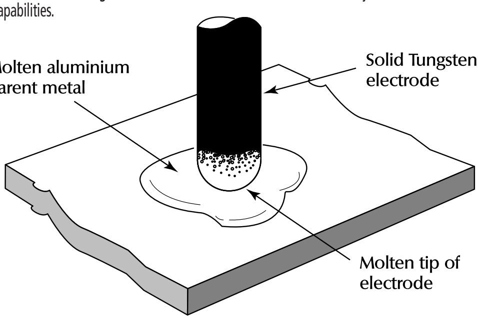
2) Tungsten Electrodes cont.

Zirconiated Tungsten Electrodes:

Zirconiated tungsten welding electrodes have arc stability characteristics that are similar to pure tungsten besides the higher current carrying capability found in the thoriated tungsten. This welding electrode provides a good balance of properties. It is more resistant to contamination than pure tungsten and better for radiographic-quality welding applications than thoriated tungstens.

These electrodes have been designed primarily for use with High Frequency stabilised Alternating Current (AC-HF) and are alloyed with varying percentages of zirconium.
Zirconiated electrodes must be pre-ground to form a tapered tip with a radius end before use.

When current flows through a Zirconiated electrode the end tip which has been prepared with the radius end heats up and becomes slightly molten forming a balled end. This balled end is very important in AC-HF welding as it allows the AC current to obtain arc stability and its arc directional capabilities.



Uses: designed for high quality clean welding of Aluminium and Magnesium alloys.

Advantages:

- high current carrying capacity.
- high resistance to contamination from aluminium oxides (self cleaning action).
- resultant weld metal quality is of high radiographic standard.

Ceriated Tungsten Electrodes:

"The best of both worlds". These electrodes contain varying percentages of cerium and have been designed to function on both AC and DC currents.

Ceriated tungsten welding electrodes have an addition of approximately 2% cerium oxide (CeO_2) which helps to reduce welding electrode burn-off. In performance, the ceriated welding electrode will react much like pure tungsten by providing a stable arc and reducing the amount of tungsten "spitting". These characteristics allow this welding electrode to perform well on aluminium in balanced wave machines (A.C.) and on steel in the D.C. mode.
This electrode can replace both Thoriated and Zirconiated electrodes in most instances.

WELDING OF ALUMINIUM

2) Tungsten Electrodes cont.

Preparation before welding is dependent upon the current used.
Uses: designed for quality and general purpose work on most metals.

Advantages:

- reduces the number and types of electrodes required to complete different jobs.
- higher resistance to contamination than the thoriated and zirconiated types.
- higher current carrying capacity.
- a longer electrode tip life.
- non-radioactive material.

3) Preparing Tungsten Electrodes:

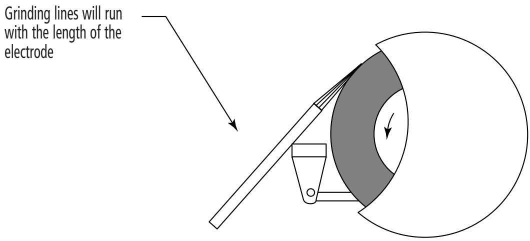
Tungsten electrodes are pre-ground before commencement of welding to allow efficient performance during welding.

Preparation is dependent upon two factors:

- Welding polarity being used (AC-HF or DC)
- The type of Parent Metal being welded.

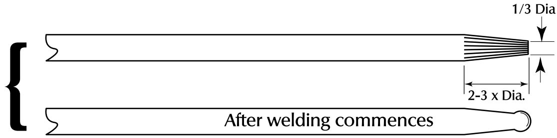
The Correct Grinding Technique:

- When grinding Tungsten electrodes, it is very important to make sure the grinding lines run longitudinally to the electrodes axis.
- If the grinding lines run around the circumference of the electrode, they may cause the following problems:
  - ridges will be formed around the circumference which can cause tungsten particles to drop off the tip during welding. This will result in tungsten inclusions, a weld defect.
  - these ridges will reduce the stability of the arc and cause "arc wander".

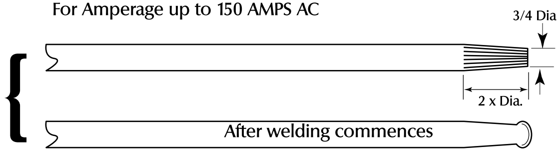


WELDING OF ALUMINIUM

Preparing Zirconiated & Ceriated Tungstens for AC-HF Welding:



For Amperage up to 150 AMPS AC



For Amperage over 150 AMPS AC

Current Carrying Capacities of Tungsten Electrodes:

ELECTRODE DIAMETER	THORIATED	ZIRCONIATED	CERIATED
0.5mm	5-50	5-35	5-60
1.0mm	10-90	15-55	7-95
1.6mm	20-120	35-75	20-130
2.4mm	50-190	45-160	60-230
3.2mm	80-250	50-225	80-320
4.0mm	120-370	90-300	130-450
5.0mm	200-500	150-400	210-600

4) Gas Tungsten Arc Welding - "Process Explanation" and "Power Source Terminology"

The Gas Tungsten Arc Welding (GTAW) process utilises heat generated by an electric arc maintained between the workpiece and a non consumable tungsten welding electrode. The arc is enveloped by a stream of inert gas. GTAW weld quality is primarily controlled by workpiece, filler wire, and tungsten electrode quality, type of power source, and welder technique. Discussed below are several important items that must be addressed in order to produce high quality welds.

High Frequency (HF):

The high frequency mode will initiate and maintain the arc during the zero crossing of the A.C. sine wave. Three positions exist on most GTAW machines eg. TRANSTIG 200 AC/DC:

1. Start - This mode helps arc initiation without making actual contact to the work with the tungsten welding electrode. The "Start" mode is most often used in D.C. welding.

2. Continuous - this also helps initiate the arc and continues throughout the process to maintain the arc during periods when current (amperage) is at the zero crossing point of the sine wave. This mode is most often used in A.C. welding. This type of mode is often a built in feature on most CIGWELD GTAW machines, and occurs automatically when AC current for GTA welding is selected.

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WELDING OF ALUMINIUM

4) Gas Tungsten Arc Welding - "Process Explanation" and "Power Source Terminology" cont.

3. Off - The high frequency system does not engage during any part of the process in this mode. Contact between the tungsten electrode and work surface must occur before the arc can be initiated. A "Touch Start or Scratch Start Practice" to initiate the arc can cause contamination of the the tungsten electrode in the GTAW process. The "Off" mode is often used for DC- TIG or stick welding (MMAW) where scratch starting will initiate the arc.

WELDING OF ALUMINIUM

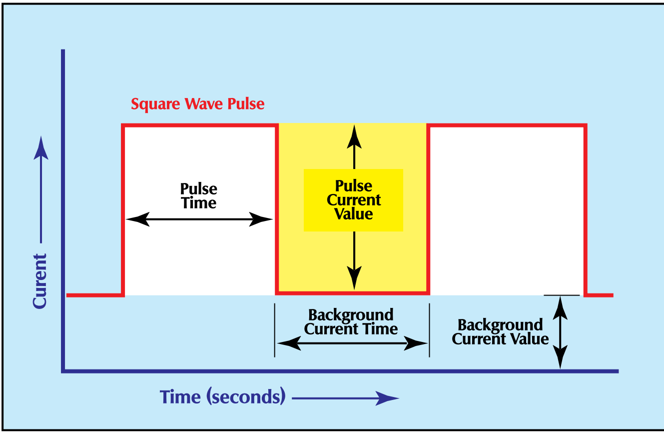
4) Gas Tungsten Arc Welding - "Process Explanation" and "Power Source Terminology" cont.

Pulsed GTAW (TIG) Welding:

In Pulsed Gas Tungsten Arc Welding the current consists of two parts, "see below"

1) the high pulse which melts the metal,
2) the low background current which maintains the arc and allows the weld to cool. The rate of pulse current is usually in the range of 1-10 pulses per second. Pulsed TIG welding offers the following advantages;

a) reduced distortion,
b) reduced heat build up,
c) improved tolerance to joint fit up, and
d) user friendly operation.



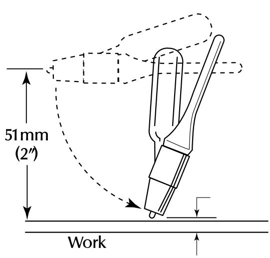
5) GTAW (TIG) Techniques

Starting the Arc:

After gas flow is established and providing HF is used, the electrode does not have to touch the workpiece or starting block to effect arc ignition. The superimposed high frequency current bridges the gap between the electrode and the workpiece or starting block and thus establishes a path for the welding current to follow.

For power sources that do not have a button or foot control start such as the TRANSTIG 150 the following steps are recommended;

a) the torch should first be positioned in a near horizontal position about 50mm above the workpiece or starting block (a piece of copper is recommended for a starting block as it provides less risk of contamination).



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WELDING OF ALUMINIUM

5) GTAW (TIG) Techniques cont.

b) the torch is then moved quickly downwards until the electrode is within approx 3mm of the workpiece or starting block as shown on the previous page. The arc will then be initiated.

c) to stop an arc, the torch should be returned to the horizontal position in a rather rapid manner so that the arc will not mark or damage the weld surface or workpiece. Some care will be necessary, particularly with high quality work and in pipe preparation when breaking the arc. In some instances it is advisable to run off, on to a tab or up the side of the pipe preparation when completing a pass.

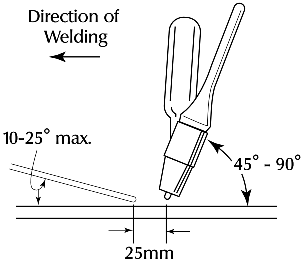
Torch Angles:

The proper manipulation of the welding torch is very important in making a good weld. When welding in the flat position,

- The hand should be placed lightly on a surface, so that the hand can move across the joint evenly. Movement of the torch by the fingers alone, usually results in incorrect torch angles and a poor weld.

- When adding filler wire, the wire should be gripped in the fingers. The hand should be as close as possible to the arc to hold the wire steady. The wire should move in conjunction with the torch movement. When adding wire, move the wire with the thumb through the fingers. The end of the wire should extend 150mm to 200mm from the hand. Too much extension of the filler wire results in a wobbly wire end making the puddle uneven and allowing the filler wire to become contaminated. Adding wire to the puddle requires steadiness and concentration to place the right amount of material at the right place, at exactly the right time.

- Torch angles vary only slightly depending on the welding position. The torch is usually pointed in the direction of travel with a 45-90° angle from the horizontal position. The filler rod is added ahead of the weld pool 10 to 25 degrees from the plane of the weld bead. The filler rod or wire should always be placed within the inert gas shield and at the leading edge of the weld pool. Too large a rod or wire disturbs and often freezes the pool, while a rod too small in size forces the welder to feed too fast for steady operation.

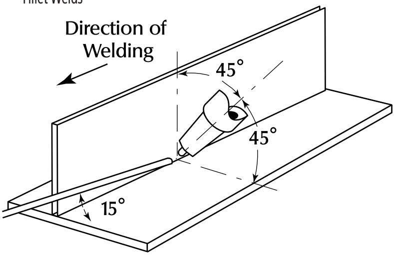


WELDING OF ALUMINIUM

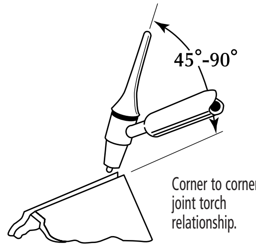
5) GTAW (TIG) Techniques cont.

Torch Angles, for Different Welding Positions:

Fillet Welds



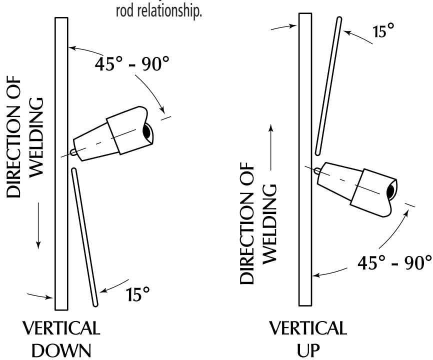
Corner to Corner Weld (Outside Corner)



Corner to corner joint torch relationship.

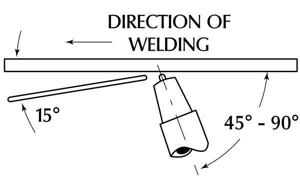
Vertical Welds

Vertical joint torch and filler rod relationship.



Overhead Welding

Overhead joint torch and filler relationship.



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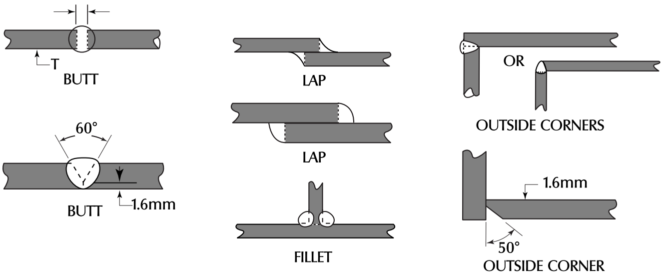
WELDING OF ALUMINIUM

6) Joint Types and Parameters in GTAW

Joints types applicable to the following parameter table: Parameter Table for GTAW (TIG) Welding of Aluminium:



Aluminium GTAW (TIG) Welding - Alternating Current - High Frequency (AC-HF)						
Metal Thickness	Joint Type	Tungsten Electrode Diameter	Filler Rod Diameter (if required)	Amperage	Gas	
					Type	Flow L/min*
1.0mm	Butt/Corner Lap/Fillet	1.0mm	1.6mm	30-45 35-50	Argon	5-7
1.2mm	Butt/Corner Lap/Fillet	1.0mm	1.6mm	40-60 45-70	Argon	5-7
1.6mm	Butt/Corner Lap/Fillet	1.6mm	1.6mm	60-85 70-95	Argon	7
3.2mm	Butt/Corner Lap/Fillet	2.4mm 3.2mm	2.4mm	125-150 130-160	Argon	10
5.0mm	Butt/Corner Lap/Fillet	3.2mm 4.0mm	3.2mm	180-225 190-240	Argon	10
6.0mm	Butt/Corner Lap/Fillet	4.8mm 4.0mm	4.8mm	240-280 250-320	Argon	13

*Flow rates are for argon only, see manufacturers' recommendations for mixtures. Size and shape of gas nozzle has an effect on the flow required for an effective gas cover.

WELDING OF CAST IRON

Introduction

This guide is not an exhaustive reference. Nonetheless, it provides the reader with a thorough technical guide to the welding of a number of different types of cast iron.

Types of Cast Iron

Cast irons can generally be divided into the following groups:

1. Grey Cast Irons

   Nominally contain 2.5-4.0% carbon and high silicon. Used for many applications, including those under conditions of static compressive load, lightly stressed process equipment and where severe thermal and mechanical shock would not normally be expected.

   Due to the presence of graphite in its structure, grey cast iron is easily machined, helps in the lubrication of sliding surfaces and is therefore good for bearings and for damping mechanical vibration. Grey cast iron is however quite brittle and has low tensile strength. It has uses in the machinery and automotive industries, including brake drums, clutch plates and cam shafts. Furnace parts, ingot and glass moulds and melting pots that operate at elevated temperatures are made of grey cast iron, as are various types of pipes, valves, flanges and fittings for both pressure and non-pressure applications.

2. SG-Spheroidal Graphite Cast Irons (Nodular Cast Iron, Ductile Cast Iron)

   SG cast irons have mechanical properties similar to those of mild steel and far greater than grey cast iron, in many cases replacing steel castings and forgings as well as grey cast iron in many applications. SG cast irons contain graphite making them machinable.

   Applications include culverts, sewers, pressure pipes as well as fittings, valves and pumps. The advantages of these products are their relatively good toughness and weldability when compared to grey cast iron

3. Austenitic Cast Irons

   Austenitic cast irons are nickel alloys of grey, SG and white cast irons.

   Due to the nickel addition, austenitic cast irons exhibit corrosion resistance, erosion resistance, cavitation resistance and exhibit resistance to high temperature service. Austenitic cast irons are stronger and tougher than grey cast iron, producing good wear and galling resistance as well as good machinability.

   Austenitic (SG) cast iron is approximately twice as strong as austenitic (grey) cast iron.

   Austenitic white cast irons containing nickel, chromium and molybdenum make up the range of Ni-Hard, Ni-Resist and Nicrosilal grades. Ni-Hard is used for abrasion resistance, Ni-Resist for corrosion resistance and Nicrosilal for heat resistance.

4. White Cast Irons ("Chilled" Iron)

   Unlike the grey and SG cast irons, white cast irons are virtually free of graphite. They are quite unmachinable and very brittle with high hardness and low tensile strength. They are often used in the manufacture of crushing rolls.

   "Meehanite"* is a high tensile white cast iron made by adding calcium silicide to white cast iron. The silicide addition gives uniform hardness as well as physical properties superior to that of grey cast iron.

   *(registered trademark of International Meehanite Metal Co. Ltd.)

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WELDING OF CAST IRON

5. Malleable Cast Irons

   Malleable cast irons, which include the white heart and black heart irons, are formed by heating white iron for a set period of time. Malleable cast irons have a higher tensile strength and better ductility than grey cast iron and will bend or deform before breaking as well as standing shock better than grey cast iron.

   Applications include flanges, pipe fittings and valve parts. Automotive parts include steering components, compressor crank shafts and hubs, transmission and differential parts, connecting rods and universal joints.

Identifying the type of cast iron:

There are a number of ways of identifying the type of cast iron that is to be welded.

1. Visual observation

   Grey and SG cast iron have a dirty, dark grey appearance due to the presence of graphite in the structure. White cast irons will have a whitish colour in a fracture in the casting. Malleable and austenitic cast irons have a cleaner appearance than grey or nodular.

2. Source of supply

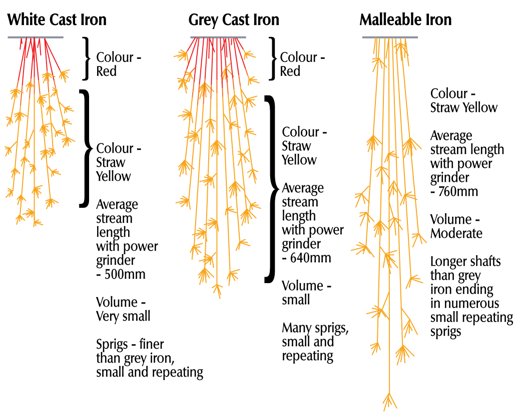
   If possible, check with the supplier of the cast iron. Quite often the item will be an old item in need of repair, so its origins may be difficult to discern.

