

API-936 STUDY MATERIAL



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- **Scope:-**
- **The responsibilities of inspection personnel who monitor and direct the quality control process of monolithic Refractories.**
- **Monolithic refractories:-**
- **Castable or plastic refractories applied by casting, gunning, or hand/ram packing to form monolithic lining structures of any shape.**



Key elements of Quality control:-

- a) Documentation:- Owner specification and/or contractor execution plan.
- b) Material qualification:- Testing at independent or manufacturer's laboratory. Inspector directs sampling, monitors specimen preparation and witnesses testing.
- c) Applicator qualification:- Contractor demonstration of capabilities in simulated installation which is witnessed and inspected by the inspector.
- d) Installation monitoring:- Inspector monitors contractor work and test sample preparation.



Key elements of Quality control:-

- e) As-installed testing:- Inspector coordinates sampling and testing of as-installed materials.
- f) Pre-dry out inspection:- Inspector performs visual/hammer test inspection of applied linings.
- g) Dry out monitoring:- For dry out prior to normal start-up of equipment, the inspector monitors heating rates and hold times.
- h) Post dry out inspection:- Inspector performs visual/hammer test inspection of applied linings.



Responsibilities

- Owner
- The owner shall prepare a detailed specification. Which include following
- Design details.
- a)Lining products, thickness, method of application, and extent of coverage.
- b)Anchor materials, geometry, layout and weld details,Suggested color coding for metallic anchors
- c) Details of metal fiber reinforcement including dimensions, concentration, type, and metallurgy.
- d) Curing and dryout procedures, including constraints on dryout heating
- (e.g. design temperature limits and/or maximum differential temperatures that shall be maintained to avoid damaging the unit and/or components).



Responsibilities

- **Quality requirements**
 - a. Physical property requirements to be used for qualification and installation quality control by specific product, installation method and location where the product will be utilized.
 - b. Sampling frequency as product intended to use either abrasion service or other service .
 - c. Required lining thickness tolerances.
 - d. Criteria for hammer testing and the extent of cracking and surface voids permitted.
- **Approve**
 - The owner shall approve the engineering drawings, execution plan and dryout procedure prior to any installation activity.



Responsibilities

- Resolve
 - a) exceptions, substitutions, and deviations to the requirements of the execution plan, this standard, and other referenced documents;
 - b) conflicts between the execution plan, this standard, and other referenced documents.
 - c) actual or potential work deficiencies discovered and submitted by the inspector.



Contractor`s responsibility:-

- The contractor shall prepare a detailed execution plan in accordance with this standard and the requirements of the owner's specification and quality standards.
- The execution plan shall approval, and agreed to in full before work starts.



Contractor`s responsibility:-

- 1) Execution details shall include:
 - a. designation of responsible parties
 - b. designation of inspection hold points and the required advance notification to be given to the inspector
 - c. surface preparation and welding procedures.
 - d. procedures for material qualification, material storage, applicator qualification, installation and quality control.
 - e. curing (including the curing compound, if any , to be used) and dryout procedures for the completed lining system.



Contractor`s responsibility:-

2. Submission to the owner of all exceptions, substitutions, and deviations to the requirements of the execution plan, this standard and other referenced documents. Owner's approval shall be secured before implementation of the changes.
3. Scheduling of material qualification tests and delivery of those materials and test results to the site.
4. Scheduling and execution of work to qualify all equipment and personnel required to complete installation work including documentation and verification by the inspector.



Contractor`s responsibility:-

5. Preparation and identification of all testing samples (preshipment, applicator qualification, and production/ installation) and timely delivery to the testing laboratory.
6. Advance notification to the owner of the time and location where work will take place so that this information Can be passed on to the inspector.
7. Execution of installation work, including preparation of as-installed samples .



Contractor`s responsibility:-

8. Provide inspector verified documentation of installation records, including:
 - a. product(s) being applied.
 - b. pallet code numbers and location where applied.
 - c. installation crew members (designating nozzleman and gun operator when gunning).
 - d. mixing and/or gunning equipment utilized.
 - e. fiber and water percentages.
 - f. mixing details including time, temperature, and aging time (if gunned).



Contractor`s responsibility:-

- g. location and identity of samples taken for installation quality control.
 - h. shell temperatures.
 - i. weather conditions and any other unusual conditions or occurrences.
 - j. dryout records.
9. Accountability for installed refractories meeting specified standards, including as-installed testing results and lining thickness tolerance limits .



Inspector`s responsibilities:-

1. Ensure that material and applicator qualification test results are fully documented.
2. Monitor qualification, production work and dryout (when applicable) conducted by the manufacturer and contractor to ensure compliance with job specifications and agreed-to quality practices.
3. Notify the owner and the contractor of any work deficiencies or potential deficiencies. Notification shall be made according to the job specific requirements outlined in the procedures. Notification shall take place as soon as possible, and shall occur within one working day after discovery of the deficiency.



Inspector`s responsibilities:-

4. The inspector shall make no engineering decisions unless approved by the owner.
5. Conflicts between the specified execution plan and the actual installation procedures or installed refractory quality results shall be submitted to the owner for resolution.
6. Inspect and hammer test installed linings before dryout and after dryout (when possible), and report any anomalies to the owner.
7. Check and verify that accurate installation and dryout records are being documented by the contractor .
8. Record all non-conformances and/or potential problems to which the inspector has alerted the contractor and owner.



Manufacturer`s responsibilities

1. provide a compliance datasheet for each product.
2. provide material that meets the approved compliance datasheet.
3. provide all documentation required .
4. for plastic refractories, provide the minimum acceptable workability index (per ASTM C181) for successful refractory application.



Inspector Qualifications

1. The inspector shall have no commercial affiliations with the contractor or manufacturer(s).
2. The inspector shall be certified .
3. The inspector shall possess this standard, owner specifications, the project execution plan, and other specific requirements outlined by the owner, contractor , and/or manufacturer.
4. The inspector shall have working knowledge of these documents.
5. The inspector shall submit a resume documenting their experience (including similar materials and application) to the owner for approval.



Materials

- 1) Physical Property Requirements
- a) Refractories applied in accordance with this standard shall be sampled and tested to verify that the physical properties meet intended criteria, product specific physical property requirements shall be determined by agreement prior to material qualification. Qualification shall be based upon the sampling/testing procedures described in this standard.