3. Mechanical tests

   These are the best tests for identification.

   a) Spark test

   An easy and useful method is the spark test. The metal is touched against a high speed emery wheel and the sparks are observed against a black background. The sparks should then be compared against the chart below. SG cast irons can be identified in the same manner as malleable cast irons. Meehanite cast irons can be identified in the same manner as grey cast irons.



WELDING OF CAST IRON

b) Chisel test
Can be used for the separation of grey cast iron and malleable iron. Grey cast iron chips break easily, whereas chips from malleable cast iron will curl from the corner of the piece.

c) Spectrographic analysis
This test is the most accurate of all. However it needs to be undertaken by a qualified laboratory to ensure accurate results.

Welding Cast Irons

In general cast irons can be welded using the MMAW, FCAW, Gas and Braze Welding, Brazing, Powder Spraying and Soldering processes. The table below is a process selection guide listing the relevant CIGWELD consumable.

Process / Cast Iron	MMAW	FCAW	Gas Welding	Braze Welding	Brazing	Soldering
Grey	1	2	3,5	4, 5	4, 5	7
SG (Nodular/ Ductile)	1	2		4, 5	4, 5	
Austenitic	1					
White			Considered unweldable			
Ni-Hard				Considered unweldable		
Ni-Resist	1					
Nicrosilal				Considered unweldable		
Malleable	1	2		4, 5	4, 5	
Meehanite	1					

1=Castcraft 55, Castcraft 100
2=Nicore 55
3=Comweld General Purpose Cast Iron
4=Comweld Comcoat C, Comweld Manganese Bronze
5=Comcoat N, Comcoat Nickel Bronze
6=Comweld 965 Silver Solder

Preparation prior to welding

General

Cast iron is considered weldable, although to a far lesser degree than carbon steel. There have been many successful cast iron repair welds performed in maintenance and casting reclamation applications. The degree of brittleness and likelihood of cracking of the welded material will depend on the type of casting the heat treatment and the welding procedure. For example SG cast iron is more likely to absorb welding stresses than grey cast iron.

Preparation

The most important aspect of welding cast iron is to have the surface clean and free of defects prior to welding.

WELDING OF CAST IRON

Grinding & machining

All sand, slag and scale must be removed from the area of the casting to be welded by mechanical means such as grinding, machining, chipping or rotary burrs. Physical defects such as blowholes, sand inclusions, sponginess and shrinkage cracks need to be removed. Cracks should be excavated to their full length and depth. Excavate spongy areas and pinholes. Quite often a pinhole will open up to expose a large cavity hidden underneath. During preparation grinding wheels can become impregnated with carbon which can be smeared on the finished surface making joining difficult because of the high carbon content of the surface. Because of this the final 1-2mm should be prepared by chipping, rotary burrs or a coarse file to clean the surface.

Oxy-acetylene

An oxidising oxy-acetylene flame can be used to burn off any surface graphite. This also provides a light preheat which is advantageous.

Arc-air gouging

Arc-air gouging is not usually recommended. However, it can be used to remove the bulk of metal providing the last 1-2mm is removed by grinding.

Oil soaked castings

Often castings are soaked in oil due to their environment eg. gear boxes. They may appear clean after mechanical cleaning, however oil will still be present in the pores of the casting. The elimination of the residual can be achieved by heating the casting to 200-300°C for 2-3 hours followed by wire brushing. This will help overcome porosity and poor welds. "Gassy" castings can be treated by heating the weld area to a dull red for a short time before welding. For small components, treatment in a furnace at 650°C for 15 minutes will give fairly complete degasification. On heavier castings the relevant face is welded and the resultant porous metal is removed and the surface rewelded until a clean surface is obtained.
Castings high in phosphorous are difficult to weld and can be identified by a glassy and shiny appearance. Often brazing is the best way to repair these castings.

To repair cracked castings, drill a hole at each end of the crack to prevent it spreading further and grind out to the bottom. Begin welding at the drilled end of the crack, where restraint is greatest and move towards the free end.

Castings which have to transmit fairly heavy working loads often have the weld joint assisted by mechanical means, such as bolted straps, or hoops which are shrunk on. Broken teeth of large cast iron gears are sometimes repaired by studding. Holes are drilled and tapped in the face of the fracture and mild steel studs screwed in. These are then covered with weld metal and built up to the required dimensions. They are machined afterwards or ground to shape.

Precautions when welding cast irons

Factors to consider are the same whatever the type of cast iron.

1. Low ductility with a danger of cracking due to stresses set up by welding. (This is not so important when welding SG iron due to its good ductility)

2. Formation of a hard brittle zone in the weld area. This is caused by rapid cooling of molten metal to form a white cast iron structure in the weld area and makes the weld unsuitable for service where fairly high stresses are met.

3. Formation of a hard, brittle weld bead due to pick-up of carbon from the base metal. This does not occur with weld metals which do not form hard carbides such as Monel and high nickel alloys. These are used where machinable welds are desired.

WELDING OF CAST IRON

Preheating

Although a large amount of satisfactory welding is done without preheating, cracking due to the rigidity or lack of ductility of castings, especially complicated shapes, may be minimised by suitable preheating.

In general all cast irons need to be preheated when oxy-acetylene welding to reduce the heat input requirements. High preheat is needed when using a cast iron consumable because the weld metal has low ductility near room temperature. A consumable that deposits relatively low strength, such as Castcraft 100, can be used with the base metal at or slightly above room temperature. The weld can readily yield during cooling and relieve welding stresses that might otherwise cause cracking in the weld.

1. Local preheating occurs where parts not held in restraint may be preheated to about 500°C in the area of the weld, with slow cooling after welding is completed. Cracking from unequal expansion can take place during the preheating of complex castings or when the preheating is confined to a small area of a large casting which is why local preheating should always be gradual.

2. Indirect preheating involves a preheat of 200°C for other critical parts of the job in addition to local preheating. This is done so that they will contract with the weld and minimise contraction stresses. Such a technique is suitable for open frames, spokes etc.

3. Complete preheating is used for intricate castings, especially those varying in section thicknesses such as cylinder blocks. It involves complete preheating to 500°C followed by slow cooling after welding. The preheating temperature should be maintained during welding. A simple preheating furnace may be made of bricks into which gas jets project. Another may be filled with charcoal which burns slowly and preheats the job evenly.

Postweld Heating

After any welding on cast iron, especially welds intended for use in severe service or subject to close machining tolerances, the slowest cooling rate possible should be allowed, the part either remaining in the preheating furnace or cooling under a blanket of insulating powder or sand. It is sometimes the practice to post-heat welded joints to relieve stresses and soften hard areas. In this case it is normal to heat the casting to a temperature of 595-620°C. The casting should be held at this temperature for one hour per 25mm of thickness. The cooling rate should not exceed 10°C per hour until the casting has cooled to about 370°C. (For maximum softening and stress relief, heat at 900°C followed by slow cooling to 540°C or lower.) To obtain optimum ductility, the above heat treatment should be carried out immediately following welding.

For the best results with SG cast iron, the casting should be placed in a furnace (595-650°C) and the temperature raised to 900°C. The casting should be held at temperature for 2-4 hours. It is then cooled to 705°C, held there for 5 hours, then cooled to 590°C in the furnace and finally to room temperature. Malleable cast iron may be reheat-treated after welding.

Peening

Satisfactory welds may be made on cast iron without preheating by using electrodes depositing soft metal and peening the weld with a blunt tool (such as a ball hammer) immediately after welding. This spreads the weld metal and counteracts the effect of contraction.

Good practice is to deposit short weld runs (50mm at a time) and then peen before too much cooling takes place. (Castcraft 100 is soft and allows peening).

WELDING OF CAST IRON

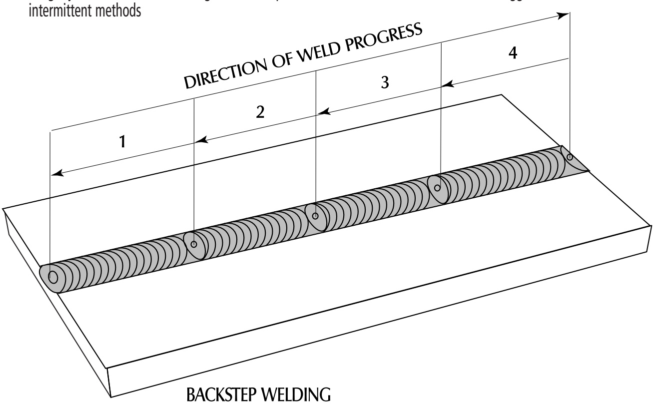
Joint Design

In general, joint design used for carbon steels are applicable for cast irons. Below are some suggested single-vee and double-vee preparations.

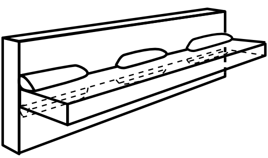
Welds should be as narrow as is practical for access - particularly for grey iron, as wide welds build up more stress than narrow ones. A double vee uses only half the weld metal of a single vee. For thick materials that are not accessible from both sides, a U-preparation is a good compromise.

See diagrams below for various joints designs:

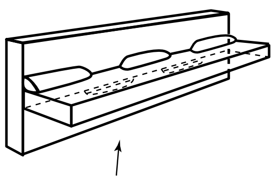
Longer joints can be welded using the backstep, block, cascade, chain intermittent and staggered intermittent methods



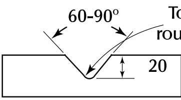
BACKSTEP WELDING



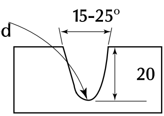
INTERMITTENT CHAIN WELDING



INTERMITTENT STAGGERED WELDING

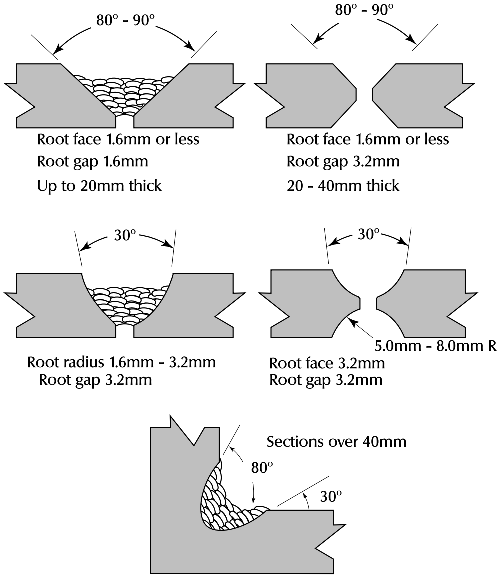


V-groove for narrow defects,



U-grooves for deep defects

WELDING OF CAST IRON



Corner defect repair weld

MMAW welding of cast irons

The most suitable electrodes for MMAW of cast irons are pure nickel (AWS A5.15 ENi-CI, Castcraft 100) and 55% nickel / 45% iron (AWS A5.15 ENiFe-CI, Castcraft 55).

Grey Cast Iron

Castcraft 100 is more suitable for single layers and for filling small defects as the deposit remains highly machinable. Single-layered welds of Castcraft 55 are not as machinable as Castcraft 100, however they do have increased strength and ductility. Castcraft 55 welds are more tolerant towards contaminants such as sulphur and phosphorous and are superior to Castcraft 100 electrodes when welding castings high in phosphorous.

Peening is a must for grey cast irons.

Joining of cast iron to steel can be performed with either Castcraft 55 or 100, but Castcraft 55 is preferred. Ferrous based electrodes, including hydrogen controlled types are generally not recommended for welding cast iron. Brackets, lugs and even wear plates can be attached to castings using the correct parameters and Castcraft 55.

WELDING OF CAST IRON

SG Cast Iron

Grey iron can be repaired with either Castcraft 55 or 100 whereas SG cast iron can only really be repaired using Castcraft 55 due to its higher tensile strength and better ductility. When welding SG cast irons, penetration should be low and wide joints or cavities should be built up from the sides towards the centre. Stringer beads or narrow weaves should be used. Deposit short beads and allow to cool to preheat temperature. Peening is advisable but not as critical as when welding grey cast iron.

Austenitic cast irons

These are usually welded with Castcraft 55. Although Austenitic castings can be welded with Castcraft 55 the weld may be unsuitable for applications where corrosion/heat resistance qualities do not match the parent metal.

GMAW welding of cast irons

Cast irons are generally considered unweldable using the GMAW process.

FCAW welding of cast irons

Flux cored welding of cast irons is carried out using higher current than that for MMAW. This is offset by faster travel speeds as for normal FCAW welding. Both grey, SG and malleable cast irons can be welded using the FCAW process. Preparation and heat treatment are much the same as for MMAW.

The most suitable consumable that can be used is an AWS ENiFe-CI equivalent like Nicore 55.

Oxy-acetylene welding of cast irons

For successful oxy fusion welding, it is essential that the part be preheated to a dull, red heat (approximately 650°C). A neutral or slightly reducing flame should be used with welding tips of medium or high flame velocity. The temperature should be maintained during welding. As with MMAW preparation it is necessary to use a furnace to ensure even heating of large castings. It is important that the casting be protected from draughts during welding and provision should be made to ensure that the required preheat is maintained. It is important to avoid sudden chilling of the casting otherwise white cast iron may be produced which is very hard and brittle. This may cause cracking or make subsequent machining impossible.

Oxy welding is suitable for grey cast irons with an AWS A5.15 RCI (Comweld General Purpose Cast Iron - Super Silicon), RCI-A type electrode and should be used with a suitable flux such as Comweld Cast Iron Flux.

An AWS RBCuZn-D (Comweld Nickel Bronze & Comweld Comcoat N) type can also be used with Comweld Bronze Flux.

SG cast irons can only be oxy welded with an AWS RCI-B type consumable.

Braze Welding of cast irons

Braze welding should only be used to repair old castings because of the poor colour match achieved with newer castings. Braze welding is suitable for grey, SG and malleable cast irons, however joint strength equivalent to fusion welds are only possible with grey cast iron. A neutral or slightly oxidising flame should be used.

WELDING OF CAST IRON

Braze welding has advantages over oxy welding in that the consumable melts at a lower temperature than the cast iron. This allows lower preheat (320-400°C). As with other forms of welding the surface must be properly cleaned so that carbon doesn't contaminate the weld deposit.

The applicable consumables to use are AWS RBCuZn-C (Comweld Manganese Bronze & Comweld Comcoat C) types and AWS RBCuZn-D (Comweld Nickel Bronze & Comweld Comcoat N) types.

Brazing of cast irons

Any brazing processes suitable for steel are applicable to cast irons. Pre- and post- braze operations should be similar to that of standard brazing processes.

Consumables suitable for brazing carbon steel can be used for cast irons.

Powder Spraying of cast irons

Powder spraying is particularly suited to edges, corners, shallow cavities and thin sections as there are usually no undercut marks. Porous metals can be surfaced before arc welding.

As with other welding processes, the base metal must be extremely clean and free from contaminants. Cavities and porous areas must be ground out to a saucer or cup shape with no overhanging edges. Sharp corners, edges and protruding points must be removed or radiused as they may go into solution in the molten metal causing hardspots.

Spraying and fusing should be as per the normal powder spraying process.

Poor quality or difficult irons can be joined by coating both parts separately with 1-2 mm of spray-fused alloy and then joining the coatings together with a suitable nickel MMAW electrode.

Consumables are based on a nickel-silicon-boron mixture.

Soldering of cast irons

Soldering of cast irons is usually limited to the repair of small surface defects, often sealing areas from leakage of liquids or gases. The casting must be thoroughly cleaned.

A suitable consumable is Comweld 965 Solder.

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WELDING OF COPPER AND COPPER ALLOLYS

Introduction:

Copper and Copper alloys remain to this day among the most important engineering materials due to their good electrical and thermal conductivity, corrosion resistance, metal-to-metal wear resistance and distinctive aesthetic appearance. Copper and most copper alloys can be joined by welding, brazing and soldering. The major markets for copper and its alloys include the building industry, electrical and electronic products, industrial machinery and equipment and transportation.

This section outlines the different types of copper alloys and gives guidance on processes and techniques to be used in fabricating copper alloy components without impairing their corrosion or mechanical properties or introducing weld defects.

1) Types of Copper Alloys:

The eight major groups of copper and copper alloys are:

- i Copper - 99.3% minimum Copper content.
- ii High copper alloys - up to 5% alloying elements.
- iii Copper-Zinc alloys (Brass).
- iv Copper-Tin alloys (Phosphor Bronze).
- v Copper-Aluminium alloys (Aluminium Bronze).
- vi Copper-Silicon alloys (silicon bronze).
- vii Copper-Nickel alloys.
- viii Copper-Nickel-Zinc alloys (Nickel silver).

i) Pure Copper: 99.3% minimum Copper content- Copper is normally supplied in one of three forms:

- (a) Oxygen free copper.
- (b) Oxygen-bearing copper (tough pitch and fire-refined grades) - the impurities and residual oxygen content of oxygen-bearing copper may cause porosity and other discontinuities when these coppers are welded or brazed.
- (c) Phosphorous deoxidised copper.

ii) High Copper Alloys:

- (a) Free machining copper - Low alloying additions of sulphur or tellurium can be made to improve machining. These grades are considered to be unweldable due to a very high susceptibility to cracking. Free machining coppers are joined by brazing and soldering.
- (b) Precipitation - hardenable copper alloys - Small additions of beryllium, chromium or zirconium can be added to copper and then given a precipitation hardening heat treatment to increase mechanical properties. Welding or brazing of these alloys will over-age the exposed area resulting in degradation of mechanical properties.

iii) Copper-Zinc Alloys (Brass):

Copper alloys in which zinc is the major alloying element are generally called brasses. Brass is available in wrought and cast form, with the cast product generally not as homogeneous as the wrought products. Additions of zinc to copper decreases the melting temperature, the density, the electrical and thermal conductivity and the modulus of elasticity. The additions of zinc will increase the strength, hardness, ductility and coefficient of thermal expansion. Brasses can be separated into two weldable groups, low zinc (up to 20% zinc) and high zinc (30-40% zinc). The main problems encountered with brass is due to zinc volatilisation which results in white -

WELDING OF COPPER AND COPPER ALLOLYS

1) Types of Copper Alloys **cont.:**

fumes of zinc oxide and weld metal porosity. The lower zinc alloys are used for jewellery and coinage applications and as a base for gold plate and enamel. The higher zinc alloys are used in applications where higher strength is important. Applications include automotive radiator cores and tanks, lamp fixtures, locks, plumbing fittings and pump cylinders.

iv) Copper-tin Alloys (Phosphor Bronze):

Copper alloys which contain between 1 percent and 10 percent tin. These alloys are available in the wrought and cast forms. These alloys are susceptible to hot cracking in the stressed condition. The use of high preheat temperatures, high heat input, and slow cooling rates should be avoided. Examples of specific applications include bridge bearings and expansion plates and fittings, fasteners, chemical hardware and textile machinery components.

v) Copper-Aluminium Alloys (Aluminium Bronze):

Contain from 3-15 percent aluminium with substantial additions of iron, nickel and manganese. Common applications for Aluminium Bronze alloys include pumps, valves, other water fittings and bearings for use in marine and other aggressive environments.

vi) Copper-Silicon Alloys (Silicon Bronzes):

Available in both wrought and cast forms. Silicon Bronzes are industrially important due to their high strength, excellent corrosion resistance, and good weldability. The addition of silicon to copper increases tensile strength, hardness and work hardening rates.