Materials

- b) The acceptance/rejection criteria for both material and applicator qualification testing are determined by average physical properties for each sample, which shall fully meet the criteria established for that material .
- c) Acceptance/rejection criteria for as-installed testing shall be based upon criteria and procedures agreed to prior to work start. The physical properties criteria shall be extended to account for field conditions.



Materials

2) Storage

a) General

- Refractory materials are affected by moisture, humidity and elevated ambient temperatures. Proper storage of these materials is critical to the development of optimal physical properties. Shelf life is also affected by the ambient conditions. Storing refractory in the proper conditions will enhance shelf life.

b) Weather Protection

- Refractory materials shall be stored in a weather protected area. The storage facility shall prevent moisture contact with the refractory. Storage shall be on an elevated, ventilated platform. Moisture shall be directed away from the refractory.



Materials

c) Temperature

- Refractory materials shall be stored at a temperature of 40°F to 100°F (5°C to 38°C).

d) Shelf Life

- Time limits for material tests shall set the refractory shelf life requirements. if the manufacturer`s recommendations are more stringen ; the manufacturer`s recommendations shall apply.



Materials

e) Discarding Criteria

- Materials that exceed the shelf life shall be discarded. Packages with broken seals or that have become damp or wet or for plastics only ,refractory with workability index below the manufacturer`s minimum required value shall be subject to re-qualification or discard



Materials

3) Packaging and Marking

- a) General
- Packaging of refractory is important to preserving the integrity of the material. Markings provide valuable information to determine the age of material, assist in establishing water content requirements and track the placement of material as defined in the quality control program provided by the contractor.



Materials

b) Regulations and Material Safety Datasheets (MSDS)

- Refractory materials shall comply with all applicable federal, state, and local codes and regulations on storage, handling, safety, and environmental requirements.
- The latest issue of the refractory manufacturer's compliance datasheets, application instructions, and MSDS shall be available at the installation site and complied with during the installation of monolithic refractory linings.

c) Packaging

- Hydraulic bonded castable
- refractories shall be packaged in sealed, moisture-proof bags.



Materials

- Chemical setting
- refractories shall be packaged in heat-sealed plastic to assure vapor-tight enclosure. Mechanical protection shall be provided by cardboard, rigid plastic or metal outside containers.

d) Marking

- Refractory bags or containers shall be marked with the product name, batch number and date of manufacture clearly shown.
- Refractory bags or containers shall be marked with the contained refractory weight. The actual weight shall not deviate from the marked weight by more than $\pm 2\%$.
- The bag or container for cast, hand-packed or rammed mixes shall be marked with the mixing instructions.
- Each pallet shall be uniquely identified by pallet code number and code date.



Materials

4) Anchors

- Selection, installation, inspection and testing of anchors shall be in accordance with the design drawings and specifications.



Qualification and Testing

a) General

- Testing shall be in strict accordance with ASTM procedures as modified below. The laboratory conducting the test procedures shall be subject to audit and approval by the owner.
- Quality control testing shall consist of density, cold crushing strength (CCS), permanent linear change (PLC), abrasion loss (when applicable), and workability index (plastics only). Other tests required by the owner shall be as defined in the owner's specifications.



Qualification and Testing

b) Cold Crushing Strength (CCS)

- Testing shall be in accordance with ASTM C133, and the following.
- Cube loading surfaces shall be parallel to within a tolerance of $\pm 1 / 32$ in. (± 0.8 mm) and perpendicular to within a tolerance of ± 1 degree, whether cast or gunned.
- CCS shall be determined on samples that have been fired to 1500°F (815°C) .
- NOTE Green density shall be determined before drying or firing.



Qualification and Testing

- The loading head of the test machine shall have a spherical bearing block.
- For cast or hand packed specimens, the load shall be applied to either pair of faces cast against the side of the mold.
- For specimens cut from a larger cast panel, an open face shall not be used for the top or bottom (i.e. load application faces) during the test.



Qualification and Testing

- For gunned specimens, load shall be applied perpendicular to the gunning direction, in other words, on cut faces perpendicular to the face of the panel.
- Bedding material shall be non-corrugated cardboard shims, placed between the test specimen and the loading surfaces.
- New shims shall be used for each test cube. Shim dimensions shall be approximately 3 in. 3 in. 1 / 16 in. (75 mm 75 mm 1.5 mm) thick.
- Two thinner shims making up the same total thickness may be used in place of a single shim.
- Testing machine minimum sensitivity and maximum loading rate



Qualification and Testing

Castable Density lb/ft ³ (kg/m ³)	Testing Machine	
	Sensitivity ^a lbf (N)	Loading Rate ^b psi/min (kPa/s)
> 100 (1600)	500 (2222)	2500 (290) ^c
60 to 100 (960 to 1600)	100 (444)	300 (35) ^c
< 60 (960)	25 (111)	250 (29) ^c

^a If load is registered on a dial, the dial calibration shall permit reading to the nearest load value specified. Readings made within 1/32 in. (0.8 mm) along the arc described by the end of the pointer are acceptable.

^b Loading rate shall be based on the nominal cross sectional area of the test specimen.

^c 50% of the expected load may be applied initially at any convenient rate.



Qualification and Testing

C) Abrasion (Erosion) Resistance

- Testing shall be in accordance with ASTM C704 and the following.
 - a) Fire to 1500°F (815°C)
 - b) Weigh the specimens to the nearest 0.1 g.
 - c) Abrasion shall be to an original free (not troweled, molded, or cut) surface.
 - d) Use the silicon carbide only one time before discarding.
 - e) From the initial weight and volume, calculate the initial bulk density to the nearest 0.1 g/cm³. Calculate and report the amount of refractory lost by abrasion in cubic centimeters to the nearest 0.1 cc.



Qualification and Testing

D) Density

- Density shall be determined at room temperature on specimens dried or fired .
- Testing procedure shall be as follows:
 - a) measure specimen dimensions to the nearest 0.02 in. (0.5 mm) and determine the specimen volume. Weigh the specimen to the nearest 0.002 lb (1.0 g).
 - b) calculate density by dividing weight by volume and report in units of pounds per cubic foot or kilograms per cubic meter.



Qualification and Testing

E) Permanent Linear Change (PLC)

- General
- Testing shall be in accordance with ASTM C113 and the following.
 - The length of each test specimen shall be measured to the nearest 0.001 in. (0.025 mm) along the 9 in. (230 mm) dimension at each of the four edges of the specimen.
 - At room temperature, determine the green refractory dimension by measuring the length of the specimen. For heat-setting plastic refractories the green dimension shall be determined from the form dimensions. Oven dry the specimens .



Qualification and Testing

- After cooling to room temperature, measure the dried length of the specimen and then fire .
 - After cooling to room temperature, measure the fired length of specimen.
 - Green-to-dried and Dried-to-fired PLC
- a) General
- Determine the green-to-dried and dried-to-fired PLC as follows. Report the PLC as an average percent shrinkage in length for each specimen to $\pm 0.05\%$.



Qualification and Testing

b) Green-to-dried

- Determine the green-to-dried length change of each of the four edges of the specimen and
- Divide each change by the green length of that edge. Average the four values to obtain the green-to-dried PLC of the specimen.

c) Dried-to-fired

- Determine the dried-to-fired length change of each of the four edges of the specimen .
- Divide each change by the dried length of that edge. Average the four values to obtain the dried-to-fired PLC of the specimen.



Qualification and Testing

d) Workability Index

- Testing shall be in accordance with ASTM C181.
- Each sample shall consist of five specimen.



Pre-shipment Refractory Qualification Testing

a) General

- Refractories to be installed by gunning, casting, or hand/ram packing shall be tested to ensure that they comply with specified physical property requirements .
- Tested physical properties shall be density, PLC, CCS or abrasion resistance (for abrasion resistant refractory), and workability index (for plastic refractory)



Pre-shipment Refractory Qualification Testing

- b) Subject to owner`s approval,the contractor shall arrange for testing at either an independent laboratory or the manufacturer`s plant and the direct the work to assure that mixing techniques, water quality and content, ambient temperatures, mix temperatures, etc., represent those needed for production installation.
- The testing party is responsible for conducting sampling, specimen preparation, testing, and documentation of results.



Pre-shipment Refractory Qualification Testing

- c) For plastic refractories, the manufacturer shall provide the actual workability index determined seven days after manufacture and the minimum acceptable workability index for suitable installation of each plastic refractory supplied.
- Anchoring components, including metallic anchors, ceramic anchor attachments and ceramic components including ceramic anchors, and tubesheet ferrules shall be certified according to the owner's criteria.



Pre-shipment Refractory Qualification Testing

- e) The contractor shall inform the owner of testing arrangements and timing so that the owner may notify inspector to witness or spot check the testing.
- When engaged as a witness, the inspector shall select the container be tested and observe all sampling, specimen preparation, and testing.
- In cases where an independent laboratory utilized or the contractor assumes complete accountability for testing results, inspector participation may be waived or reduced by the owner.



Pre-shipment Refractory Qualification Testing

- f) Based upon the service designation, minimum testing frequency shall be as follows:
- Erosion service:- one sample per pallet or partial pallet from each production run.
 - Other services:-one sample for three pallets or less from each production run.
 - When the refractory is packaged in bags or other similar container, the sampled bag shall be randomly selected.



Forming of Refractory Test Specimens

- a) As directed by the contractor and subject to approval by the owner, the entire selected container of refractory shall be mixed and test specimens formed using metal or plastic forms of the required specimen dimensions.
- Alternatively, samples may be made to larger dimensions and then cut to the required dimensions after 24-hour cure.
- NOTE :-other similar bulk containers, a representative sample of appropriate size shall be collected from each container at the time of packaging of the production run.



Forming of Refractory Test Specimens

- b) For cast installations, refractory shall be cast in the same manner as the installation. For vibration cast installations, vibration shall be used in the forming of the test specimens.
- c) For pump cast installations, refractory shall be poured into forms.
- d) For hand packed installations, refractory shall be hand packed.



Forming of Refractory Test Specimens

- e) For gunned installations, refractory shall be gunned to produce a large panel.
 - Specimens shall be cut from the central portion of the panel (i.e. away from the edges). Alternatively, specimens may be cast or hand packed subject to owner approval of a suitable, product specific correlation on the submitted product compliance datasheet to gunned properties supplied by the manufacturer.
- f) Plastic and other ramming refractories shall be formed using a mallet or handheld pneumatic rammer.
 - Specimen formation using a pneumatic or ramming press, as described by ASTM C1054, is not permitted.



Application Period

- Refractory shall be applied within four months of the initial qualification tests. If the initial qualification period is exceeded, the refractory batch may be requalified.
- Requalification permits usage for an additional three months after each requalification test.
- Refractory older than the manufacturer's recommended shelf life shall not be used.



Re-testing

- In the event a sample fails to meet specified requirements, it may be retested once. The retest shall be conducted using a new sample representing the same pallet(s) of the same batch of refractory as the failed sample.
- Use the same testing facility, testing procedure, inspector, and inspection methods.
- A different facility may be used, subject to the owner's approval.
- If the retest is unsuccessful, the refractory represented by the sample(s) shall not be used.



Qualification of Installation Procedure and Crew/Installers

- Prior to installation, the contractor shall demonstrate that the specified quality standards will be met using the material qualified for the job, including metal and organic fibers as applicable, and the installation method, equipment and personnel to be utilized for the installation work.
- This shall be done by simulating the installation and sampling and testing the applied materials as follows.



1. Pneumatic Gunning

- A test panel shall be prepared by each nozzleman/gun operator team for each refractory being installed.
- The panel shall be inspected, sampled, and tested prior to commencing the actual installation.
- A test panel measuring 24 in. 24 in. (600 mm 600 mm) shall be fabricated.
- The panel thickness, anchors and anchor pattern shall be in accordance with the actual installation job.



1. Pneumatic Gunning

- The test panel forms shall be constructed with a removable back and sides to permit visual inspection of the installed castable.
- The method of anchor attachment shall permit removal of the forms without damage to the refractory or the anchors (e.g. use a bolt through the form). Interior surfaces of the forms shall be coated with a manufacturer approved releasing agent to facilitate removal from the refractory.
- The test panel shall be inclined 45 degrees above the horizontal and supported on a frame so that the panel's midpoint is approximately 6 ft (1.9 m) above grade.