Low silicon bronze (1.5% Si) is used for hydraulic pressure lines, heat exchanger tubes, marine and industrial hardware and fasteners. The high silicon Bronze (3% Si) is used for similar applications as well as for chemical process equipment and marine propeller shafts.

vii) Copper Nickel Alloys:

The cupronickel alloys containing 10-30% Ni have moderate strength provided by the nickel which also improves the oxidation and corrosion resistance of copper. These alloys have good hot and cold formability and are produced as flat products, pipe, rod, tube and forgings. Common applications include plates and tubes for evaporators, condensers and heat exchangers.

viii) Copper Nickel Zinc Alloys (Nickel Silvers):

Contain zinc in the range 17-27% along with 8-18% Nickel. The addition of nickel makes these alloys silver in appearance and also increases their strength and corrosion resistance, although some are subject to dezincification and they can be susceptible to stress corrosion cracking.

Specific applications include hardware, fasteners, optical and camera parts, etching stock and hollowware.

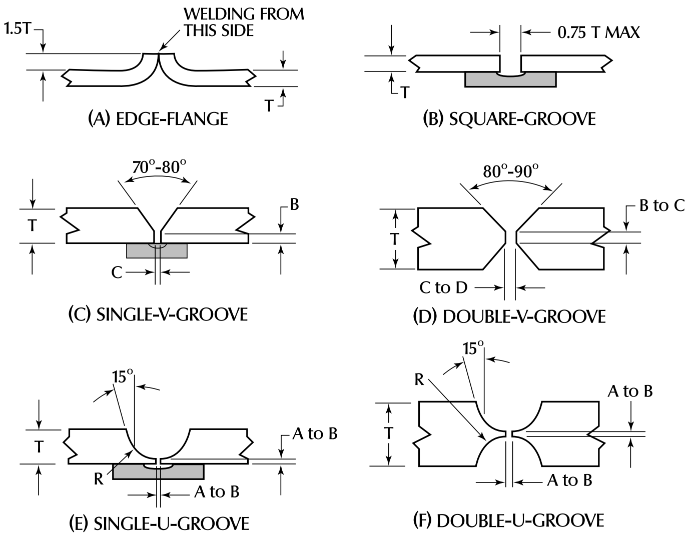
WELDING OF COPPER AND COPPER ALLOLYS

2) Weldability of Copper and Copper Alloys:

Welding processes such as Gas Metal Arc Welding and Gas Tungsten Arc Welding are commonly used for welding copper and its alloys, since high localised heat input is important when welding materials with high thermal conductivity. Manual Metal Arc Welding of Copper and Copper alloys may be used although the quality is not as good as that obtained with the gas shielded welding processes. The weldability of copper varies among the pure copper grades (a) (b) and (c). The high oxygen content in tough pitch copper can lead to embrittlement in the heat affected zone and weld metal porosity. Phosphorus deoxidised copper is more weldable, with porosity being avoided by using filler wires containing deoxidants (Al, Mn, Si, P and Ti). Thin sections can be welded without preheat although thicker sections require preheats up to 60°C. Copper alloys, in contrast to copper, seldom require pre-heating before welding. The weldability varies considerably amongst the different copper alloys and care must be taken to ensure the correct welding procedures are carried out for each particular alloy to reduce the risks of welding defects.

2.1 Weld joint designs for Joining Copper and Copper alloys:

The recommended joint designs for welding copper and copper alloys are shown in Figures 1 & 2. Due to the high thermal conductivity of copper, the joint designs are wider than those used for steel to allow adequate fusion and penetration.

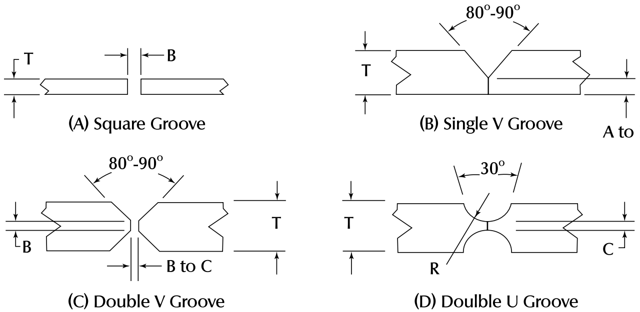


NOTE: A = 1.6mm, B = 2.4mm, C = 3.2mm, D = 4.0mm, R = 3.2mm, T = thickness

Figure 1. - Joint designs for Gas Tungsten Arc Welding and Manual Metal Arc welding of Copper and Copper Alloys.

WELDING OF COPPER AND COPPER ALLOLYS

2) Weldability of Copper and Copper Alloys cont.:



NOTE: A = 1.6mm, B = 2.4mm, C = 3.2mm, D = 4.0mm, R = 6.0mm, T = thickness

Figure 2. - Joint Designs for Gas Metal Arc Welding of Copper.

2.2 Surface Preparation:

The weld area should be clean and free of oil, grease, dirt, paint and oxides prior to welding. Wire brushing with a bronze wire brush followed by degreasing with a suitable cleaning agent. The oxide film formed during welding should also be removed with a wire brush after each weld run is deposited.

2.3 Pre-heating:

The welding of thick copper sections requires a high preheat due to the rapid conduction of heat from the weld joint into the surrounding base metal. Most copper alloys, even in thick sections, do not require pre-heating because the thermal diffusivity is much lower than for copper. To select the correct preheat for a given application, consideration must be given to the welding process, the alloy being welded, the base metal thickness and to some extent the overall mass of the weldment. Aluminium bronze and copper nickel alloys should not be preheated.

It is desirable to limit the heat to as localised an area as possible to avoid bringing too much of the material into a temperature range that will cause a loss in ductility. It is also important to ensure the preheat temperature is maintained until welding of the joint is completed.

3) Gas Metal Arc Welding (GMAW) of Copper and Copper alloys:

3.1 GMAW of Copper:

ERCu copper electrodes are recommended for GMAW of copper. CIGWELD's Autocraft Deoxidised Copper is a versatile 98% pure copper alloy for the GMAW of copper. The gas mixture required will be largely determined by the thickness of the copper section to be welded. Argon is generally used for 6mm and under.

WELDING OF COPPER AND COPPER ALLOLYS

3) Gas Metal Arc Welding (GMAW) of Copper and Copper alloys cont.:

The helium-argon mixtures (Alushield Heavy) are used for welding of thicker sections.

The filler metal should be deposited with stringer beads or narrow weave beads using spray transfer. Table 1 below gives general guidance on procedures for GMAW of Copper.

***Refer to Figure 2**

Metal Thickness	Joint Design*	Electrode Diameter	Preheat# Temperature	Welding Current	Voltage Range	Gas Flow Rate (l/min)	Travel Speed
1.6mm	A	0.9mm	75°C	150-200	21-26	10-15	500 mm/min
3.0mm	A	1.2mm	75°C	150-220	22-28	10-15	450 mm/min
6.0mm	B	1.2mm	75°C	180-250	22-28	10-15	400 mm/min
6.0mm	B	1.6mm	100°C	160-280	28-30	10-15	350 mm/min
10mm	B	1.6mm	250°C	250-320	28-30	15-20	300 mm/min
12mm	C	1.6mm	250°C	290-350	29-32	15-20	300 mm/min
16mm +	C, D	1.6mm	250°C	320-380	29-32	15-25	250 mm/min

Table 1. - Typical Conditions for GMAW of Copper# and Copper Alloys.

Recommended Shielding Gases for the GMA welding of Copper and Copper Alloys:

- Welding Grade Argon.
- Ar + >0-3% O_2 or equivalent shielding gases.
- Ar + 25% He or equivalent shielding gases.
- He + 25% Ar or equivalent shielding gases.

3.2 GMAW of Copper Silicon Alloys:

ERCuSi-A type welding consumables plus argon shielding and relatively high travel speeds are used with this process. Autocraft Silicon Bronze is a copper based wire recommended for GMAW of Copper Silicon Alloys. It is important to ensure the oxide layer is removed by wire brushing between passes. Preheat is unnecessary and interpass temperature should not exceed 100°C.

3.3 GMAW of Copper Tin Alloys (Phosphor Bronze):

These alloys have a wide solidification range which gives a coarse dendritic grain structure, therefore care must be taken during welding to prevent cracking of the weld metal. Hot peening of the weld metal will reduce the stresses developed during welding and the likelihood of cracking. The weld pool should be kept small using stringer beads at high travel speed.

4) Gas Tungsten Arc Welding (GTAW) of Copper and Copper Alloys:

4.1 Gas Tungsten Arc Welding of Copper:

Copper sections up to 16.0mm in thickness can be successfully welded using the Gas Tungsten Arc Welding process. Typical joint designs are shown in Figure 1. The recommended filler wire is a filler metal whose composition is similar to that of

WELDING OF COPPER AND COPPER ALLOLYS

4) Gas Tungsten Arc Welding (GTAW) of Copper and Copper Alloys cont.:

the base metal. For sections up to 1.6mm thick Argon shielding gas is preferred and helium mixes is preferred for welding sections over 1.6mm thick. In comparison to argon, argon/helium mixes permit deeper penetration and higher travel speeds at the same welding current.

A 75% Helium-25% Argon mixture is commonly used to give the good penetration characteristics of helium combined with the easy arc starting and improved arc stability properties of Argon.

Forehand welding is preferred for Gas Tungsten Arc Welding of Copper with stringer beads or narrow weave beads. Typical conditions for manual GTAW of copper is shown in Table 2 below.

*Refer to Figure 1

Metal Thickness (mm)	Joint Design*	Shielding Gas	Tungsten Type & Welding Current	Welding Rod Diameter	Preheat# Temperature	Welding Current
0.3-0.8	A	Argon	Thoriated/DC-	---	---	15-60
1.0-2.0	B	Argon	Thoriated/DC-	1.6 mm	---	40-170
2.0-5.0	C	Argon	Thoriated/DC-	2.4 - 3.2 mm	50°C	100-300
6.0	C	Argon	Thoriated/DC-	3.2 mm	100°C	250-375
10.0	E	Argon	Thoriated/DC-	3.2 mm	250°C	300-375
12.0	D	Argon	Thoriated/DC-	3.2 mm	250°C	350-420
16.0	F	Argon	Thoriated/DC-	3.2 mm	250°C	400-475

Table 2. - Typical conditions for Gas Tungsten Arc Welding of Copper# and Copper Alloys.

4.2 Gas Tungsten Arc Welding of Copper-Aluminium alloys:

The ERCuAl-A2 filler rod can be used for GTAW of Aluminium Bronze Alloys. Alternating Current (AC) current with argon shielding can be used to provide an arc cleaning action to assist in removing the oxide layer during welding. Direct Current (DC-) electrode negative with Welding Grade Argon or Argon-Helium mixes can be used in applications requiring deeper penetration and faster travel speed. Preheat is only required on thicker sections.

4.3 Gas Tungsten Arc Welding of Silicon-Bronze:

Comweld Silicon Bronze Rod (ERCuSi-A) can be used to weld Silicon Bronze in all positions. The Aluminium Bronze welding rod ERCuAl-A2 may also be used. Welding can be performed with DC- using argon or argon/helium shielding or AC using argon shielding gas.

5) Manual Metal Arc Welding (MMAW) of Copper & Copper Alloys:

5.1 Manual Metal Arc Welding of Copper:

MMAW is normally used for the maintenance and repair welding of copper, copper alloys and bronzes. Bronzecraft AC-DC electrode (ECuSn-C) can be used for the following:

- Minor repair of relatively thin sections.
- Fillet welded joints with limited access.
- Welding copper to other metals.

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WELDING OF COPPER AND COPPER ALLOLYS

5) Manual Metal Arc Welding (MMAW) of Copper & Copper Alloys:

Joint designs should be similar to that shown in Figure 1. Direct Current electrode positive (DC+) should be used with a stringer bead technique. Sections over 3.0mm require a preheat of 250°C or greater.

5.2 Manual Metal Arc Welding of Copper Alloys:

Bronzecraft AC-DC (ECuSn-C) can be used to weld Copper-Tin and Copper-Zinc alloys. Large butt angles are required and the weld metal should be deposited using the stringer bead technique.

Copper Alloy	Recommended AWS Electrode Code	CIGWELD Welding Electrode	Electrode Polarity	Joint Design
Brasses	ECuSn-A or ECuSn-C	Bronzecraft AC-DC	DC+	C in Figure 1
Phosphor Bronze	ECuSn-A or ECuSn-C	Bronzecraft AC-DC	DC+	C in Figure 1

Table 3 - Recommendations for MMAW of Brasses and Phosphor Bronzes.

6) Brazing of Copper and Copper Alloys:

The principle of brazing is to join two metals by fusing with a filler metal. The filler metal must have a lower melting point than the base metals but greater than 450°C (use of a filler metal with a melting point less than 450°C is soldering). The filler metal is usually required to flow into a narrow gap between the part by capillary action.

Brazing is used widely for the joining of copper and copper alloys, with the exception of Aluminium bronzes containing greater than 10 percent aluminium and alloys containing greater than 3 percent lead. Brazing of copper is used extensively in the electrical manufacturing industry, and in the building mechanical services, heating, ventilation and air-conditioning fields.

To achieve an adequate bond during brazing, the following points should be considered:

1. The joint surfaces are clean and free of oxides etc.
2. The provision of the correct joint gap for the particular brazing filler metal.
3. The establishment of the correct heating pattern so that the filler metal flows up the thermal gradient into the joint.

6.1 Surface Preparation:

Standard solvent or alkaline degreasing procedures are suitable for cleaning copper base metals. Care must be taken if mechanical methods are used to remove surface oxides. To chemically remove surface oxides, an appropriate pickling solution such as ChromeBright, should be used.

6.2 Joint Design Considerations:

1. The distance between the joints to be joined must be controlled to within certain tolerances which depend upon the brazing alloy and the parent metal used. The optimum joint gap typically lies between 0.04 and 0.20mm.

WELDING OF COPPER AND COPPER ALLOLYS

6) Brazing of Copper and Copper Alloys:

2. Generally a joint overlap of three or four times the thickness of the thinnest member to be joined is sufficient. The aim is to use as little material as possible to achieve the desired strength.

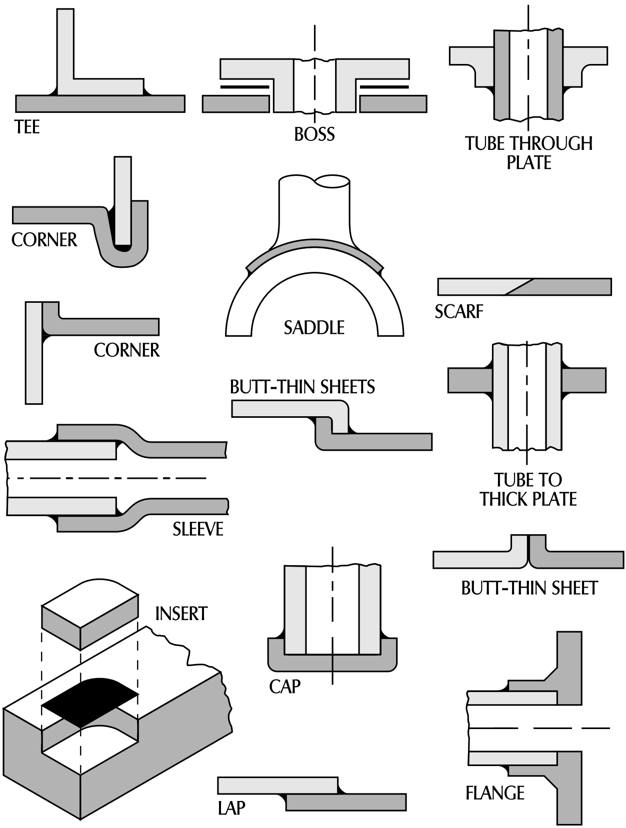

Figure 3 - Common Joint designs for Brazing.

6.3 Flame adjustment:

Use a neutral flame. A neutral flame is where equal amounts of oxygen and acetylene are mixed at the same rate. The white inner cone is clearly defined and shows no haze.

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WELDING OF COPPER AND COPPER ALLOLYS

6) Brazing of Copper and Copper Alloys cont.:

6.4 Flux Removal:

If flux has been used, the residue must be removed by one of the following methods:

- Dilution in hot caustic soda dip.
- Wire brushing and rinsing with hot water.
- Wire brushing and steam.

Incomplete flux removal may cause weakness and failure of the joint.

7) Braze Welding of Copper:

Braze welding is a technique similar to fusion welding except with a filler metal of lower melting point than the parent metal. The Braze welding process derives its strength from the tensile strength of the filler metal deposited as well as the actual bond strength developed between the filler metal and parent metal. Oxy-acetylene is usually preferred because of its easier flame setting and rapid heat input.

7.1 Choice of alloy:

The alloy most suited to the job requirement depends on the strength required in the joint, resistance to corrosion, operating temperature and economics.

Alloys commonly used are:

- COMWELD Tobin Bronze 211 (Braze Welding).
- COMWELD Comcoat T Flux Coated.

7.2 Joint Preparation:

Typical joint designs are shown in Figure 4 over the page.

WELDING OF COPPER AND COPPER ALLOLYS

7) Braze Welding of Copper cont.:

7.2 Joint Preparation:

Typical joint designs are shown in figure 4 below.

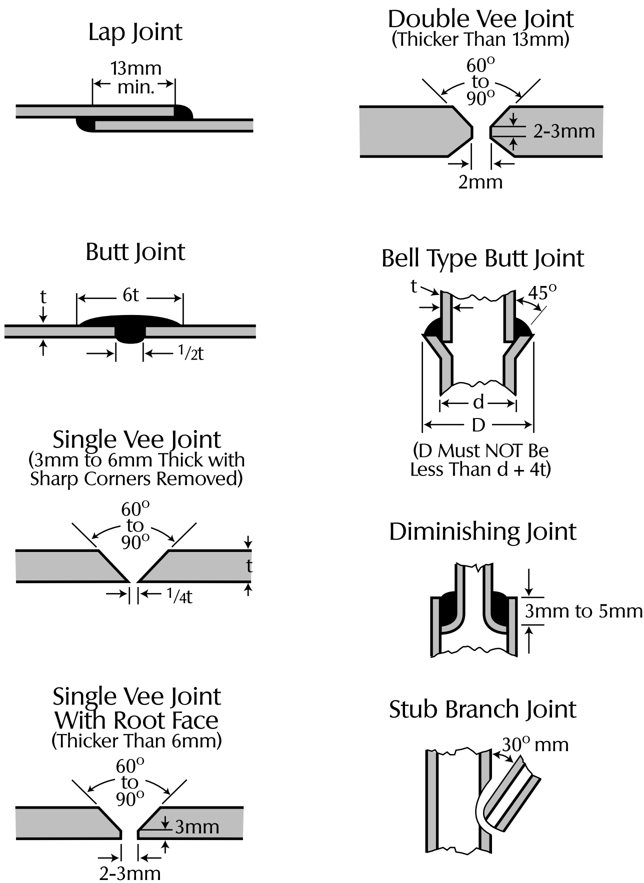

Figure 4 - Typical joint designs for Braze welding of copper.