1. Pneumatic Gunning

- The nozzleman/gun operator team shall demonstrate their abilities by gunning the test panel in this inclined position and testing.
- At least 24 hours after completion of the panel, remove the forms and inspect the panel for voids, laminations, non-uniformities, entrapped rebound, or other flaws. The panel shall then be sectioned or broken and the exposed surfaces inspected for voids, laminations, non-uniformities, and rebound entrapment.
- Test specimens shall be cut from the center of each panel and tested physical property requirements for density, PLC, and CCS or, where applicable, abrasion resistance .



1. Pneumatic Gunning

- Alternatively, with waived and measurements of the panel dimensions and weight used to determine the green density, which is then compared to a previously approved manufacturer supplied value.
- Panel dimensions and weight shall be determined before the panel is sectioned or broken.
- Satisfactory examination and test results shall serve to qualify the mixing and installation procedures and the nozzleman/gun operator teams.
- The nozzleman and gun operator shall not gun refractory materials until they are qualified.



2 Casting

- A mock-up shall be prepared by each applicator, for each mixing/ installation procedure, and for each refractory being installed.
- The mock-up shall simulate the most difficult piece of the installation work for which the subject refractory and mixing/ installation procedure will be used, or shall be of the size/shape agreed to in the documentation phase .
- The mock-up shall be inspected, sampled and tested prior to commencing the actual installation.
- The mock-up shall simulate forming and general installation procedures, including mixing, handling/delivery to the lining cavity and associated quality control requirements.



2 Casting

- Installation of refractory shall be in the same orientation to be used for the actual installation and shall simulate installation obstacles (e.g. around nozzle protrusions and beneath overhangs), and fit-up tolerances if work involves lining of sections to be fit-up at a later date.
- The refractory thickness, anchors, and anchor pattern shall be in accordance with the actual installation job.
 - For vibration cast installations, the mock-up shall demonstrate the adequacy of the vibration method, equipment and means of vibrator attachment.
 - For pouring and pump cast installations, only vibration that will be used in the actual installation shall be allowed in the mock-up.



2 Casting

- The forms shall be constructed to permit removal for visual inspection of the refractory.
- The method of anchor attachment shall permit removal of the forms without damage to the anchors or the refractory.
- Interior surfaces of the forms shall be coated with a manufacturer approved release agent to facilitate removal from the applied refractory.
- Test specimens (number, type, and preparation in accordance with 8.5) shall be prepared using material sampled from the mixes prepared for casting the mock-up.



2 Casting

- Specimens shall be formed in molds using the same level of agitation as the mock-up. physical property requirements for density, PLC, and CCS or, where applicable, abrasion resistance .
- Refractory cast in the mock-up shall be cured for 12 hours minimum prior to stripping the forms.
- Remove the forms and visually inspect the refractory. The applied lining shall be homogeneous and free of voids or segregations and shall meet specified tolerances.



2 Casting

- Satisfactory examination and test results , shall serve to qualify the applicators and the mixing and installation procedures as well as the mix water levels.
- The applicator(s) shall not cast refractory linings until they are qualified.



3. Thin Layer Abrasion (Erosion) Resistant Refractories

- A test panel 12 in. 12 in. 3 / 4 in. or 1 in. (300 mm 300 mm 19 mm or 25 mm), shall be packed by each applicator for each anchoring system and refractory being installed by the applicator.
- The test panel shall be inspected, sampled, and tested prior to commencing the actual installation.
- Panel thickness shall be the same as the lining to be installed. Mixing and application techniques (for example, pneumatic ramming, hand packing), orientation (sidewall or overhead), etc., shall be in accordance with the actual installation job.



3. Thin Layer Abrasion (Erosion) Resistant Refractories

- The hexmetal or hexalt anchoring system(s) (as used for the actual installation) shall be attached to a backing plate in such a manner that the backing plate may be removed without damaging the refractory or the anchoring system.
- For hexalt systems, perimeter forms shall also be used to contain the refractory. The backing plate (and forms, if required) shall be coated with a manufacturer approved release agent to facilitate removal from the applied refractory.
- Examination of the panel may be performed immediately after ramming, or within 24 hours, as directed by the owner.
- Remove the backing plate and examine the panel from the backside.



3. Thin Layer Abrasion (Erosion) Resistant Refractories

- The lining shall be free of voids, incomplete filling of the anchoring system and inadequate compaction of the refractory.
- Test specimens shall be prepared using materials sampled from the mixes applied. Specimens shall be formed in molds , using the same placement method as the test panel.
- Specimens shall be tested in accordance with 8.1 for density, PLC, and abrasion resistance.



3. Thin Layer Abrasion (Erosion) Resistant Refractories

- For each batch of plastic refractories the workability index shall be determined and shall exceed the minimum acceptable value for installation .
- Satisfactory examination and test results shall serve to qualify the applicator(s) and the mixing and installation procedures, as well as the mix water levels.
- The applicator(s) shall not apply refractory linings until they are qualified.



4. Thick Layer Plastic Installations [Greater Than 2 in. (50 mm)]

- A test panel shall be pneumatically ram packed by each applicator and for each refractory being installed.
- The test panel shall be inspected, sampled, and tested prior to commencing the actual installation.
- The test panel shall be 24 in. 12 in. (600 mm 300 mm) with an applied lining thickness, anchors and anchor pattern in accordance with the actual installation job.
- In the event ceramic anchors are to be used in the construction, panel shall be large enough to properly demonstrate setting one entire ceramic anchor assembly.
- The test panel shall be constructed with removable back and sides to permit visual inspection of the installed refractory.



4. Thick Layer Plastic Installations [Greater Than 2 in. (50 mm)]

- Anchors shall be attached to the form in a manner that permits removal of the backing plate without damage to the refractory or the anchoring system.
- Interior surfaces of the backing plate and forms shall be coated with a manufacturer approved releasing agent to facilitate removal from the applied refractory.
- Test panel refractory shall be installed by pneumatic ramming in a manner and orientation (e.g. sidewall or overhead) simulating the actual installation.
- After refractory installation is completed, the test panel forms and backing plate shall be removed immediately and the refractory examined from the backside.



4. Thick Layer Plastic Installations [Greater Than 2 in. (50 mm)]

- The refractory shall be free of inadequate consolidation and voids. The sample shall be sectioned and examined to confirm that the refractory plastic is free of inadequate consolidation and/or voids around the anchors.
- For plastic refractories the workability index shall be determined and shall exceed the minimum acceptable value for installation
- Satisfactory results shall serve to qualify the equipment, techniques, and applicator.
- The applicator(s) shall not ram pack refractory materials until they are qualified.



Production (As-installed) Refractory Sampling and Testing

1 . Gunning (Wet or Dry Gun)

- A minimum of one sample of applied refractory shall be gunned by each gunning crew per material per shift using a wire mesh basket.
- At least one sample shall be prepared for each lined item.
- The basket shall be approximately 12 in. 12 in. (300 mm 300 mm) and at least 4 in. (100 mm) deep but no greater than the installed refractory thickness.
- The basket shall be constructed of wire mesh with 1 / 2 in. (13 mm) square openings.



Production (As-installed) Refractory Sampling and Testing

1 . Gunning (Wet or Dry Gun) (contd...)

- The basket shall be supported on the wall where the lining application is proceeding, filled, and immediately removed.
- All loose refractory or rebound material shall be removed from the area where the basket was placed during sample preparation.
- Production samples shall remain in the same environment as actual production installation for the first 24 hours.
- The required test specimens shall be diamond saw-cut from the refractory applied in the basket.



Production (As-installed) Refractory Sampling and Testing

- 1 . Gunning (Wet or Dry Gun) (contd...)
- Testing for density, PLC, and CCS or, where applicable, abrasion resistance.
- Alternatively, panels with enclosed sides may be used in place of the wire baskets if the panel dimensions are at least 18 in. X 18 in. X 4 in. (450 mm x 450 mm x 100 mm), but no deeper than the installed refractory.
- Test specimens shall be cut from the center of the panels to avoid inclusion of rebound possibly trapped along the sides of the panels.



Production (As-installed) Refractory Sampling and Testing

2. Casting

- A minimum of one sample of the material being installed shall be cast by each mixing crew per material per shift.
- At least one sample shall be prepared for each lined item.
- Test specimens may be formed by casting directly into molds or by casting into larger forms and diamond saw cutting to the required specimen dimensions after curing.
- Production samples shall remain in the same environment as actual production installation for the first 24 hours.
- Vibration shall be used in casting of samples as applicable to simulate installation work.
- Testing for density, PLC, and CCS or , where applicable, abrasion resistance.



Production (As-installed) Refractory Sampling and Testing

3. Plastics and Thin Layer Erosion Resistant Linings

- A minimum of one sample shall be packed by each applicator per material per shift.
- At least one sample shall be prepared for each lined item.
- Test specimens (abrasion plates and linear change bars) shall be formed directly from the refractory being installed using the ramming technique used for the installation.
- The specimen test for density, PLC, and CCS or, where applicable, abrasion resistance.



Production (As-installed) Refractory Sampling and Testing

4. Acceptance/Rejection Criteria

- The average physical properties of each sample of the as-installed refractory shall meet the criteria.
- Inspector verified records shall be kept by the contractor to identify the samples and the areas of the installed lining that they represent.
- Failure to meet the criteria shall be cause for rejection of the area of the refractory lining that the sample represents.



Production (As-installed) Refractory Sampling and Testing

4. Acceptance/Rejection Criteria (Contd...)

- In the event of disagreement over the installed refractory quality , core samples may be taken from the questionable area of the applied lining and retested using the same test procedure and evaluation criteria.
- If the re- test is unsuccessful, the area of the lining represented by the sample shall be replaced.
- The contractor shall prepare records identifying and locating all areas of rejected and replaced lining (e.g. a map), the reason for the rejection, the means of repair, and the refractory used.



Production (As-installed) Refractory Sampling and Testing

5 . Test Specimen Preparation

- Based on the use designation the minimum number of refractory specimens for each sample shall be as follows.
- The specimen shall be cured as per specifications.

Physical Property	Range of Acceptable Results ^a	
	Minimum ^b	Maximum ^b
Abrasion loss	None	120%
Cold crushing strength	50%	None
Density	± 1lb/ft ³ (± 80 kg/m ³)	± 15 lb/ft ³ (± 80 kg/m ³)
Permanent linear change	Zero ^c	120%
^a Average of all specimen test results per sample. The minimum and maximum values are based upon the physical property value(s) listed on the manufacturer's compliance datasheet or other value in accordance with 5.1.2 a). ^b When the manufacturer's compliance datasheet indicates a range for the physical property, the applicable limits shall apply to the upper and lower values of the compliance datasheet range. ^c Zero means 0.00% shrinkage. Products that expand shall not be used.		



Production (As-installed) Refractory Sampling and Testing

5 . Test Specimen Preparation (contd...)

- Hydraulic bonded castable refractories shall be cured for a minimum of 24 hours after placement.
- During this period the exposed surfaces of the refractory shall be covered or sealed with an impermeable coating or material.
- Air-setting, phosphate bonded castable refractories shall be air cured, uncovered, for a minimum of 24 hours after forming.
- During this period, the refractory shall be protected from moisture.
- Heat-setting, plastic refractories shall be allowed to air dry for a minimum of 24 hours followed by oven drying in a form suitable for drying temperatures.
- Once refractory specimens have been fully cured, they shall be removed from the forms, and/or cut to required dimensions.



Production (As-installed) Refractory Sampling and Testing

5 . Test Specimen Preparation (contd...)

- The specimens shall be marked for identification with temperature resistant paint (to prevent burn-off during firing).
- Specimens shall be dried and fired as required by the testing procedure

Type of Test		Number of Specimens	Size of Specimens
For erosion service	Abrasion resistance	2	4 1/2 in. × 4 1/2 in. × 1 in. (114 mm × 114 mm × 25 mm)
	Permanent linear change	1	2 in. × 2 in. × 9 in. (50 mm × 50 mm × 230 mm)
	Density	—	Use abrasion plates or linear change bars (before their targeted test)
For other service	Cold crushing strength	3	2 in. × 2 in. × 2 in. (50 mm × 50 mm × 50 mm)
	Permanent linear change	1	2 in. × 2 in. × 9 in. (50 mm × 50 mm × 230 mm)
	Density	—	Use crushing cubes or linear change bars (before their targeted test)



Production (As-installed) Refractory Sampling and Testing

5 . Test Specimen Preparation (contd...)