WELDING OF COPPER AND COPPER ALLOLYS

7) Braze Welding of Copper cont.:

7.3 Flame adjustment:

Use slightly oxidising flame.

7.4 Flux:

Use COMWELD Copper and Brass Flux, mix to a paste with water and apply to both sides of joint. Rod can be coated with paste or heated and dipped in dry flux.

7.5 Preheating:

Preheating is recommended for heavy sections only.

7.6 Blowpipe and rod angles:

Blowpipe tip to metal surface 40° to 50°. Distance of inner cone from metal surface 3.25mm to 5.00mm. Filler rod to metal surface 40° to 50°.

Plate Thickness(mm)	Filler Rod(mm)	Blowpipe Acetylene Consumption (Cu. L/Min)	Tip Size
0.8	1.6	2.0	12
1.6	1.6	3.75	15
2.4	1.6	4.25	15
3.2	2.4	7.0	20
4.0	2.4	8.5	20
5.0	3.2	10.0	26
6.0	5.0	13.5	26

Table 5 Data for the Braze welding of Copper

7.7 Welding Technique:

After preheating or after the joint is raised to a temperature sufficient to permit alloying of the filler rod and copper, melt a globule of metal from the end of the rod and deposit it into the joint, wetting or tinning the surface. When tinning occurs, begin welding using forehand technique. Do not drop filler metal on untinned surfaces. See figure 5.

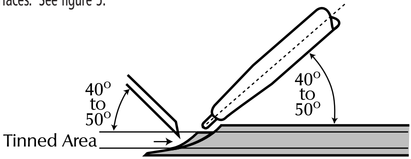

Figure 5 - Braze welding forehand technique.

7.8 Flux Removal:

Any of the following methods may be used to remove flux residue:

- Grinding wheel or wire brush and water.
- Sand blasting
- Dilute caustic soda dip.

WELDING OF DISSIMILAR METALS

At times, due to engineering design, it will be required that two, or in some cases more, dissimilar materials are to be joined by welding.

It is essential that the two materials be identified and wherever possible the design criteria be obtained, eg. elevated temperatures, chemical environment or wear by abrasion, etc.

Often it is not possible to obtain the base material analysis as in the case of maintenance or repair and it is left to the welding operator to select a consumable and a procedure purely based on his or her previous experience.

Welding Recommendations (refer to Table 1. on the next page)

A. One common combination of materials is stainless steel to mild steel and this combination can be successfully welded with a 309 type consumable. Both manual metal arc electrodes and gas metal arc wires are available.

B. Should the stainless steel be of a heat resisting type, such as the 310 variety, then a 310 consumable is recommended. These 310 materials resist oxidation up to 1,200° C, making them ideal for furnace applications associated with the oil, metal and ceramic refining industries. The decision to use these materials is usually specified by the welding engineer.

C. When welding cast iron to mild steel and possibly stainless steel, a nickel-iron consumable such as Castcraft 55 electrode or Nicore 55® flux core wire is often recommended.

D. When welding steel to copper/brass select a consumable that is most compatible with the grade of copper/brass. Autocraft Silicon Bronze gas metal arc welding wire is commonly used with many copper alloy grades.

E. For cast iron to copper/brass, select a consumable most suited to the copper alloy rather than the cast iron. A procedure commonly used is to butter the surface of the cast iron with Castcraft 55/Nicore 55®, then use either Bronzecraft AC/DC or Autocraft Silicon Bronze to complete the joint.

F. A material that is not commonly used, but is chosen in high chemical attack applications, is Monel. This material can be welded to mild steel by using a E NiCu-B electrode. It may be necessary to butter the mating surface of the mild steel with a E NiCu-B electrode prior to the joining of the two materials.

Refer to Table 1 on the next page for details regarding various welding consumables to join dissimilar metals.

WELDING OF DISSIMILAR METALS

Table 1. Welding Consumables for Joining Dissimilar Metals

Material 1	Material 2	Welding Recommendations*	MMAW	GMAW	FCAW	Gas & TIG Welding
Mild Steel	Stainless Steel	A	Satincrome 309Mo-17 Weldall	Autocraft 309LSi	Shieldcrome 309LT	Not recommended
Mild Steel	Cast Iron	C	Castcraft 55	N/A	Nicore 55®	Comweld Mang. Bronze or Comweld Nickel Bronze
Mild Steel	Copper	D	Bronzecraft AC/DC	Autocraft Silicon Bronze	N/A	Comweld Mang. Bronze or Comweld Nickel Bronze
Cast Iron	Copper/Brass	E	* Bronzecraft AC/DC * Castcraft 55	* Autocraft Silicon Bronze * Nicore 55®	N/A	Comweld Mang. Bronze or Comweld Nickel Bronze
Mild Steel	Austenitic Manganese	-	Austex	Autocraft 309LSi	Shieldcrome 309LT	Not recommended
Mild Steel	Monel	F		N/A	N/A	N/A

* See welding recommendations A, B, C, etc, on the previous page.

HARDFACING INFORMATION

What is Hardfacing and where is it used?

'Hardfacing is the process of depositing, by one of various welding techniques, a layer or layers of metal of specific properties on certain areas of metal parts that are exposed to wear'.

By expanding this definition a little further, it can be seen that hardfacing has more to offer than most other wear prevention treatments:

1. It is performed by welding. Thus it is part of a well established practice with which people are familiar. There are very few new skills to be learned and in the vast majority of cases, existing equipment can be employed.

2. A layer or layers of metal can be deposited. This means that hardfacing provides protection in depth. It can be applied in a thickness required to give long lasting protection.

3. Metal of specific properties is deposited. There are a wide variety of deposit types available, each specifically designed to withstand certain forms of wear and service conditions.

4. Hardfacing is applied only to specific areas of metal parts that are exposed to wear. There is often no need to protect the entire surface of a component from wear. Hardfacing can be applied selectively and in different thicknesses to suit the exact requirements of a piece of equipment, thereby proving a most economical way of combating wear.

According to the American Welding Society, 'hard surfacing" or hardfacing is defined as;

'The deposition of filler metal on a metal surface to obtain the desired properties and/or dimensions', the desired properties being those that will resist abrasion, heat and corrosion.

A further definition of hardfacing is: "The application of hard, wear-resistant material to the surface component by welding, spraying or allied welding process for the main purpose of reducing wear or loss of metal by abrasion, impact, erosion, galling and cavitation". It also applies where corrosion and elevated temperatures are present with one or more of the above service conditions.

Hardfacing is a particular form of surfacing that excludes the application of materials primarily for corrosion prevention or resistance to high temperature scaling or the application of low hardness, friction over-lays to prevent galling - eg. bronze surfacing. It also excludes the hardening of surfaces solely by heat treatments such as flame hardening, or nitriding.

A wide range of Cobalarc electrode and Stoody wire products are available for the three main types of hardfacing applications carried out in industry;

1. **Build-up or re-building applications.**
2. **Hard surfacing or overlay applications.**
3. **Both build-up and overlay applications.**

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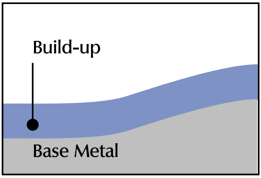
HARDFACING INFORMATION

What is Hardfacing and where is it used?

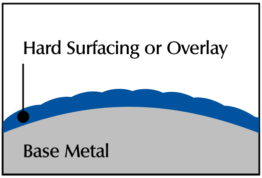
1. **Build-up or re-building applications**
   - Used to return the part or component to its original dimensions.

   eg. Mangcraft, Ferrocraft 61etc.



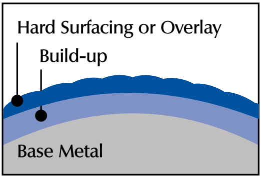
2. **Hard Surfacing or overlay applications.**
   - Used by itself to give a component added resistance to wear.

   eg. Cobalarc 650 and Coarseclad-G.



3. **Build-up and overlay applications.**

   Build-up and overlay can be used together to re-build a part to its original size and protect the contact surface from further wear. Some alloys can serve as both a build-up and overlay deposit, such as Cobalarc Mang Nickel-O wire which is recommended for heavy build up. During service the final layers of Mang Nickel-O can work harden under heavy impact to form a wear resistant overlay.



"Buttering layers" or "buffer layers" are a form of build-up or intermediate layer, deposited prior to the application of an overlay or hard surfacing deposit. See the **"Use of buffer layers"** for further details.

Hardfacing (or build-up and or overlay) is therefore used in two main areas:

1. **For the build-up or rebuilding** of worn components to their original size and shape using suitable build-up or build-up and overlay alloys as described above.

2. **The overlay or hard surfacing** of new, or as new, components to protect them from wear during service. High alloy welding consumables are available for overlay applications which offer far better wear resistance than the original component material. Despite the higher price of these welding consumables the working life of the component can be extended by over twice that of the original component. Further more, if overlays are used as part of a preventative maintenance program the original component can be manufactured from a less expensive base material.

HARDFACING INFORMATION

Why should Hardfacing be carried out?

1. **Hardfacing extends the life of worn components and equipment:**
   - Build-up or hard surfacing can extend the life of a component by as much as 250% compared to that of a new or non hardfaced component.

2. **Hardfacing increases the operating efficiency of equipment by reducing downtime:**
   - Hardfaced components last longer, cause fewer shutdowns or stoppages and therefore increase the operating efficiency of the equipment.

3. **Hardfacing reduces overall costs:**
   - The cost of refurbishing a worn component is typically 50 - 75% of the cost of a new component.

4. **Hardfaced parts can be manufactured from cheaper base metals:**
   - A part which is hard surfaced before use can often be manufactured from a cheaper base metal than one which is not designed to be hard surfaced before use.

5. **Hardfacing minimise the inventory of spare parts:**
   - If worn parts are usually refurbished there is no need to keep high stock holdings.

How to choose the right hardfacing consumable

Hardfacing alloy selection and correct welding procedures are best determined by answering the following four questions:

1. **What is the base metal of the component?**
2. **What welding process is to be used?**
3. **What type of wear is being experienced?**
4. **What finish is required?**

1. What is the base metal of the component?

Knowing the base metal composition of the component is important in deciding what welding consumable to use and what welding procedure to adopt.

The most common ferrous base metals used fall into two broad classifications:

- **Carbon and low alloy steels.**
- **Austenitic Manganese steels.**

Carbon and low alloy steels. Carbon and low alloy steels are strongly magnetic and can easily be distinguished from austenitic manganese steels which are non-magnetic. There are many types of carbon and low alloy steels used in equipment manufacture. They are not easy to distinguish from one another but must be identified in order to establish accurate preheat, interpass, welding consumable, cooling rate and stress relief requirements.

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HARDFACING INFORMATION

How to choose the right hardfacing consumable

Generally speaking as alloy content increases base metals become more difficult to weld and the use of correct preheat and interpass temperatures and slow cooling become more critical. Please refer to the **Welding of Steels** in this handbook.

Austenitic manganese steels. These high manganese (typically 14%) steels are strong and tough and as such are often used in the manufacture of components subject to both abrasion and extreme impact. Unique to manganese steels, they can be work hardened during high impact service to yield a component which is hard and abrasion resistant on the surface and yet tough, strong and ductile underneath. Unlike carbon and low alloy steels, manganese steels are rarely preheated; in fact base metal temperature during welding must be kept below approximately 300°C to avoid embrittlement. Welding practices such as step welding, water spraying or "welding in water" are often carried out to avoid base metal embrittlement. Manganese steels are an excellent base for the application of chromium white iron hard surfacing deposits such as Cobalarc Coarseclad-G, -O.

2. What welding process is to be used?

The welding processes most commonly used today for hardfacing are:

1. **Manual Metal Arc Welding**
2. **Flux Cored Arc Welding**
3. **Submerged Arc Welding**

Other processes such as oxy-acetylene welding and gas tungsten arc (GTA or TIG) welding are more often used for specialist hardfacing applications because of their low deposition rates.

Factors to be considered when selecting a suitable welding process / consumable include:

- **Welding equipment available.**
- **Operator skills available.**
- **Welding location - indoors or outdoors.**
- **Size and shape of component and area to be hardfaced.**
- **Welding position - can component be moved to allow downhand welding?**
- **Availability of hardfacing consumables.**

1. Manual Metal Arc Welding.

The most common type of welding process used with a wide range of extruded and tubular welding electrodes available for build-up and hard surfacing applications as well as for joining applications.

The most common types of manual electrodes are those designated as A4 and A1 types in Australian/New Zealand Standard AS/NZS 2576 - Welding Consumables for Build-up and wear resistance.

A1 type = Tubular electrodes with no alloy contribution from the flux coating, eg. Cobalarc 9.

A4 type = Low carbon steel rod with an alloy additive flux coating, eg. Cobalarc 350.

Note: See Consumables Classification Charts in this Pocket Guide for an explanation of AS/NZS 2576.

HARDFACING INFORMATION

How to choose the right hardfacing consumable

2. Flux Cored Arc Welding.

A semi-automatic process which is a variant of the gas metal arc welding process, where a continuous tubular electrode (instead of a solid wire) is used to provide the build-up or hard surfacing deposit.

The most common types of tubular wires are those designated as B5 and B7 types in AS/NZS 2576.

B5 type = Tubular wires which are used with an external gas shielding, eg. Stoody Coarseclad-G.

B7 type = Tubular wires which are self shielding or require no external shielding gas, eg. Stoody Coarseclad-O.

Because of the high level of build-up and hard surfacing carried out "on site" or out-of-doors self shielded (B7 type) wires are the most popular. Self shielded wires are also called open arc wires because the welding arc is visible during welding.

The flux cored arc welding process has become increasingly popular for build-up and hardfacing applications because of the flexibility in alloy selection and wire size and the high deposition rates achievable in practice.

3. Submerged Arc Welding.

Commonly used in the automatic mode, with either:

- An alloy additive tubular wire/strip and neutral flux (B1 type in AS/NZS 2576),
- An alloy additive solid wire/strip and neutral flux (B2 type in AS/NZS 2576),
- An alloy additive solid wire/strip with an alloy additive flux (B3 type in AS/NZS 2576) or,
- A low carbon steel wire/strip with an alloy additive flux (B4 type in AS/NZS 2576)

The submerged arc welding process is commonly used to build-up or hard surface large components automatically. The B1 type wire / flux combination is the most popular option used because of the flexibility in alloy types available in a tubular wire.

3. What type of wear is being experienced

In selecting a build-up or hard surfacing alloy the aim is to provide the best solution to the specific wear problem at hand. This solution is usually arrived at by considering a combination of factors including; past experience, a knowledge of the wear types experienced, a knowledge of welding alloy wear performance and verification through practical tests. It would be easier to select a welding consumable for a particular application if the component was always subjected to the one set of wear conditions. Unfortunately this is never the case, with wear modes differing from one component to another and from one application to another.

Experience has shown that there are three major types of wear:

- **Metal-to-metal wear,**
- **Abrasive wear,**
- **Environmental wear.**

A detailed treatment of these wear types is beyond the scope of this handbook, please refer to Australian/New Zealand Standard AS/NZS 2576.

How to choose the right hardfacing consumable

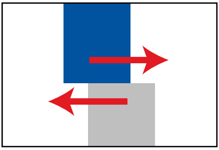
3. What type of wear is being experienced cont.

The three major types of wear can be further sub-divided into;

▲ Metal-to-metal wear:

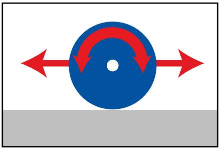
1. Adhesive or sliding wear:

In sliding wear, friction occurs between two surfaces which are in intimate contact.



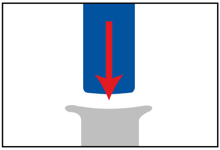
2. Rolling wear:

In rolling wear, contact stresses are often high and wear occurs by a fatigue mechanism.



3. Impact wear:

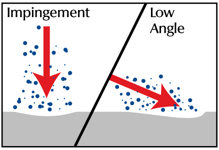
In impact wear, parts encounter repeated impact which can cause brittle fracture or gross plastic deformation.



▲ Abrasive wear:

1. Erosion:

In erosive wear, parts encounter high velocity fluids (liquids or gaseous) with or without solid particles. The two major types of erosion experienced are:



1A. Solid particle erosion:

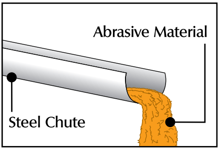
Wear of a part by the action of solid particles impinging on the surface.

1B. Liquid droplet and cavitation erosion:

Wear of a part by the action of liquid droplets or bubbles on the surface.

2. Low stress (scratching) abrasion:

In low stress abrasion, the abrasive particles, which are usually small and unconstrained, scratch the surface continuously to cause wear. The particles are not fractured or ground up during service.



HARDFACING INFORMATION

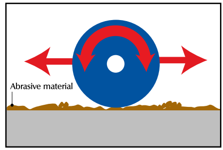
How to choose the right hardfacing consumable

What type of wear is being experienced cont.

▲ Abrasive wear:

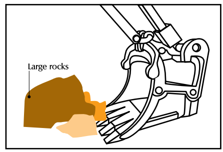
3. High stress (grinding) abrasion:

In high stress abrasion, the abrasive particles, which are initially small (rocks < 50mm in diameter), are fractured or ground-up during service.



4. Gouging abrasion:

In gouging abrasion, the abrasive particles, which are usually large (rocks > 50mm in diameter), gouge or groove the surface during service.



▲ Environmental wear:

Corrosion and elevated temperatures can combine with the abrasive wear mechanisms detailed above to exacibate the wear of a component. A detailed treatment of environmental wear mechanisms is beyond the scope of this handbook, please refer to AS/NZS 2576.

Limiting Service Conditions

Table 1. is a guide to selecting the appropriate Cobalarc hardfacing product based on the wear types identified from a specific application. The severity of loading, impact and temperature on a component must be considered along with the main wear mechanisms identified in order to select an appropriate Cobalarc hardfacing product.