- Oven drying and firing shall be as follows. a)Oven dry: hold for 12 hours minimum at 220°F to 230°F (104°C to 110°C) in a forced air, convection dryer. Heating to this level shall be in accordance with manufacturer's recommendations. Heat setting plastics shall be oven dried in the forms.
- Oven fire: heat at 300°F/h (170°C/h) maximum to 1500°F (815°C), hold for five hours at 1500°F (815°C); cool at 500°F/h (280°C/h) maximum to ambient.
- Remove heat setting plastics from the molds after oven drying and before oven firing.
- For heat-setting plastic refractories, see ASTM C1054 for procedures to remove from steel forms, drying and firing to avoid handling damage, skinning, bloating, and surface tears.



Installation/Execution

1. Surface Preparation

- Immediately before refractory installation, all surfaces to be lined shall be cleaned to meet SSPC SP-7/NACE No. 4 standards for grit blasting if rust, weld slag, oil, dirt, or other foreign materials are present on the surface to lined.
- If grit blast cleaning is required, anchor leg coverings (if present) shall be removed before the grit blast cleaning.
- After grit blast cleaning, the surfaces to be lined shall be vacuum cleaned to remove all debris and new anchor leg coverings shall be installed.
- Water shall not be used for washing unless it contains a suitable inhibitor.
- Surface cleaning in accordance with SSPC SP-3 shall be acceptable only for limited areas such as spot grinding for repairs.



Installation/Execution

2. Water Quality

- Water used for mixing in the refractory shall be potable.
- The chloride content of the water shall not exceed 200 ppm.
- When refractory is installed on stainless steel surfaces the chloride content shall not exceed 50 ppm.
- NOTE The 50 ppm limit does not apply when the stainless steel is limited to the anchoring system or metal reinforcing fibers.

3. Water-contaminated Refractory

- Containers of refractory exhibiting evidence of water contamination shall be discarded.
- Any individual container of refractory material containing hard lumps (i.e. cannot be easily broken by hand) shall be discarded.



Installation/Execution

4. Preparation for Lining Installation

a) Timing

- Refractory installation shall not begin until completion of welding, post weld heat treatment, and pressure testing.
- If the refractory installation must take place before pressure testing, all pressure retaining weld seams shall remain unlined, i.e. exposed to the testing medium.



Installation/Execution

- b) Lining Penetrations
- Structural members, nozzle extensions, and other items within the limits of the lining shall be wrapped with 1 / 8 in. (3 mm) thickness of a nonabsorbent material to prevent moisture absorption from, or bonding to, the refractory lining. The wrapping shall be taped smoothly into place.



Installation/Execution

c) Openings

- Openings shall be closed by means of sealed wood or metal-jacketed plugs, slightly tapered (smaller toward the shell), and of such dimensions to fit snugly into the openings.
- Surfaces of the plugs shall be lightly coated with a manufacturer approved release agent or covered with plastic to prevent bonding to the refractory.
- Plugs shall not be removed from the openings or disturbed until at least 24 hours after the refractory installation.



Installation/Execution

d) Obstructions

- Obstructions (e.g. scaffolding) that could interfere with the satisfactory and continuous application of the refractory lining shall be avoided.
- Nozzle Necks
- Insulating refractory in the nozzle neck shall be cast or hand packed to within 1 in. (25 mm) of the inside of the shell or head to which it is attached. The remaining 1 in. (25 mm) shall be installed monolithically with the shell lining.



Installation/Execution

- Voids or spaces to be packed with ceramic fiber blanket insulation (e.g. annular space in nozzles equipped with inner sleeves) shall be completed before the installation of refractory.
- Nozzles shall be packed to a point flush with the inside face of the shell. After nozzle packing, the ceramic fiber density shall be at least 8 lb/ft³ (64 kg/m³).
- Ceramic fiber blanket insulation shall be used only where specifically shown on the approved drawings.



Installation/Execution

- **Anchor Preparation**
- Anchors shall be cleaned of spatter and foreign materials before refractory is installed.
- For multilayer linings, anchors for the hot-face layer shall be protected and kept free of all backup refractory and foreign material before application of the hot-face layer.
- If anchor leg coverings are required, placement of the coverings shall be confirmed immediately before refractory placement.



Installation/Execution

e) Equipment Cleaning

- Mixers, guns, conveyors, hoses, and all other equipment shall be thoroughly cleaned before use.
- Equipment shall be cleaned at each material change, shift change, and more often if buildup of castable takes place.
- Cleaning is required between each mix of phosphate-bonded refractory.
- For non-phosphate bonded refractories, the cleaning interval shall be such as to prevent buildup of refractory materials on the mixer internals (including the drum). For low-moisture (low-cement) mixes and other refractories sensitive to water content, excess water shall be removed after each batch.
- All tools used in mixing, transporting, and applying the refractory lining shall be cleaned after each batch and kept free of all deleterious materials.



Installation/Execution

f) Site

- The work area shall be kept clean and protected to ensure that lining installation can proceed in an orderly manner without incorporating dirt, debris, rain, or other deleterious material into the lining.



Installation/Execution

5. Application Temperature

- The temperature of the air and shell at the installation site shall be between 50°F and 90°F (10°C and 32°C) during refractory installation and for 24 hours thereafter . Shading and enclosure shall be used to protect against extremes in temperature, sun exposure, and weather (e.g. wind and rain). 9.5.2 For cold weather conditions, heating and/or external insulation may be used to maintain temperatures above the minimum requirement.
- For hot weather conditions, shading, water spraying the unlined surface and/or air conditioning may be used to maintain temperatures below the maximum requirement.
- Temperature limits for refractory and mix water shall be in accordance with the manufacturer's requirements. In the absence of manufacturer's mix temperature limits, mix temperature shall be between 60°F and 80°F (15°C and 27°C).



Installation/Execution

6. Gunning

- a) Dry Gunning
- Pre-wet the refractory by mixing with water prior to charging into the gun. Pre-wetting reduces dusting and segregation and helps avoid plugging in the feed hose. Optimum water addition, mixing time, and aging of the pre-wetted material shall be in accordance with the manufacturer's qualification testing.
- Gunning equipment shall provide a smooth and continuous supply of water and material to the nozzle and shall not contribute to laminations, voids, rebound entrapment, or other deleterious effects in the installed lining.



Installation/Execution

- Shotboards or perpendicular edge cuts shall be used to terminate work areas. When stoppages greater than 20 minutes are encountered, or initial set is determined by the inspector, only full thickness lining shall be retained.
- Begin gunning at the lowest elevation, building up the lining thickness gradually over an area of not more than 10 ft² (1 m²) to full thickness. Work in an upward direction to minimize the inclusion of rebound. Rebound material shall not be reused.
- Downhand gunning beyond 30 degrees below horizontal is prohibited. The refractory shall be placed by an alternative placement technique such as casting, hand packing, or repositioning to avoid downhand gunning.



Installation/Execution

- Shotboard height and/or depth gauges shall be used for thickness measurement. After gunning and confirmation of sufficient coverage, the refractory shall be trimmed (cut-back) in a timely manner with a serrated trowel or currycomb.
- Cut-back shall be performed when the surface is not damaged by the cut-back techniques (15 to 20 minutes after placement is typical) , and before initial set occurs.
- Interrupted build-up of lining thickness is not permitted after the initial set, defined as either the surface being exposed for more than 20 minutes or becoming dry to the touch, whichever occurs first.



Installation/Execution

b)Wet Gunning

- Wet gunning is a unique installation procedure that requires specialized equipment and a different skill set than is common in refractory installation. When wet gunning is established as the more suitable installation technique the contractor, in conjunction with the refractory manufacturer, shall prepare a detailed installation procedure, and present it to the owner for approval.
- All quality control elements defined in this standard shall apply to the application of refractory by wet gunning.
- Optimum water addition at the mixer, mixing time, and the rate of flocculating agent addition shall be in ones and the applicator qualification testing.



Installation/Execution

- Gunning equipment shall provide a smooth and continuous supply of material and flocculating agent to the nozzle and shall not contribute to laminations, voids, or other deleterious effects in the installed lining.
- Shotboards or perpendicular edge cuts shall be used to terminate work areas. When stoppages greater than 20 minutes are encountered, or initial set is determined by the inspector, only full thickness lining shall be retained.
- Begin gunning at the lowest elevation, building up the lining thickness gradually over an area of not more than 10 ft² (1 m²) to full thickness. Work in an upward direction.



Installation/Execution

- Shot board height and/or depth gauges shall be used for thickness measurement. After gunning and confirmation of sufficient coverage, the refractory shall be trimmed (cut-back) in a timely manner with a serrated trowel or currycomb.
- Cut-back shall be performed when the surface is not damaged by the cut-back techniques (15 to 20 minutes after placement is typical) , and before initial set occurs.
- Interrupted build-up of lining thickness is not permitted after the initial set, defined as either the surface being exposed for more than 20 minutes or becoming dry to the touch, whichever occurs first.
- present it to the owner for approval. All quality control elements defined in this standard shall apply to the application of refractory by wet gunning.



Installation/Execution

- Optimum water addition at the mixer, mixing time, and the rate of flocculating agent addition shall be in accordance with the manufacturer's recommendations and the applicator qualification testing.
- Gunning equipment shall provide a smooth and continuous supply of material and flocculating agent to the nozzle and shall not contribute to laminations, voids, or other deleterious effects in the installed lining.
- Shotboards or perpendicular edge cuts shall be used to terminate work areas. When stoppages greater than 20 minutes are encountered, or initial set is determined by the inspector, only full thickness lining shall be retained.



Installation/Execution

- Begin gunning at the lowest elevation, building up the lining thickness gradually over an area of not more than 10 ft² (1 m²) to full thickness.
- Work in an upward direction.
- Shot board height and/or depth gauges shall be used for thickness measurement. After gunning and confirmation of sufficient coverage, the refractory shall be trimmed (cut-back) in a timely manner with a serrated trowel or currycomb.



Installation/Execution

- Cut-back shall be performed when the surface is not damaged by the cut-back techniques (15 to 20 minutes after placement is typical) , and before initial set occurs.
- Interrupted build-up of lining thickness is not permitted after the initial set, defined as either the surface being exposed for more than 20 minutes or becoming dry to the touch, whichever occurs first.



Installation/Execution

7 .Casting

- Forming shall be sufficiently strong to support the hydraulic head of wet refractory that will be retained and to resist any imposed mechanical loads, such as vibration. The forms shall be waterproof and leak free.
- Dimensional tolerances shall meet specified requirements.
- A manufacturer approved release agent shall be used to facilitate stripping of the forms.
- Refractory shall be mixed using the procedures, equipment, and water levels demonstrated in the material and applicator qualification tests.



Installation/Execution

- For casting and vibration casting, the mixer capacity shall be sufficient to facilitate placement with no more than 10 minutes delay between successive mix batches.
- For pump casting, mixer capacity shall be sufficient to allow for continuous pump operation without stops and starts to wait for material.
- For vibration casting, two or more vibrators shall be mounted externally on the equipment or component to be lined.
- Vibrators shall be attached by strapping or a similar method; do not attach vibrators to nozzles, welded lugs, or other components.
- Vibrators shall have adequate force to move and consolidate the material being vibrated.



Installation/Execution

- Each vibrator shall be independently controlled to focus the vibration and prevent segregation due to over vibration.
- Vibrator selection, number, placement, and method of attachment shall be included in the installation procedure, approved by the owner and demonstrated in the mockup casting
- For pouring or pump casting, submersion vibrators or rodding may be used to aid refractory flow and filling of the formed enclosure.
- Self-leveling castables shall not be vibrated.



Installation/Execution

8. Thin Layer Abrasion (Erosion) Resistant Linings

- General Chemical setting, erosion resistant refractories shall be mixed in a planetary mixer, such as those manufactured by Hobart .
- The mixer shall have stainless steel paddles and bowls. Tools shall also be stainless steel. Mixing shall be in strict accordance with the manufacturer's recommended procedures, using water levels determined during material and applicator qualification testing.
- Refractory shall be compacted using a handheld reciprocating pneumatic rammer, or a rubber mallet, and/or wood block as demonstrated in the applicator qualification tests.



Installation/Execution

- During placement, refractory shall be fully compacted in and around the anchor supports and, for hexalt anchoring systems, into the previously installed lining before it begins to set up, to form a homogeneous lining structure free of voids and laminations.
- The initially placed thickness shall be greater than the desired thickness.
- The full depth of the refractory lining shall be placed in one continuous operation (e.g. the initial placement shall completely fill the hexmetal biscuit).
- After refractory consolidation, overfill shall be removed flush with the tops of the hexmetal or hexalt anchors using a trowel or curry comb and discarded.