In Table 1. the service conditions of load, impact and temperature are graded as follows:

Loading:

● ● ● = **HIGH loading** where there is gross deformation of the wear surface,
● ● = **MODERATE loading** where there is some local deformation of the wear surface,
● = **LOW loading** where there is no local deformation of the wear surface.

Impact:

HIGH = **HIGH impact** causing fracture or plastic deformation of the wear surface,
LOW = **LOW impact** causing no fracture or plastic deformation of the wear surface.

Temperature:

< 200°C - Service temperatures from ambient to 200°C,
> 200°C < 500°C - Service temperatures greater than 200°C and less than 500°C,
> 500°C - Service temperatures greater than 500°C.

Cobalarc Product Selection by Wear Type - Table 1:

Cobalarc product	Limiting service conditions*			WEAR TYPE							
				Metal-to-metal			Abrasive wear				
	Loading	Impact	Temp.	Sliding	Rolling	Impact	Solid particle erosion	Liquid droplet erosion	Low stress abrasion	High stress abrasion (Grinding)	Gouging abrasion
Cobalarc Mangcraft, Stoody Mang Nickel-O	●●●	HIGH	<200°C	---	---	R	---	---	---	R	R
Cobalarc Austex,	●●●	HIGH	<500°C	---	R	R	---	---	---	---	---
Cobalarc 350, Stoody 350-G, -O,	●●●	HIGH & LOW	<200°C	R	R	R	---	---	---	---	---
Cobalarc Toolcraft	●●●	LOW	<500°C	R	R	R	---	---	---	R	---
Cobalarc 650, 750 Stoody 650-G, -O Stoody 850-O†	●●●	HIGH	<200°C	---	---	---	R	---	R	R	R

* See previous page for limiting service condition definitions.

R = Recommended. HR = Highly Recommended.

† Stoody 850-O is not recommended for high impact applications

HARDFACING INFORMATION

Cobalarc Product Selection by Wear Type - Table 1:

Cobalarc product	Limiting service conditions*			WEAR TYPE							
				Metal-to-metal			Abrasive wear				
	Loading	Impact	Temp.	Sliding	Rolling	Impact	Solid particle erosion	Liquid droplet erosion	Low stress abrasion	High stress abrasion (Grinding)	Gouging abrasion
Cobalarc CR70, Stoody 101 HC-G-O	●●	HIGH	<500°C	---	---	---	R	R	HR	HR	HR
Cobalarc 9,	●●	HIGH	<500°C	---	---	---	R	R	HR	HR	HR
Cobalarc Borochrome Stoody Fineclad-O	●●	LOW	<500°C	---	---	---	R	HR	HR	HR	R
Cobalarc 4,	●	LOW	<200°C	---	---	---	HR	R	HR	R	R
Bronzecraft AC-DC	●●	LOW	<200°C	R	R	R	---	---	---	---	---
Comweld Manganese Bronze and Comweld Comcoat C	●	LOW	<200°C	R	R	---	---	---	---	---	---
Comweld Nickel Bronze and Comweld Comcoat N	●●●	HIGH	<200°C	HR	R	R	R	R	R	---	---

* See previous page for limiting service condition definitions. R = Recommended. HR = Highly Recommended.

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Cobalarc Applications by Industry Sector

AGRICULTURAL EQUIPMENT

APPLICATION	Cobalarc electrode	Stoody wire
▲ Slasher Blades	Toolcraft	Stoody 965 G-O
▲ Tools and Drill Bits	Toolcraft	-
▲ Scarifier Points	Cobalarc 750, Cobalarc 9	Stoody 850-O
▲ Plough Shares	Cobalarc CR70	Stoody 101 HC G-O
▲ Ammonia Injector Knives	Cobalarc 9, Cobalarc 4	
▲ Subsoiler teeth	Cobalarc CR70, Cobalarc 4	Stoody 101 HC G-O
▲ Ripper Shanks	Cobalarc 9	
▲ Furrow Shovels	Cobalarc 9	
▲ Post Hole Augers	Cobalarc 9	
▲ Pilot bit	Cobalarc Toolcraft	
▲ Rollers and Tractor Machine Parts	Cobalarc 350	Stoody Super Buildup G-O
▲ Root Cutters	Cobalarc CR70, Cobalarc 9	Stoody 101 HC G-O

HARDFACING INFORMATION

Cobalarc Applications by Industry Sector

EARTHMOVING, MINING, CRUSHING & QUARRYING

APPLICATION	Cobalarc electrode		Stoody wire	
	Build-up	Hard Surfacing	Build-up	Hard Surfacing
▲ Track Pads	Cobalarc 350		Stoody Super Buildup	
▲ Rippers	---	Cobalarc 9	---	Stoody 101 HC, 100 HC
▲ Grouser Bars	Cobalarc 350	Cobalarc 650	Stoody Super Buildup	Stoody 965
▲ Loader Buckets	---	Cobalarc 9	---	Stoody 101 HC, 100 HC
▲ Idlers and Idler Rolls	Cobalarc 350	-	Stoody Super Buildup	-
▲ Teeth and Points	---	Cobalarc 9	---	Stoody 101 HC, 100 HC
▲ Drilling Augers	---	Cobalarc CR70, Cobalarc 9	---	Stoody 101 HC, 100 HC
▲ Crusher Jaws*, Crusher Cones*, Crusher Roll Shells*, Gyratory Crusher Mantle*	Cobalarc Mangcraft,	Cobalarc CR70, Cobalarc 9	Stoody Dynamang	Stoody 101 HC, 100 HC
▲ Hammer Mill Hammers*	Cobalarc Mangcraft,	Cobalarc CR70, Cobalarc 9	Stoody Dynamang	Stoody 101 HC, 100 HC
▲ Impact Breaker Bars*	Cobalarc Mangcraft,	Cobalarc CR70, Cobalarc 9	Stoody Dynamang	Stoody 101 HC, 100 HC
▲ Fan Blades	---	Cobalarc 9, Cobalarc Borochrome	---	Stoody Fineclad
▲ Pug Mill Paddles	---	Cobalarc 9, Cobalarc 4	---	
▲ Sizing Screens		Cobalarc CR70, Cobalarc Borochrome		Stoody 101 HC, 100 HC Stoody Fineclad
▲ Chutes	---	Cobalarc Borochrome	---	Stoody Fineclad
▲ Kiln Trunnions	Cobalarc 350	Cobalarc 650	Stoody Super Buildup	Stoody 965

* Manufactured from austenitic manganese steel

Cobalarc Applications by Industry Sector

SUGAR INDUSTRY

APPLICATION	Cobalarc electrode		Stoody wire	
	Build-up	Hard Surfacing	Build-up	Hard Surfacing
▲ Cane Crushing Rolls	---	Cobalarc CR70, Cobalarc Borochrome	---	Stoody Fineclad
▲ Preliminary Cane Leveller or Kicker Blades	---	Cobalarc 9, Cobalarc Borochrome	---	Stoody Fineclad
▲ Cane Shredder Hammer	Ferrocraft 7016, Ferrocraft 61		Supre-Cor 5	
▲ Scraper, Trash and Return Plates	Cobalarc Austex	Cobalarc CR70, Cobalarc 9, Cobalarc Borochrome	Autocraft 309LSi	Stoody 101 HC, 100 HC Stoody Fineclad
▲ Shredder Grid Bars	Cobalarc Austex	Cobalarc CR70, Cobalarc 9	Autocraft 309LSi	Stoody 101 HC, 100 HC
▲ Cane Preparation Knives	---	Cobalarc 9, Cobalarc Toolcraft	---	Stoody 101 HC, 100 HC
▲ Spiky Feed Rolls	Cobalarc Austex	Cobalarc CR70, Cobalarc 9	Autocraft 309LSi	Stoody 101 HC, 100 HC
▲ Cane Harvester Base Cutters and Elevator Rolls	---	Cobalarc 9	---	Stoody 101 HC, 100 HC

HARDFACING INFORMATION

Cobalarc Applications by Industry Sector

DREDGING INDUSTRY

APPLICATION	Cobalarc electrode		Stoody wire	
	Build-up	Hard Surfacing	Build-up	Hard Surfacing
▲ Carbon Steel Pump Casings	Cobalarc 350	Cobalarc CR70, Cobalarc Borochrome	Stoody Super Buildup	Stoody 101 HC, 100 HC Stoody Fineclad
▲ Manganese Steel Pump Casings	Cobalarc Mangcraft,	Cobalarc CR70, Cobalarc Borochrome	Stoody Dynamang	Stoody 101 HC, 100 HC Stoody Fineclad
▲ Dredge Pump Impellers	---	Cobalarc Borochrome, Cobalarc CR70	---	Stoody Fineclad, Stoody 101 HC, 100 HC
▲ Dredge Pump Side Plates	---	Cobalarc Borochrome, Cobalarc 9	---	Stoody Fineclad
▲ Manganese Steel Dredge Cutter Heads and Teeth		Cobalarc Borochrome, Cobalarc 9		Stoody Fineclad
▲ Dredge Bucket Lips	---	Cobalarc Borochrome, Cobalarc 9	---	Stoody Fineclad
▲ Pipeline Ball Joints	---	Cobalarc Borochrome, Cobalarc 9	---	Stoody Fineclad
▲ Ladder Roll Bearing Box	Cobalarc 350	---	Stoody Super Buildup	
▲ Dredge Ladder Rolls	Cobalarc 350	Cobalarc 650	Stoody Super Buildup	Stoody 965
▲ Dredge Pump Inlet Nozzle	---	Cobalarc Borochrome, Cobalarc CR70	---	Stoody Fineclad, Stoody 101 HC, 100 HC
▲ Bucket Pins		Cobalarc 650		Stoody 965
▲ Carbon Steel Lower Tumblers		Cobalarc 650		Stoody 965
▲ Manganese Steel Lower Tumblers	Cobalarc Mangcraft,	Cobalarc Mangcraft,	Stoody Dynamang	Stoody Dynamang

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HARDFACING INFORMATION

Cobalarc Applications by Industry Sector

CEMENT, BRICK & CLAY INDUSTRIES

APPLICATION	Cobalarc electrode		Stoody wire	
	Build-up	Hard Surfacing	Build-up	Hard Surfacing
▲ Kiln Trunnions	Cobalarc 350		Stoody Super Buildup	---
▲ Screw Flight Shaft Bearings, Hangers and Pins	---	Cobalarc CR70	---	Stoody 101 HC, 100 HC Stoody Fineclad
▲ Drag Chain Links	---	Cobalarc CR70	---	Stoody 101 HC, 100 HC Stoody Fineclad
▲ Cage Bars	Cobalarc Austex	Cobalarc 9		Stoody Fineclad
▲ Manganese Steel Mill Hammers	Cobalarc Austex, Cobalarc Mangcraft	Cobalarc 9	Stoody Dynamang	Stoody 101 HC, 100 HC
▲ Bag Packer Screws	---	Cobalarc Borochrome	---	Stoody Fineclad
▲ Slurry Tank Agitator Shaft	---	Cobalarc Borochrome	---	Stoody Fineclad
▲ Muller Tyres	Cobalarc Austex, Weldall	Cobalarc CR70 Cobalarc 9		Stoody 101 HC, 100 HC
▲ Pug Mill Auger Flights	---	Cobalarc Borochrome Cobalarc 9 Cobalarc 4	---	Stoody Fineclad
▲ Pug Mill Knives	---	Cobalarc 4	---	
▲ Feeder Blades	---	Cobalarc 4	---	
▲ Shredder Cones	---	Cobalarc 9 Cobalarc Borochrome	---	Stoody Fineclad
▲ Shredder Knives	---	Cobalarc Borochrome	---	Stoody Fineclad
▲ Brick Pin Assembly	---	Cobalarc Borochrome	---	Stoody Fineclad
▲ Roll Crusher Teeth	---	Cobalarc 9	---	Stoody 101 HC, 100 HC

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HARDFACING INFORMATION

Cobalarc Applications by Industry Sector

IRON AND STEEL INDUSTRY

APPLICATION	Cobalarc electrode		Stoody wire	
	Build-up	Hard Surfacing	Build-up	Hard Surfacing
▲ Blast Furnace Bells	---	---	---	Stoody 101 HC, 100 HC (burden area)
▲ Coke Chutes	---	Cobalarc 9, Cobalarc Borochrome	---	Stoody Fineclad
▲ Coke Oven Pusher Shoes	---	Cobalarc 9, Cobalarc Borochrome	---	Stoody Fineclad
▲ Coupling Boxes	Cobalarc 350	Cobalarc 650, Cobalarc 750	Stoody Super Buildup	Stoody 965
▲ Screw Conveyors	---	Cobalarc CR70, Cobalarc 9	---	Stoody 101 HC, 100 HC
▲ Grizzly Bars and Fingers		Cobalarc CR70, Cobalarc 9		Stoody 101 HC, 100 HC
▲ Pig Iron Casting Machine Rails	---	Cobalarc 650, Cobalarc Toolcraft	--- Stoody Super Buildup	Stoody 965 Stoody 850
▲ Wobblers	Cobalarc 350	Cobalarc 650, Cobalarc 750		Stoody 965
▲ Ingot Buggy Wheels and Tracks	---	---	Stoody Super Buildup	Stoody 965
▲ Sand Slinger Cups Inlet Nozzle	---	Cobalarc Borochrome, Cobalarc CR70	---	Stoody 101 HC, 100 HC Stoody Fineclad

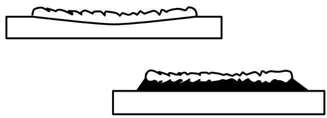
HARDFACING INFORMATION

USE OF BUFFER LAYERS

The term buffer layer is used to describe the presence of an intermediate deposit between the base material and the actual hardfacing deposit and in a number of cases is both desirable and necessary.

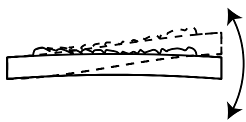
1. Hardfacing on a soft material for high load service.

When a hardfacing deposit is placed on a softer base materials there is a tendency for it to “sink in” under high loading. To overcome this a strong, tough layer is deposited onto the base materials prior to hardfacing.



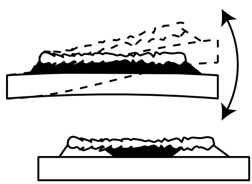
2. Hardfacing on components subject to heavy Impact/Flexing.

When a component is subjected to heavy impact and/or flexing there is the possibility that relief checks which are common in the higher hardness range of hardfacing products will act as stress concentrators and propagate through to the base materials, particularly where the base material is a high strength steel. The use of a suitable buffer layer between the base and hardfacing deposit will overcome this problem.



3. Hardfacing over Partly Worn Components.

In many instances components which have been hardfaced and put into service wear unevenly and when presented for hardfacing again there are areas of the original hardfacing deposit still existing. For the softer, multilayer deposits and/or deposits which have not fractured under impact, hardfacing can be re-applied directly. However for fractured and very hard deposits it is necessary they be removed by grinding, gouging etc. prior to re-hardfacing. If this is not possible the use of buffer layer will secure the existing hardfacing and provide a tough base for subsequent hardfacing layers.



NOTE: When applying buffer layers, particularly on 11-14% manganese steel or the higher strength base materials ensure that the buffer layer extends beyond the hardfacing deposit. This will overcome the possible propagation of relief checks or cracks occurring along the edge of the hardface deposit.

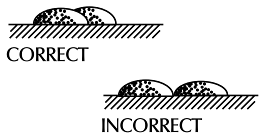
HARDFACING INFORMATION

HARDFACING DEPOSIT PATTERNS

The amount of hard surfacing and the pattern of coverage will be determined by a number of factors including the function of the component, service conditions and the state of repair. The three main patterns used are:-

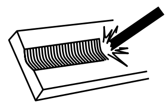
1. Continuous Coverage.

Is used for re-building and hardfacing parts that have a critical size or shape, such as rolls, shafts, tracks, crusher jaws and cones. It is also required on parts subject to a high degree of fine abrasion or erosion. Typical examples would be pump and fan impellers, sand chutes, valve seats, mixer paddles and dredge bucket lips. Sufficient over-lapping of each bead is necessary to ensure adequate coverage.

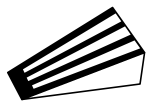


2. Stringer Beads.

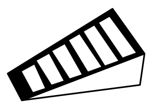
Other than complete coverage, stringer beads are widely used for many applications including, ripper teeth, buckets/bucket teeth, rock chutes, sheep foot tempers etc.



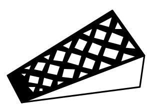
For teeth working in coarse rocky conditions the bead is deposited in the direction of the material travel, allowing the large lumps of rock etc. to slide along the top of the hardfacing bead.



In fine sandy conditions the stringer beads should be transverse (across) the path of material travel, this allows the fine materials to compact between the beads and so give self protection.



For conditions where there is a combination of coarse and fine material the "checker" or "waffle" pattern is generally used.



3. Dot Pattern.

For less critical areas such as the sides/ends of buckets, shovels etc. the dot pattern is used. It is useful in keeping the heat input down, particularly for the 11%-14% austenitic manganese steels. The dot size is generally 15-20mm diameter by 8mm high and placed at about 50mm centres.

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Cobalarc Product Selection by Alloy Type and Application

Group 1. Steel Products	Alloy Type	AS/NZS class	Description & Applications
Cobalarc Mangcraft, Stoody Dynamang-O	Austenitic manganese steels.	1215-A4 1215-B7	Tough, work hardens on impact. Crusher jaws, rolls, mantles, ball mill liners.
Cobalarc Austex,	Austenitic stainless steels.	1315-A4	Tough, corrosion and heat resistant. Forms strong welds between dissimilar irons / steels. Tramway rails, crossings, bearings at medium temperatures, tractor track grousers, anvils, pneumatic tools, shredder bars.
Cobalarc 350, Stoody Super Buildup-G	Low carbon martensitic steels.	1435-A4 1435-B5/7	Excellent compressive strength and metal-to-metal wear resistance. Re-building and surfacing of clutch parts, railway points and crossings, track components.
Cobalarc Toolcraft	Tool steels.	1560-A4	Strong, secondary hardening characteristics. Machine tools, lathe tools, shears, drills, guillotine blades, cutting knives, punches, dies, metal forming tools.
Cobalarc 650, Cobalarc 750, Stoody 965-G-O Stoody 850-O	High carbon martensitic steels.	1855-A4 1860-A4 1855-B5/B7 1865-B7	Hard, relatively in-expensive, good general abrasion resistance. Surfacing of post-hole augers, earth scoops, conveyor screws, drag line buckets, pump housings, subsoiler teeth, scarifier points, plough shears.

HARDFACING INFORMATION

Cobalarc Product Selection by Alloy Type and Application

Group 2. Chromium White Irons	Alloy Type	AS/NZS class	Description & Applications
Cobalarc CR70, Stoody 101 HC-G-O	Austenitic chromium carbide irons.	2355-A4 2360-B5/B7	Strong, high level of chromium carbides for excellent abrasion resistance. Ideal for gouging (coarse) abrasion conditions. Crusher cones and mantles, swing hammers, grizzly bars, scarifier points, shovel teeth, earthmoving buckets and sugar harvesting and milling equipment.
Cobalarc 9,	Complex chromium carbide irons.	2460-A1	Strong, high level of complex carbides for excellent abrasion resistance. Ideal for wide range of abrasion conditions with relatively high impact loading. Sizing screens, ball mill liner plates, dredge pump impellers, crusher jaws, pug mill paddles, agricultural implements, scrapers, fan blades, bucket lips and side plates.
Cobalarc Borochrome, Stoody Fineclad-O	Martensitic chromium carbide irons.	2560-A4 2565-B7	Strong, high level of chromium carbides for excellent abrasion resistance. Ideal for low stress scratching (wet or dry) abrasion conditions with relatively low impact loading. Wet applications in mining and crushing industries, agricultural implements, sand slingers, cement chutes, fan blades and slurry pump components.

Group 3. Tungsten Carbide Composites	Alloy Type	AS/NZS class	Description & Applications
Cobalarc 4,	Tungsten carbide granules in an iron rich matrix.	3460-A1	Hard, tungsten carbide (WC) iron deposit resistant to severe abrasion and low impact loading. Ideal for earth cutting and boring applications. Rock drills, ditcher teeth, ripper points, oil drill collars auger blades and teeth, oil well drills, bulldozer end bits.

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HARDFACING INFORMATION

Cobalarc Product Selection by Alloy Type and Application

Group 4. Copper Alloys	Alloy Type	AS/NZS class	Description & Applications
Bronzecraft AC-DC,	Phosphor bronze	6200-A2	Good bearing properties, wear & corrosion resistant. Medium load bearings, crankpress, transmission housings, pump rotors.
Comweld Manganese Bronze, Comweld Comcoat C	High tensile brass.	6300-C1 6300-C1	Low friction bearing characteristics, wear and corrosion resistant. Light load bearings, Hydraulic rams and pistons.
Comweld Nickel Bronze, Comweld Comcoat N	Nickel bronze (9-13% Ni).	6400-C1 6400-C1	Low friction bearing characteristics, work hardenable, corrosion resistant. Gear teeth, cams, bearings, percussion heads, slides, service where work hardening is required.

HARDFACING INFORMATION

Costing Information:

Based on the fact that the decision to hardface is an economic one, that is, to extend the working life of a component (ie. rebuild rather than replace), then the calculation of the true cost of hardfacing the component is important.

Points to consider in calculation of an estimated cost include:-

1. Volume of build-up of hardsurfacing deposit required.
2. Cost of welding consumables.
3. Preparation prior to welding (including grinding, preheat etc.).
4. Post weld requirements (heat treatment, grinding, machining etc.).
5. Power, labour and overhead costs.

Other important factors relating to the selection of the welding process/consumable are:-

1. Deposition rate (kg of weld metal / hr).
2. Deposition efficiency (%).
3. Operating factor or Duty cycle (%).

Cost Calculations:

WELDING ELECTRODE OR WIRE COST ; A ($ per kg of weld metal deposited):

$$\frac{\text{Electrode or Wire Price (\$ / kg)}}{\text{Deposition Efficiency * (\%)}} = \text{A (\$ / kg)}$$

FLUX COST ; B (SAW only) ($ per kg of weld metal deposited):

$$\frac{\text{Flux Price (\$ / kg) x Consumption Rate (kg / hr)}}{\text{Deposition Rate (kg / hr)}} = \text{B (\$ / kg)}$$

POWER COST; C ($ per kg of weld metal deposited);

$$\frac{\text{Cost of power (\$ / kWhr) x Volts x Amps}}{\text{Deposition Rate (kg / hr)}} = \text{C (\$ / kg)}$$

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HARDFACING INFORMATION

COSTING INFORMATION:

LABOUR COST; D ($ per kg of weld metal deposited):

$$\frac{\text{Labour Cost (\$ / hr) x Deposition Rate (kg / hr)}}{\text{Operating Factor* (\%)}} = \text{D (\$ / kg)}$$

OVERHEAD COST; E ($ per kg of weld metal deposited):

$$\frac{\text{Overhead cost (\$ / hr) x Deposition Rate (kg / hr)}}{\text{Operating Factor* (\%)}} = \text{E (\$ / kg)}$$

Total cost; F ($ per kg of weld metal deposited):

$$\text{F (\$ / kg)} = A + B + C + D + E$$

Total cost (TC) of hardfacing the steel component:

$$\text{TC (\$)} = \text{Volume of Build-up or hard surfacing deposit (cm}^3\text{) x F x 0.008}$$

*Deposition Efficiencies and Operating Factors for Hardfacing Cost Calculations:

Process	Deposit Efficiency (%)	Typical Operating Factor (%)
MMAW	60 - 75	15 - 20
FCAW†	80 - 90	25 - 30
SAW	90 - 95#	35 - 40

† Semi-automatic operation.
# SAW wire only.

DEPOSITION DATA

Deposition Rates, Electrode Efficiency, and Electrode Weld Metal Recovery!

What are the differences?

Deposition Rates

The deposition rate of a welding consumable (electrode, wire or rod) is the rate at which weld metal is deposited (melted) onto a metal surface. Deposition rate is expressed in kilograms per hour (kg/hr).

Deposition rate is based on continuous operation, not allowing for stops and starts such as, electrode change overs, chipping slag, cleaning spatter, machine adjustments or other reasons.

When welding current is increased so to does the deposition rate. When electrical stick out is increased in the case of GMAW and FCAW the deposition rate will also increase.

Deposition rates are calculated by doing actual welding tests, and the following shows the formula for measuring deposition rates.
Deposition Rate = Weight of test plate before welding – Weight of test plate after welding ÷ Measured period of time (normally 60 seconds).

e.g. Plate before welding: 2kg - 2.95kg Plate after welding = 95grams, welded in 60 seconds.
95grams x 60/1000 = 5.7kg/hr.

Electrode Efficiency (Deposition Efficiency)

Technically to ISO 2401-1972 electrode efficiency (AS/NZS 1553.1: 1995 deposition efficiency) is the difference between the weight of the weld metal deposited and the weight of the filler metal consumed (not including flux and stub ends) in making the weld. The efficiency of an electrode is calculated by using the following formula;

Electrode Efficiency % to ISO 2401and AS/NZS 1553.1 =

$$\frac{\text{Weight of test plate including weld metal} - \text{Weight of test plate before welding}}{\text{Mass of the Core Wire of 5 electrodes} - \text{Weight of core wire of the 5 stub ends}} \times 100$$

e.g. Satincraft 13 Ø4mm x 380mm.
Plate before welding: 2kg - 2.15kg Plate after welding = 150grams,
weight of five (5) electrode core wires, Ø4mm x 380mm long before welding = 188grams,
weight of five (5) electrode stub ends, Ø4mm x 50mm long after welding = 24.7grams,
150grams ÷ 163.3grams x 100 = 91.85% Electrode Efficiency (Deposition Efficiency).

e.g. Ferrocraft 22 Ø3.2mm x 380mm.
Plate before welding: 2kg - 2.167kg Plate after welding = 167grams,
weight of five (5) electrode core wires, Ø3.2mm x 380mm long before welding = 124grams,
weight of five (5) electrode stub ends, Ø3.2mm x 50mm long after welding = 16.3grams,
167grams ÷ 107.7grams x 100 = 155.06% Electrode Efficiency (Deposition Efficiency).

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DEPOSITION DATA

Electrode Weld Metal Recovery (Process Efficiency)

Electrode weld metal recovery to ISO 2401-1972 allows us to calculate the amount of welding consumable which will actually be deposited into the finished weld metal less any waste such as, stub ends, slag and spatter not adhered to the test plate.

An example is when 100kgs of electrodes are used with a quoted efficiency of 60%, the net result is that only 60kg of the weight of that electrode will actually end up in the deposited weld metal. The remaining 40% (40kg) of the electrode is waste.

To achieve weld metal recovery rates practical tests are carried out by weighing the test plate before and after welding, weighing the consumables before welding and then using the following formula allowing for 50mm stub ends. If the welder discards more than 50mm stub ends than the recovery rate (process efficiency) will be lower.

Weld Metal Recovery % to ISO 2401 =

$$\frac{\text{Weight of test plate before welding} - \text{Weight of test plate after welding}}{\text{Weight of the Consumable}} \times 100$$

e.g. Satincraft 13 Ø4mm x 380mm.
Plate before welding: 2kg - 2.15kg Plate after welding = 150grams,
weight of five (5) electrodes, Ø4mm x 380mm long before welding = 261.20grams,
150grams ÷ 261.20grams x 100 = 57.43% Weld Metal Recovery (Process Efficiency).

e.g. Ferrocraft 22 Ø3.2mm x 380mm.
Plate before welding: 2kg - 2.167kg Plate after welding = 167grams,
weight of five (5) electrodes, Ø3.2mm x 380mm long before welding = 281.50grams,
167grams ÷ 281.50grams x 100 = 59.33% Weld Metal Recovery (Process Efficiency).

General Process Efficiencies

Generally process efficiencies can be stated as averages for costing purposes. The following table outlines CIGWELD's suggested process efficiency percentages.
If the welding application calls for the Oxy-Acetylene or GTAW welding processes to be employed, then it is prudent to use all of the consumable by joining stub ends to ensure that 100% of the filler metal is utilised.

Welding Process			Average Efficiency
Gas Tungsten Arc Welding (GTAW) & Oxy-Acetylene Welding (OAW)		100%	
Manual Metal Arc Welding (MMAW)			60%
Gas Metal Arc Welding (GMAW)	Short Arc,	Ar + 25% CO_2	92%
Gas Metal Arc Welding (GMAW)	Spray Arc,	Ar + 25% CO_2	95%
Gas Metal Arc Welding (GMAW)	Pulse Arc,	Ar + 25% CO_2	98%
Flux Cored Arc Welding (FCAW)	E70T-4 types,	self shielded	82%
Flux Cored Arc Welding (FCAW)	E71T-1 types,	Ar + 25% CO_2	85%
Flux Cored Arc Welding (FCAW)	E70T-5 types,	Ar + 25% CO_2	88%
Flux Cored Arc Welding (FCAW)	E70C-6M types,	Ar + 25% CO_2	92%
Cobalarc Flux Cored Hardfacing Wires		Gas shielded	80%

GMAW and FCAW average efficiencies can vary in result depending upon the shielding gases used, machine settings, stick out, spatter losses, wire sniped off before starts etc.

DEPOSITION DATA

CIGWELD Electrodes, Deposition Rates, Electrode Efficiencies, and Electrode Weld Metal Recovery Rates

The following Table lists some popular CIGWELD consumables and their Deposition Rates, Electrode Efficiencies and Weld Metal Recovery Rates:

CIGWELD Product	Size (mm)	Amps	Deposition Rate kg/hr	Electrode Efficiency	Weld Metal Recovery
Ferrocraft 12XP	3.2	110	0.90	109%	66%
Ferrocraft 12XP	4.0	150	1.20	111%	69%
Satincraft 13	3.2	115	0.92	91%	56%
Satincraft 13	4.0	160	1.30	92%	58%
Ferrocraft 11	3.2	110	1.00	90%	64%
Ferrocraft 11	4.0	145	1.30	90%	66%
Ferrocraft 21	3.2	120	1.20	113%	63%
Ferrocraft 21	4.0	170	1.70	112%	62%
Ferrocraft 22	3.2	150	2.00	155%	59%
Ferrocraft 22	4.0	210	2.80	157%	61%
Ferrocraft 16TXP	3.2	120	1.20	95%	58%
Ferrocraft 16TXP	4.0	165	1.60	90%	56%
Ferrocraft 7016	3.2	120	1.10	101%	63%
Ferrocraft 7016	4.0	170	1.50	97%	60%
Ferrocraft 61	3.2	125	1.30	110%	57%
Ferrocraft 61	4.0	180	1.80	113%	59%
Alloycraft 90	3.2	125	1.30	111%	60%
Alloycraft 90	4.0	180	1.80	114%	62%
Satincrome 316L-17	3.2	95	0.90	105%	55%
Satincrome 316L-17	4.0	130	1.10	108%	54%
Castcraft 55	3.2	100	0.95	116%	69%
Castcraft 55	4.0	125	1.15	115%	70%
Cobalarc 750	3.2	115	1.00	109%	62%
Cobalarc 750	4.0	145	1.30	112%	64%
Cobalarc CR70	3.2	115	1.20	191%	69%
Cobalarc CR70	4.0	165	1.70	206%	71%
Cobalarc 9	6.3	120	1.0	85%	77%

The information provided in this table is a guide only, actual on the job figures may vary. Results are influenced by many factors including, welding parameters, arc length, travel speed and machine characteristics.

DEPOSITION DATA

CIGWELD Solid and Flux Cored Wires, Deposition and Weld Metal Recovery Rates

The following Table lists some popular CIGWELD consumables and their Deposition and Weld Metal Recovery Rates:

CIGWELD Product	Size (mm)	Volts	Amps	WFS m/min	Deposition Rate kg/hr	Weld Metal Recovery
Autocraft LW1-6	0.8	20	150	12.0	2.5	96%
Autocraft LW1-6	0.9	26	180	12.0	3.1	96%
Autocraft LW1-6	1.0	28	240	13.5	4.8	95%
Autocraft LW1-6	1.2	32	300	10.8	5.6	97%
Autocraft Silicon Bronze	0.9	24	180	13.2	3.2	95%
Autocraft 316LSi	0.9	22	180	10.0	2.8	97%
Autocraft 316LSi	1.2	26	250	8.5	4.4	98%
Autocraft AL5356	1.0	22	180	16.3	1.5	90%
Autocraft AL5356	1.2	24	220	14.0	2.5	92%
Satin-Cor XP	1.6	28	300	5.5	4.3	86%
Satin-Cor XP	1.6	29	350	6.5	5.4	87%
Satin-Cor XP	1.6	30	400	7.0	6.0	89%
Satin-Cor XP	2.4	30	400	4.2	5.7	85%
Satin-Cor XP	2.4	31	450	5.0	6.8	86%
Satin-Cor XP	2.4	32	500	6.0	8.2	90%
Verti-Cor 3XP	1.2	25	200	6.7	2.7	86%
Verti-Cor 3XP	1.2	26	250	9.9	3.8	84%
Verti-Cor 3XP	1.2	28	320	15.0	5.9	88%
Verti-Cor 3XP	1.6	27	300	6.2	4.1	86%
Verti-Cor 3XP	1.6	28	350	9.5	6.4	81%
Verti-Cor 3XP	1.6	29	400	12.0	8.1	88%
Metal-Cor XP	1.2	26	250	10.0	5.0	92%
Metal-Cor XP	1.6	28	350	6.6	5.6	94%
Supre-Cor 5	1.2	22	170	7.8	2.3	86%
Supre-Cor 5	1.6	26	320	5.9	3.3	89%
Tensi-Cor 110TXP	1.6	28	280	5.0	3.0	88%
Tensi-Cor 110TXP	2.4	29	400	3.8	5.8	90%
Shieldcrome 309LT	1.2	26	190	11.4	3.7	84%
Shield-Cor 4XP	2.4	29	375	5.4	7.0	84%
Shield-Cor 4XP	3.0	30	500	2.9	6.7	86%
Shield-Cor 15	0.9	17	120	3.9	0.7	75%
Shield-Cor 11	1.2	17	150	3.0	1.0	80%

The information provided in this table is based on welding with constant voltage (C.V.) GMA Welding machines. Results may vary and are influenced on the job by shielding gases used, machine settings, stick out, spatter losses, wire sniped off before starts etc.

DEPOSITION DATA

Manual Arc Electrode Consumption Calculator Guide

Instructions for Use of this Data

The following tables provide data on the approximate mass in kilograms required of the different types of electrodes for welding the various weld joints used throughout industry today. This data will aid in estimating material requirements and costs. The basis for the following tabulations is given below. Where variations from the given conditions or joint preparations are encountered, adjustments in the tabulated values must be made to compensate for such differences.

Basis of Calculations

Electrode requirements have been calculated as follows:

Where M = Mass of electrodes required
D = Mass of weld metal to be deposited
E = Proportion of electrode lost

$$M = \frac{D}{1 - E}$$

To arrive at the mass of weld metal to be deposited it is necessary to calculate first the volume of metal to be added (area of the cross section of the weld multiplied by the length). This volumetric value is converted to mass by multiplying by the factor 0.0079 kilograms per cubic centimetre for steel.

Square Butt Joints, Welded both sides

Joint Dimensions		kg of electrodes per linear metre of weld* (Approx.)	kg of weldmetal deposited per liner metre of weld (Approx.)
Plate Thickness	Root Gap (R)	With Reinforcement**	With Reinforcement**
3mm	0	0.23	0.14
	1mm	0.26	0.16
5mm	1mm	0.38	0.23
	1.6mm	0.41	0.25
6mm	1.6mm	0.48	0.29
	2.5mm	0.56	0.34

* Includes spatter losses and 50mm stub end loss.
** Height of Reinforcement = 2mm.

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DEPOSITION DATA

Horizontal-Vertical (HV) Fillet welds

Fillet Weld leg length Dimensions	kg of electrodes per linear metre of weld* (Approx.)	kg of weldmetal deposited per liner metre of weld (Approx.)
3mm	0.06	0.04
5mm	0.16	0.10
6mm	0.24	0.14
8mm	0.42	0.25
10mm	0.65	0.39
12mm	0.95	0.57
16mm	1.68	1.01
20mm	2.62	1.57
25mm	4.10	2.46

* Fillet weld figures are calculated based on true mitre fillets. Convex or overwelded fillets can increase these figures by 33% or more.

Single Vee Butt Joints, (single groove butts)

Joint Dimensions			kg of electrodes per linear metre of weld* (Approx.)	kg of weldmetal deposited per liner metre of weld (Approx.)
Plate Thickness	Root Face (F)	Root Gap (R)	With Reinforcement**	With Reinforcement**
6mm	1.6mm	1.6mm	0.39	0.23
8mm	1.6mm	1.6mm	0.63	0.38
10mm	1.6mm	1.6mm	0.87	0.52
12mm	3mm	3mm	1.33	0.80
16mm	3mm	3mm	2.22	1.33
20mm	3mm	3mm	3.37	2.02
25mm	3mm	3mm	5.14	3.08

* Includes spatter, 50mm stub ends and back gouging losses.
** Height of Reinforcement = 2mm.

Double Vee Butt Joints, Welded both sides (double groove butts)

Joint Dimensions			kg of electrodes per linear metre of weld* (Approx.)	kg of weldmetal deposited per liner metre of weld (Approx.)
Plate Thickness	Root Face (F)	Root Gap (R)	With Reinforcement**	With Reinforcement**
12mm	1.6mm	1.6mm	0.92	0.55
16mm	1.6mm	1.6mm	1.46	0.88
20mm	1.6mm	1.6mm	2.12	1.27
25mm	3mm	3mm	3.33	2.00

* Includes spatter, 50mm stub ends and back gouging losses.
** Height of Reinforcement = 2mm.

DEPOSITION DATA

Consumable Weights & Lengths Tables:

1. Gas Metal Arc Welding (GMAW - MIG) Wires for Mild and Low Alloy Steels

WIRE SIZE (mm)	0.6	0.8	0.9	1.2	1.6
gms of wire per metre	2.2	4	4.85	8.5	15.7
metres of wire per kg	450	254	200	113	63

2. Flux Cored Arc Welding (FCAW) Wires for Mild and Low Alloy Steels

WIRE SIZE (mm)	1.2	1.6	2.0	2.4
gms of wire per metre	7.5	13	21	28.5
metres of wire per kg	132	77	50	36

3. Submerged Arc Welding (SAW) Wires for Mild and Low Alloy Steels

WIRE SIZE (mm)	2.4	3.2
gms of wire per metre	35.5	63
metres of wire per kg	28	16

4. Stainless Steel Gas Metal Arc Welding (GMAW - MIG) Wires

WIRE SIZE (mm)	0.9	1.2	1.6
gms of wire per metre	5.1	9	16
metres of wire per kg	198	111	63

5. Aluminium Gas Metal Arc Welding (GMAW - MIG) Wires

WIRE SIZE (mm)	0.9	1.2	1.6
gms of wire per metre	1.7	3.1	5.4
metres of wire per kg	582	327.5	184

6. Autopak Gas Metal Arc Welding (GMAW - MIG) Wires

WIRE SIZE (mm)	0.9	1.0	1.2	1.6
gms of wire per metre	4.85	6.1	8.5	15.7
km of wire / 300kg Pack	62	49	35	16 (250kg Pack)

TECHNICAL FACTS AND FIGURES

Mathematical Symbols

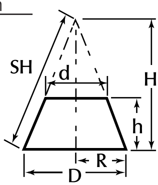
Symbol	Meaning	Symbol	Meaning
$+$	Plus or Positive	$\geq$	Greater Than or Equal To
$-$	Minus or Negative	$\leq$	Less Than or Equal To
$\pm$	Plus or Minus Positive or Negative	$\sqrt{\ }$	Square Root Of
$\times$	Multiply By	∞	Infinity
$\div$	Divided By	$\propto$	Proportional To
$=$	Equal To	$\sum$	Sum Of
$\neq$	Not Equal To	$\prod$	Product Of
$\approx$	Approximatley Equal To	Δ	Difference
$\sim$	Of the Order Of or Similar To	$\therefore$	Therefore
$>$	Greater Than	π	Pi
$<$	Less Than	$\parallel$	Parllel To
$\ngtr$	Not Greater Than	$\perp$	Perpendicular To
$\nless$	Not Less Than	$:$	Is To (Ratio)

Frustum of a Right Cone

Apex Height = H, $H = \frac{D \times h}{D - d}$

Side Height = SH,

$SH = \sqrt{R^2 + h^2}$

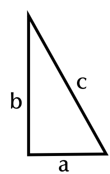


Pythagoras Theorem

$a = \sqrt{c^2 - b^2}$

$b = \sqrt{c^2 - a^2}$

$c = \sqrt{a^2 + b^2}$



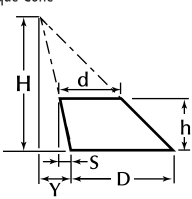
Frustum of an Oblique Cone

Apex Height = H,

$H = \frac{D \times h}{D - d}$

Horizontal Distance = Y,

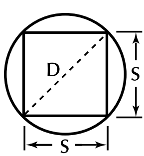
$Y = \frac{D \times S}{D - d}$



Square Plate from Circular Plate

For the area of the largest square plate that can be cut from a circular plate

$A = \frac{D^2}{2}$

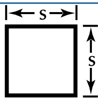
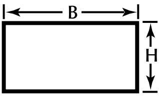
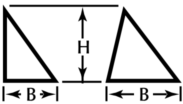
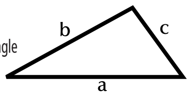
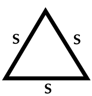
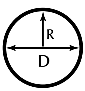
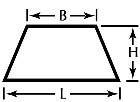
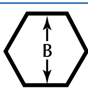
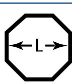


Length of side of largest square plate.

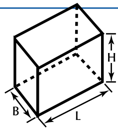
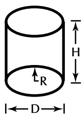
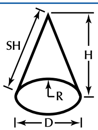
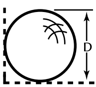
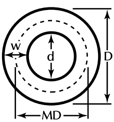
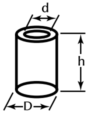
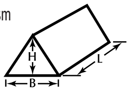
$S = 0.7071 \times D$, $D = 1.4142 \times S$

TECHNICAL FACTS AND FIGURES

Geometric Shapes - Perimeters and Areas

		Perimeter = P	Area = A
Square		P = 4 x S	A = S x S or $A = S^2$
Rectangle		P = 2 (B + H)	A = B x H
Triangle		P = Sum of 3 sides	$A = \frac{B \times H}{2}$
Scalene Triangle		P = a + b + c	$A = \sqrt{S (S - a) (S - b) (S - c)}$ S = a + b + c
Equilateral Triangle		P = 3 x S	$\frac{A = 0.433 \times S^2}{2}$
Circle		$P = \pi \times D$ $D = \frac{P}{\pi}$	$\frac{A = \pi \times D^2}{4}$ or $A = \pi R^2$
Trapezium		P = Sum of 4 Sides	$\frac{A = H \times (L + B)}{2}$
Hexagon		P = 6 x S	$A = 0.866 \times B^2$
Octagon		P = 8 x S	$A = 0.828 \times L^2$

Geometric Shapes - Surface Area, Length of Welding and Volumes

		Surface Area = SA Length of Welding = LW	Volume = V
Rectangular & Square Tanks		$SA = 2 (L \times B) + 2 (L \times H) + 2 (B \times H)$ $LW = 4L + 4B + 4H$	$V = L \times B \times H$
Cylinder		$SA = \pi \times D \times H + 2 \times \frac{\pi \times D^2}{4}$ $LW = 2 \times \pi \times D + H$	$V = \pi \times R^2 \times H$ or $V = 0.7854 \times D^2 \times H$
Cone		$SA = \frac{\pi \times D \times SH}{2} + \frac{\pi \times D^2}{4}$ $SH = \sqrt{H^2 + R^2}$ $LW = \pi \times D = SH$	$V = \frac{\pi \times R^2 \times H}{3}$ or $V = 0.2618 \times D^2 \times H$
Sphere		$SA = \pi \times D^2$	$V = \frac{\pi \times D^3}{6}$ or $V = 0.5236 \times D^3$
Annulus		$SA = \pi \times MD \times W$ or $SA = \frac{\pi}{4} (D^2 - d^2)$ or $SA = 0.7854 (D^2 - d^2)$	
Hollow Cylinder			$V = \pi \times H (D^2 - d^2)$ or $V = 0.7854 \times H (D^2 - d^2)$
Triangular Prism			$V = \frac{H \times B \times L}{2}$

1 m^3 contains 1000 litres.
1 litre of water has a mass of 1kg.
1 m^3 of water has a mass of 1000 kg

N.B. π = 3.1416

TECHNICAL FACTS AND FIGURES

Common Welding Conversion Data

Electrode Sizes		Pack Weights		Pack Weights		Lengths	
Imperial Unit	Metric Unit	Imperial Unit	Metric Unit	Metric Unit	Imperial Unit	Imperial Unit	Metric Unit
.025"	0.6mm	1lb	.45kg	1kg	2.20lb	2"	50.8mm
.030"	0.8mm	2lb	.91kg	2.5kg	5.50lb	4"	101.6mm
.035"	0.9mm	5lb	2.27kg	5kg	11.02lb	6"	152.4mm
.040"	1.0mm	10lb	4.54kg	10kg	22.05lb	8"	203.4mm
.045"	1.2mm	16lb	7.26kg	15kg	33.07lb	10"	254mm
.052"	1.3mm	20lb	9.07kg	17kg	37.48lb	12"	304.8mm
1/16"	1.6mm	25lb	11.34kg	25kg	55.11lb	14"	355.6mm
5/64"	2.0mm	30lb	13.61kg	30kg	66.14lb	15"	381mm
3/32"	2.4mm	33lb	14.97kg	50kg	110.23lb	16"	406.4mm
7/64"	2.8mm	40lb	18.14kg	60kg	132.27lb	17"	431.8mm
.120"	3.0mm	45lb	21.77kg	70kg	154.32lb	18"	457.2mm
1/8"	3.2mm	50lb	22.68kg	100kg	220.46lb	20"	508mm
5/32"	4.0mm	250lb	113.40kg	250kg	551.15lb	22"	558.8mm
3/16"	4.8mm	400lb	181.44kg	300kg	661.37lb	26"	660.4mm
7/32"	5.6mm	500lb	226.80kg	500kg	1102.29lb	30"	762mm
1/4"	6.4mm	600lb	272.16kg	810kg	1785.71lb	36"	914.4mm
5/16"	8.0mm	700lb	317.52kg	918kg	2023.81lb	39"	990.6mm
3/8"	9.5mm	1000lb	453.60kg	1000kg	2204.58lb	40"	1016mm

Conversion Data

Imperial to Metric	Metric to Imperial	Imperial to Metric	Metric to Imperial
Length		**Weight & Gas Flow**	
inch x 25.4 = mm	mm x 0.0394 = inch	oz x 28.349 = grams	grams x 0.035 = oz
inch x 2.54 = cm	cm x 0.394 = inch	stones x 6.350 = kg	kg x 0.157 = stones
feet x 0.3048 = metre	metre x 3.281 = feet	lb x 0.4536 = kg	kg x 2.2045 = lb
mile x 1.609 = km	km x 0.621 = miles	cft/hr x 0.4719 = L/min	L/min x 2.119 = cft/hr
Energy & Speed		**Pressure & Stress**	
ft.lb x 1.35582 = joules	joules x 0.73756 = ft.lb	psi x 6.895 = kPa	kPa x 0.14504 = psi
ft/min x 0.305 = m/min	m/min x 3.281 = ft/min	psi x 0.006895 = MPa	MPa x 145.04 = psi
in/sec x 2.54 = cm/sec	cm/sec x 0.394 = in/sec	psi x 0.006895 = N/mm^2	N/mm^2 x 145.04 = psi
in/min x 0.423 = mm/sec	mm/sec x 0.394 = in/min	psi x 0.0703 = kg/cm^2	kg/cm^2 x 14.223 = psi
in/min x 0.0254 = m/min	m/min x 393.78 = in/min	ksi x 6.895 = MPa	MPa x 0.14504 = ksi
Deposition Rate		**Heat Input = Joules (Volts x Amps x 60 ÷ WFS)**	
lb/hr x 0.4536 = kg/hr	kg/hr x 2.2045 = lb/hr	J/inch x 39.37 = J/metre	J/metre x .0254 = J/inch

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TECHNICAL FACTS AND FIGURES

Inch to Millimetre Conversion

INCHES	mm	INCHES
1/64	.0156	.40
	.0197	.5
1/32	.0313	.79
	.0394	1
3/64	.0469	1.19
	.0591	1.5
1/16	.0625	1.59
5/64	.0781	1.98
	.0787	2
3/32	.0938	2.38
	.0984	2.5
7/64	.1094	2.78
	.1181	3
1/8	.1250	3.18
	.1378	3.5
9/64	.1406	3.57
5/32	.1563	3.97
	.1575	4
11/64	.1719	4.37
	.1772	4.5
3/16	.1875	4.76
	.1969	5
13/64	.1969	5.16
	.2031	5.5
7/32	.2188	5.56
15/64	.2344	5.95
	.2362	6
1/4	.2500	6.35
	.2559	6.5
17/64	.2656	6.75
	.2756	7
9/32	.2813	7.14
	.2953	7.5
19/64	.2969	7.54
5/16	.3125	7.94
	.3150	8
21/64	.3281	8.33
	.3346	8.5
11/32	.3438	8.73
	.3543	9
23/64	.3594	9.13
	.3740	9.5
3/8	.3750	9.53
25/64	.3906	9.92
	.3937	10
13/32	.4063	10.32
	.4134	10.5
27/64	.4219	10.72
	.4331	11
7/16	.4375	11.11
	.4528	11.5
29/64	.4531	11.51
15/32	.4688	11.91
	.4724	12
31/64	.4844	12.30
	.4921	12.5
1/2	.5000	12.7

mm		
	.5118	13
33/64	.5156	13.10
17/32	.5313	13.49
	.5315	13.5
35/64	.5469	13.89
	.5512	14
9/16	.5625	14.29
	.5709	14.5
37/64	.5781	14.68
	.5906	15
19/32	.5938	15.08
39/64	.6094	15.48
	.6102	15.5
5/8	.6250	15.88
	.6299	16
41/64	.6406	16.27
	.6496	16.5
21/32	.6563	16.67
	.6693	17
43/64	.6719	17.07
11/16	.6875	17.46
	.6890	17.5
45/64	.7031	17.86
	.7087	18
23/32	.7188	18.26
	.7283	18.5
47/64	.7344	18.65
	.7480	19
3/4	.7500	19.05
49/64	.7656	19.45
	.7677	19.5
25/32	.7813	19.84
	.7874	20
51/64	.7969	20.24
	.8071	20.5
13/16	.8125	20.64
	.8268	21
53/64	.8281	21.03
27/32	.8438	21. 43
	.8465	21.5
55/64	.8594	21.83
	.8661	22
7/8	.8750	22.23
	.8858	22.5
57/64	.8906	22.62
	.9055	23
29/32	.9063	23.02
59/64	.9219	23.42
	.9252	23.5
15/16	.9375	23.81
	.9449	24
61/64	.9531	24.21
	.9646	24.5
31/32	.9688	24.61
	.9843	25
63/64	.9844	25
	1.0000	25.4

TECHNICAL FACTS AND FIGURES

Conversion Tables - Travel and Wire Feed Speeds

Inches per min	Feet per hour	mm per min	cm per min	Metres per min	Metres per hour
3	15	75	7.5	.075	4.5
4	20	100	10.0	.100	6.0
5	25	125	12.5	.125	7.5
6	30	150	15.0	.150	9.0
8	40	205	20.5	.205	12.3
10	50	255	25.5	.255	15.3
12	60	305	30.5	.305	18.3
14	70	355	35.5	.355	21.3
16	80	405	40.5	.405	24.3
18	90	455	45.5	.455	27.3
20	100	510	51.0	.510	30.6
22	110	560	56.0	.560	33.6
24	120	610	61.0	.610	36.6
26	130	660	66.0	.660	39.6
28	140	710	71.0	.710	42.6
30	150	760	76.0	.760	45.6
32	160	810	81.0	.810	48.6
34	170	865	86.5	.865	51.9
36	180	915	91.5	.915	54.9
38	190	965	96.5	.965	57.9
40	200	1015	101.5	1.015	60.9
45	225	1150	115.0	1.150	69.0
50	250	1275	127.5	1.275	76.5
55	276	1400	140.0	1.400	84.0
60	300	1525	152.5	1.525	91.5
65	325	1650	165.0	1.650	99.0
70	350	1775	177.5	1.775	107.0
75	375	1900	190.0	1.900	114.0
80	400	2030	203.0	2.03	122.0
85	425	2160	216.0	2.16	129.5
90	450	2285	228.5	2.29	137.5
95	475	2410	241.0	2.41	144.5
100	500	2540	254.0	2.54	152.5

Inches/ min.	Metres/ min.	Inches/ min.	Metres/ min.	Inches/ min.	Metres/ min.
110	2.80	200	5.10	425	10.80
120	3.05	225	5.70	450	11.45
130	3.30	250	6.35	475	12.10
140	3.55	275	7.00	500	12.70
150	3.80	300	7.60	525	13.30
160	4.05	325	8.25	550	13.95
170	4.30	350	8.90	575	14.60
180	4.55	375	9.50	600	15.25
190	4.90	400	10.15	625	15.90

Some of the above figures are “rounded”.

Conversion: Inches/min. x 5 = Feet/Hour
mm/min. x .6 = Metres/Hour
Inches/min. x 25.4 = mm/min.

TECHNICAL FACTS AND FIGURES

Metric Multiplying Factors

Name Prefix	Symbol	Value
Mega	M	$x10^6$
Kilo	k	$x10^3$
Hecto	h	$x10^2$
Deca	da	x10
deci	d	$x10^{-1}$
centi	c	$x10^{-2}$
milli	m	$x10^{-3}$
micro	µ	$x10^{-6}$

Symbols for Elements

Ac	Actinium	Ge	Germanium	Pr	Praseodymium
Ag	Silver	H	Hydrogen	Pt	Platinum
Al	Aluminium	He	Helium	Pu	Plutonium
Am	Americium	Hf	Hafnium	Ra	Radium
Ar	Argon	Hg	Mercury	Rb	Rubidium
As	Arsenic	Ho	Holmium	Re	Rhenium
At	Astatine	I	Iodine	Rh	Rhodium
Au	Gold	In	Indium	Rn	Radon
B	Boron	Ir	Iridium	Ru	Ruthenium
Ba	Barium	K	Potassium	S	Sulphur
Be	Beryllium	Kr	Krypton	Sb	Antimony
Bi	Bismuth	La	Lanthanum	Sc	Scandium
Bk	Berkelium	Li	Lithium	Se	Selenium
Br	Bromine	Lr	Lawrencium	Si	Silicon
C	Carbon	Lu	Lutetium	Sm	Samarium
Ca	Calcium	Md	Mendelevium	Sn	Tin
Cd	Cadmium	Mg	Magnesium	Sr	Strontium
Ce	Cerium	Mn	Manganese	Ta	Tantalum
Cf	Californium	Mo	Molybdenum	Tb	Terbium
Cl	Chlorine	N	Nitrogen	Tc	Technetium
Cm	Curium	Na	Sodium	Te	Tellurium
Co	Cobalt	Nb	Niobium	Th	Thorium
Cr	Chromium	Nd	Neodymium	Ti	Titanium
Cs	Caesium	Ne	Neon	Tl	Thallium
Cu	Copper	Ni	Nickel	Tm	Thulium
Dy	Dysprosium	No	Nobelium	U	Uranium
Er	Erbium	Np	Neptunium	V	Vanadium
Es	Einsteinium	O	Oxygen	W	Tungsten
Eu	Europium	Os	Osmium	Xe	Xenon
F	Fluorine	Ph	Phosphorus	Y	Yttrium
Fe	Iron	Pa	Protactinium	Yb	Ytterbium
Fm	Fermium	Pb	Lead	Zn	Zinc
Fr	Francium	Pd	Palladium	Zr	Zirconium
Ga	Gallium	Pm	Promethium		
Gd	Gadolinium	Po	Polonium		

TECHNICAL FACTS AND FIGURES

Comweld Rods per kg.

Diameter mm	Steel (750 mm)	Copper and Bronze (750 mm)	Aluminium (1 metre)	Cast Iron (700 mm)
1.6	84	68	185	-
2.4	37	34	82	-
3.2	21	19	46	-
5.0	9	8	19	8
6.3	5.5	5	12	4.3

Chart shows approximate number of COMWELD welding rods per kg.

Physical Properties of Metals

Element and Symbol	Atomic Weight	Melting Point °C	*Specific Heat	Density gms/cm3
Aluminium (Al)	26.97	660	0.211	2.78
Antimony (Sb)	121.76	630	0.050	6.68
Barium (Ba)	137.36	704	0.068	3.75
Bismuth (Bi)	209.00	271	0.030	9.80
Cadmium (Cd)	112.41	321	0.056	8.64
Caesium (Cs)	132.91	30	0.054	1.87
Calcium (Ca)	40.08	850	0.158	1.55
Cerium (Ce)	140.13	804	0.045	6.92
Chromium (Cr)	52.01	1800	0.111	7.1
Cobalt (Cp)	58.94	1492	0.103	8.6
Copper (Cu)	63.54	1083	0.093	8.93
Gold (Au)	197.0	1063	0.031	19.32
Iridium (Ir)	192.2	2443	0.031	22.65
Iron, Wrought (Fe)	55.85	1535	0.109	7.87
Lead (Pb)	207.21	327	0.031	11.37
Magnesium (Mg)	24.32	650	0.245	1.74
Manganese (Mn)	54.94	1240	0.107	7.44
Mercury (Hg)	200.61	-39	0.033	13.56
Molybdenum (Mo)	95.95	2625	0.065	10.0
Nickel (Ni)	58.69	1453	0.109	8.9
Platinium (Pt)	195.09	1769	0.032	21.45
Potassium (K)	39.1	63	0.177	0.862
Rhodium (Rh)	102.91	1960	0.058	12.41
Silver (Ag)	107.88	961	0.056	10.5
Sodium (Na)	22.991	98	0.296	0.971
Strontium (Sr)	87.63	770	-	2.6
Tellerium (Te)	127.61	452	0.048	6.24
Tin (Sn)	118.70	232	0.056	7.29
Titanium (Ti)	47.90	1660	0.126	4.5
Tungsten (W)	183.92	3380	0.034	19.3
Uranium (U)	238.07	1132	0.028	18.7
Vanadium (V)	50.95	1730	0.115	6.0
Zinc (Zn)	65.38	419	0.094	7.1

***In cal / gm / ˚C**

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TECHNICAL FACTS AND FIGURES

Comparison of Hardness Scales

Vickers hardness (diamond pyramid) H.V. 30 kg load	Brinell (steel ball HB) 3000 kg load	Rockwell hardness (direct reading test) HRc	Approx. Tensile Strength MPa
100	95	-	327
120	115	-	393
140	135	-	455
160	150	-	527
180	170	-	598
200	190	-	658
220	210	-	723
240	230	20	780
260	250	24	850
280	265	27	923
300	285	30	972
320	305	32	1041
340	320	34	1102
360	340	37	1166
380	360	39	1231
400	380	41	1290
420	395	43	1355
440	415	45	1417
460	435	46	1481
480	450	48	1546
500	470	49	1610
520	485	51	1674
540	505	52	1739
560	520	53	1802
580	535	54	1868
600	520	55	1922
620	535	56	1984
640	550	57	2015
660	565	58	2069
680	580	59	2108
700	590	60	2150
725	605	61	-
750	615	62	-
800	625	64	-
850	640	66	-
900	-	67	-
950	-	68	-
1000	-	69	-
1100	-	71	-
1200	-	72	-

NOTE: Figures quoted are only approximate.

TECHNICAL FACTS AND FIGURES

MASSES OF COMMON METALS

	Specific Gravity	kg / m^3	gms / cm^3
Cast Iron	7.68	7688	7.67
Steel	7.85	7849	7.85
Copper	8.94	8938	8.91
Tin Bronze	8.89	8899	8.9
Brass	8.41	8441	8.44
Zinc	7.14	6887	6.86
Aluminium	2.69	2691	2.7
Lead	11.34	11373	11.37
Magnesium	1.74	1746	1.74
Titanium	4.51	4517	4.51
Tin	7.30	7304	7.30
Stainless Steel (18/8)	7.93	7929	7.93
Stainless Steel (16%Cr)	7.75	7720	7.72
Stainless Steel (27%Cr)	7.61	7576	7.58
Aluminium bronze	8.15	8089	8.11
Phosphor bronze	8.85	8842	8.82
Manganese bronze	8.35	8329	8.30
Cupro-nickel	8.95	8970	8.94
Nickel Silver	8.75	8730	8.71
Everdur	8.55	8521	8.52
Cusilman	8.55	8521	8.52
Nickel	8.91	8858	8.85
Monel	8.85	8810	8.80
Inconel	8.55	8521	8.52

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TECHNICAL FACTS AND FIGURES

TEMPERATURE CONVERSIONS

To find a temperature conversion, read the centre column (the **bold** numbers) and read to the left side for degrees Celsius (°C) or the right side for degrees Fahrenheit (°F). eg. 10°F, reading the **bold** number, equals -12.2°C in the left column, or 10°C reading the **bold** number, equals 50°F in the right column.

°C ⟵⟶	°F / °C	⟵⟶ °F
-101	**-150**	-238
-95.6	**-140**	-220
-90.0	**-130**	-202
-84.4	**-120**	-184
-78.9	**-110**	-166
-73.3	**-100**	-148
-67.8	**-90**	-130
-62.2	**-80**	-112
-56.7	**-70**	-94
-51.1	**-60**	-76
-45.6	**-50**	-58
-40.0	**-40**	-40
-34.4	**-30**	-22
-28.9	**-20**	-4
-23.3	**-10**	14
-17.8	**0**	32
-17.2	**1**	33.8
-16.7	**2**	35.6
-16.1	**3**	37.4
-15.6	**4**	39.2
-15.0	**5**	41.0
-14.4	**6**	42.8
-13.9	**7**	44.6
-13.3	**8**	46.4
-12.8	**9**	48.2
-12.2	**10**	50
-11.7	**11**	51.8
-11.1	**12**	53.6
-10.6	**13**	55.4
-10.0	**14**	57.2
-9.44	**15**	59.0
-8.89	**16**	60.8
-8.33	**17**	62.6
-7.78	**18**	64.4
-7.22	**19**	66.2
-6.67	**20**	68.0
-6.11	**21**	69.8
-5.56	**22**	71.6
-5.00	**23**	73.4
-4.44	**24**	75.2
-3.89	**25**	77.0
-3.33	**26**	78.8
-2.78	**27**	80.6
-2.22	**28**	82.4
-1.67	**29**	84.2
-1.11	**30**	86.0
-0.56	**31**	87.8
0	**32**	89.6
0.56	**33**	91.4
1.11	**34**	93.2
1.67	**35**	95.0
2.22	**36**	96.8
2.78	**37**	98.6
3.33	**38**	100.4
3.89	**39**	102.2
4.44	**40**	104.0

°C ⟵⟶	°F / °C	⟵⟶ °F
5.00	**41**	105.8
5.56	**42**	107.6
6.11	**43**	109.4
6.67	**44**	111.2
7.22	**45**	113.0
7.78	**46**	114.8
8.33	**47**	116.6
8.89	**48**	118.4
9.44	**49**	120.2
10.0	**50**	122.0
10.6	**51**	123.8
11.1	**52**	125.6
11.7	**53**	127.4
12.2	**54**	129.2
12.8	**55**	131.0
13.3	**56**	132.8
13.9	**57**	134.6
14.4	**58**	136.4
15.0	**59**	138.2
15.6	**60**	140.0
16.1	**61**	141.8
16.7	**62**	143.6
17.2	**63**	145.4
17.8	**64**	147.2
18.3	**65**	149.0
18.9	**66**	150.8
19.4	**67**	152.6
20.0	**68**	154.4
20.6	**69**	156.2
21.1	**70**	158.0
21.7	**71**	159.8
22.2	**72**	161.6
22.8	**73**	163.4
23.3	**74**	165.2
23.9	**75**	167.0
24.4	**76**	168.8
25.0	**77**	170.6
25.6	**78**	172.4
26.1	**79**	174.2
26.7	**80**	176.0
27.2	**81**	177.8
27.8	**82**	179.6
28.3	**83**	181.4
28.9	**84**	183.2
29.4	**85**	185.0
30.0	**86**	186.8
30.6	**87**	188.6
31.1	**88**	190.4
31.7	**89**	192.2
32.2	**90**	194.0
32.8	**91**	195.8
33.3	**92**	197.6
33.9	**93**	199.4
34.4	**94**	201.2
35.0	**95**	203.0
35.6	**96**	204.8

TEMPERATURE CONVERSION FORMULA: $°C = \frac{5}{9} \times (°F - 32)$ $°F = (\frac{9}{5} \times °C) + 32$

TECHNICAL FACTS AND FIGURES

TEMPERATURE CONVERSIONS

To find a temperature conversion, read the centre column (the **bold** numbers) and read to the left side for degrees Celsius (°C) or the right side for degrees Fahrenheit (°F). eg. 250°F, reading the **bold** number, equals 121°C in the left column, or 10°C reading the **bold** number, equals 482°F in the right column.

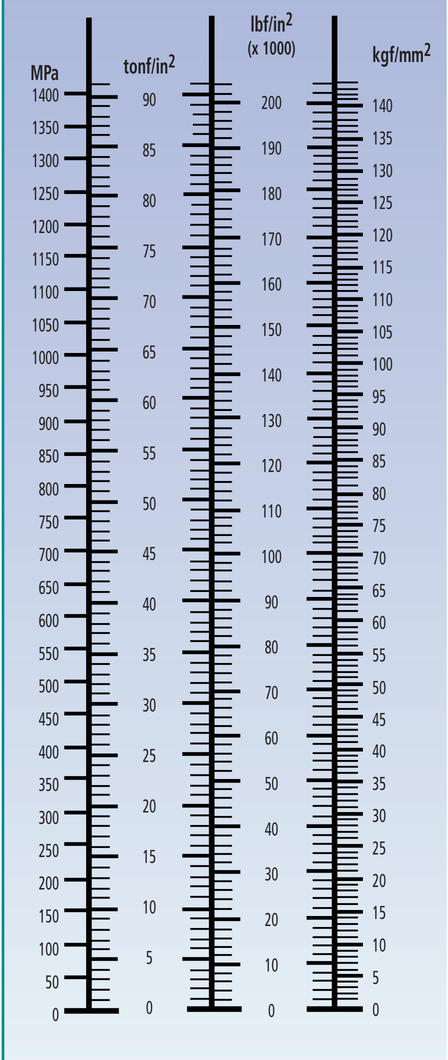
°C ⟵	⟶ °F / °C ⟵	⟶ °F
36.1	**97**	206.6
36.7	**98**	208.4
37.2	**99**	210.2
38	**100**	212
43	**110**	230
49	**120**	248
54	**130**	266
60	**140**	284
66	**150**	302
71	**160**	320
77	**170**	338
82	**180**	356
88	**190**	374
93	**200**	392
99	**210**	410
100	**212**	413
104	**220**	428
110	**230**	446
116	**240**	464
121	**250**	482
127	**260**	500
132	**270**	518
138	**280**	536
143	**290**	554
149	**300**	572
154	**310**	590
160	**320**	608
166	**330**	626
171	**340**	644
177	**350**	662
182	**360**	680
188	**370**	698
193	**380**	716
199	**390**	734
204	**400**	752
210	**410**	770
216	**420**	788
221	**430**	806
227	**440**	824
232	**450**	842
238	**460**	860
243	**470**	878
249	**480**	896
254	**490**	914
260	**500**	932
266	**510**	950
271	**520**	968

°C ⟵	⟶ °F / °C ⟵	⟶ °F
277	**530**	986
282	**540**	1004
288	**550**	1022
293	**560**	1040
299	**570**	1058
304	**580**	1076
310	**590**	1094
316	**600**	1112
321	**610**	1130
327	**620**	1148
332	**630**	1166
338	**640**	1184
343	**650**	1202
349	**660**	1220
354	**670**	1238
360	**680**	1256
366	**690**	1274
371	**700**	1292
377	**710**	1310
382	**720**	1328
388	**730**	1346
393	**740**	1364
399	**750**	1382
404	**760**	1400
410	**770**	1418
416	**780**	1436
421	**790**	1454
427	**800**	1472
432	**810**	1490
438	**820**	1508
443	**830**	1526
449	**840**	1544
454	**850**	1562
460	**860**	1580
466	**870**	1598
471	**880**	1616
477	**890**	1634
482	**900**	1652
488	**910**	1670
493	**920**	1688
499	**930**	1706
504	**940**	1724
510	**950**	1742
516	**960**	1760
521	**970**	1778
527	**980**	1796
532	**990**	1814
538	**1000**	1832

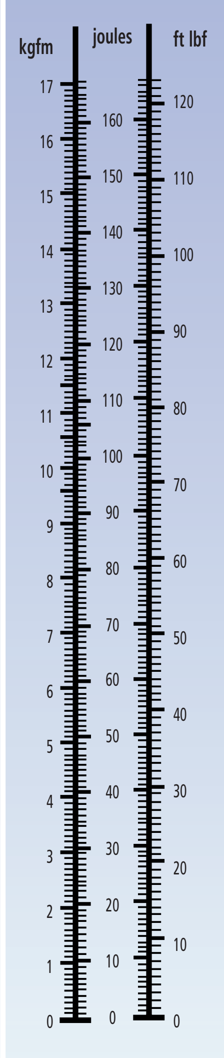
TEMPERATURE CONVERSION FORMULA: $°C = \frac{5}{9} \times (°F - 32)$ $°F = (\frac{9}{5} \times °C) + 32$

STRENGTH AND IMPACT ENERGY DATA - CONVERSIONS

STRENGTH CONVERSIONS



IMPACT ENERGY CONVERSIONS



TECHNICAL FACTS AND FIGURES

Gas Pressures - Gas Welding and Cutting

Gas Welding:		
Acetylene Pressure	100 kPa	(15 psi)
Oxygen Pressure	100 kPa	(15 psi)

Gas Cutting: (Manual)		
Acetylene Pressure	100 kPa	(15 psi)
Oxygen Pressure	200 kPa	(30 psi)

Oxygen Cylinder:		
Pressure when full	13700 kPa	(Approx. 2000 psi)

Acetylene cylinder:		
Pressure when full	1550 kPa	(Approx. 200 psi)

Note: 15 psi = 100 kPa

TEMPERATURE INDICATION

Where preheating is required, the use of temperature-indicating crayons is strongly recommended as combining reasonable accuracy with convenience. Where these are not available, however, an approximate idea of temperature may be obtained by the use of temper colours. These are colours produced on a clean surface of the material due to extremely thin oxide films, and vary in colour with temperature. It should be noted that various alloying additions can have a marked effect on oxidation, and the colours and temperatures indicated below apply only to plain carbon or low alloy steels. In order to obtain a reasonable result the surface should be freshly ground, and care should be taken to avoid applying heat directly to the ground surface.

TEMPER COLOURS	
Pale Straw	200°C
Straw	220°C
Dark Straw	230°C
Brownish Red	250°C
Violet	280°C
Dark Blue	290°C
Cornflour Blue	300°C
Pale Blue	320°C
Greyish Blue	340°C

These colours are as seen by daylight and apply to plain carbon steels. They also apply only when the steel has been at temperature for a limited period, prolonged periods producing a colour indicative of a higher temperature.

CHEMICAL NAMES AND FORMULA OF COMMON NAMES

COMMON NAME	CHEMICAL NAME	FORMULA	DESCRIPTION
Muriatic Acid or, Spirits of Salts	Hydrochloric Acid	HCl	Strongly fuming colourless liquid
Oil of Vitriol	Sulphuric Acid	H_2SO_4	Heavy, colourless, viscous liquid
Baking soda	Sodium Bicarbonate	$NaHCO_3$	White powder
Black lead	Carbon or Graphite	C	Black powder
Bleaching powder	Calcium chloro-hypo chlorite	$CaOCl_2$	White powder smelling of chlorine
Bluestone (Blue Vitriol)	Copper Sulphate	$CuSO_45H_2O$	Large blue crystals
Caustic Potash	Potassium Hydroxide	KOH	White Deliquescent powder
Caustic Soda	Sodium Hydroxide	$NaOH$	White Deliquescent powder
Chalk, Limestone, Marble	Calcium Carbonate (more or less)	$CaCO_3$	White powder; Marble-crystalline form
Epsom Salts	Magnesium Sulphate	$MgSO_47H_2O$	Small colourless crystals
Coke, Charcoal	Carbon (impure)	C	Brittle black solid
Chile Saltpeter	Sodium Nitrate	$NaNO_3$	White crystalline subst.
Condies Crystals	Potassium Permanganate	$KMnO_4$	Small purple crystals
Glauber Salts	Sodium Sulphate	$Na_2SO_410H_2O$	Large, colourless crystals
Green Vitriol	Iron sulphate	$FeSO_47H_2O$	Green crystals
Laughing Gas	Nitrous Oxide	N_2O	Colourless gas
Lime (quicklime)	Calcium Oxide	CaO	White powder
Limewater	Solution of Calcium Hydroxide	$Ca(OH)_2$	Clear, bitter liquid
Liquid Ammonia	Ammonium Hydroxide	NH_4OH	Strongly fuming liquid
Litharge	Lead Monoxide	PbO	Orange powder
Red lead	Triplumbic Tetroxide	Pb_3O_4	Fine, heavy red powder
Sal Ammoniac	Ammonium Chloride	NH_4Cl	White crystalline solid
Saltpeter (Nitre)	Potassium Nitrate	KNO_3	Colourless crystals
Slaked Lime	Calcium Hydroxide	$Ca(OH)_2$	White powder
Washing Soda	Sodium Carbonate	$Na_2CO_310H_2O$	Large white crystals
Vinegar	Acetic Acid (weak)	CH_3COOH	Brown liquid

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