Installation/Execution

- The surface shall be tamped, as necessary, to remove imperfections such as surface tearing and pull away defects.
- Water slicking of the lining surface is not permitted.
- Water used to clean tools shall be dried off prior to use of the tools on the refractory.



Installation/Execution

9) Plastic Refractories

- Plastic refractories shall be installed at the manufacturer's recommended consistency.
- Field water addition or reconditioning is not permitted.
- Reconditioning shall be performed by the manufacturer under controlled plant conditions, and the reconditioned material shall be fully requalified
- Plastic refractory shall be removed from the container/plastic wrap only when ready for application.



Installation/Execution

- Contents shall be placed on a clean surface for cutting and/or separating precut slices.
- The work surface shall be cleaned and maintained to avoid contaminating fresh refractory with dried-out material from previous cutting or separating operations.
- Under no circumstances shall dry or crumbly material be installed.



Installation/Execution

10. Thick Layer Plastic Linings

- Plastic refractories shall be installed at the manufacturer's recommended consistency.
- Field water addition or reconditioning is not permitted. Reconditioning shall be performed by the manufacturer under controlled plant conditions, and the reconditioned material shall be fully requalified .
- Plastic refractory shall be removed from the container/plastic wrap only when ready for application.
- Contents shall be placed on a clean surface for cutting and/or separating precut slices.



Installation/Execution

- The work surface shall be cleaned and maintained to avoid contaminating fresh refractory with dried-out material from previous cutting or separating operations.
- Under no circumstances shall dry or crumbly material be installed.
- Refractory shall be ram packed in successive layers of undensified slabs laid perpendicular to the hot face using a reciprocating pneumatic rammer.
- Each slab shall be fully consolidated into a uniform mass with the previously placed slab, compacting the material in and around the anchor supports to form a homogeneous lining structure free of voids and laminations.
- The initially placed thickness shall be greater than the desired lining thickness.



Installation/Execution

- After refractory consolidation, the lining shall be trimmed to the desired lining thickness using a trowel or currycomb.
- Cutback material may be reused if the material has not been contaminated and if workability characteristics are not diminished.
- The trimmed surface shall be tamped, as necessary, to remove imperfections such as surface tearing and pull away defects.
- Water slicking of the lining surface is not permitted.



Installation/Execution

- Water used to clean tools shall be dried off prior to use of the tools on the refractory.
- After plastic lining has been trimmed to proper thickness venting shall be carried out with a pointed rod.
- Shrinkage cracking shall be accommodated by the use of cut or formed control joints at a spacing recommended by the manufacturer.



Installation/Execution

10 . Metal Fiber Reinforcement

- Metal fiber reinforcement shall be used only when specified by the owner .
- Fiber additions shall be uniformly dispersed in the castable, without agglomeration.
- Details of fiber dimensions, concentration, and metallurgy shall be specified in the documentation
- If metal fiber is added during installation mixing the procedure shall be as follows: a)load castable into mixer and pre-mix;
- add pre-wet or mixing water;
- using a dispersing device, such as 1 / 2 in. (13 mm) hardware mesh, sieve the fibers into the castable with the mixer operating.



Installation/Execution

11 .Organic Fibers

- Organic fibers to facilitate moisture removal from refractory linings during dryout may be used with owner approval.
- Fiber addition shall be performed during manufacture of the castable or plastic refractory.



Installation/Execution

12. Interruption of Application

- If application of hydraulic bonded or chemical setting refractory is interrupted, the refractory lining shall immediately be cut-back to the shell between anchors with a steel trowel.
- Cutback shall be made at a right angle to the shell or in accordance to other construction joint configuration as indicated on detail drawings, and at a location where the full refractory thickness has already been applied.
- Discard all material beyond the cut and material left in the gun, hose, containers, and/or mixer for more than 20 minutes.
- Plate surfaces shall be cleaned of all refractory lining materials.
- Dislodged anchor leg coverings shall be replaced.



Installation/Execution

- During the period of interruption in application, curing of the refractory lining already applied shall be
- If installation is halted for the day, all openings in the item being lined shall be covered, closed, and sealed.
- Immediately before resuming refractory application, the exposed surface of the refractory lining to which a bond must be made shall be cleaned of all loose refractory material, roughened, and thoroughly wetted with water or coated with a manufacturer approved membrane curing compound
- Alternatively, a bonding agent such as a weak phosphoric acid solution or phosphate-bonded mortar may be used.
- If application of heat-setting plastic refractory is interrupted for less than 8 hours, pre-moistened cloth or burlap shall be used to keep the mating surface hydrated until work can progress.



Installation/Execution

13. Curing

- Curing shall be in accordance with the manufacturer's recommendation, for a minimum of 24 hours at 50°F to 90°F (10°C to 32°C), before moving the piece, stripping the forms, or heating.
- For chemical setting refractories, the lining surface shall remain uncovered and free from contact with moisture during the curing period.
- For hydraulic bonded castables, sealing and/or excess moisture shall be provided in accordance with one of the following methods.



Installation/Execution

- a) Apply a manufacturer approved membrane-type (non-reactive) curing compound to all exposed surfaces before the surface is dry to the touch. No part of the lining shall be allowed to air dry more than 1 hour prior to the application of curing compound.
- The curing compound shall be nonflammable, non-toxic, and contain pigmentation that allows for complete visual inspection of coverage. The compound shall burn off at a temperature of 150°F to 200°F (65°C to 95°C).



Installation/Execution

- b) Wetting the exposed surfaces with a fine mist of water spray within one hour of installation and then at approximately 2-hour intervals, such that all surfaces shall be maintained wet to the touch throughout the curing period. Ensure that refractory components are not washed out or dislodged.
- c) Covering the exposed surfaces with polyethylene or a damp cloth within one hour of installation. The covering shall be in contact with, but not sticking to the refractory surface. If a damp cloth is used, it shall be maintained damp throughout the curing period.



Installation/Execution

- d) No coverage is required on formed surfaces as long as the forms are retained for the full 24-hour curing period.
- Plastic refractories do not require air curing. They shall be kept dry and protected from freezing conditions prior to the initial firing.
- Manufacturer`s recommendations shall be used to properly protect phosphate bonded plastics that will remain at ambient conditions for prolonged periods of time before heat curing.



Installation/Execution

14 .Repairs

a) General

- Areas seemed defective shall be repaired.
- Sections of the lining below the minimum thickness shall be cut out entirely and replaced.
- Additional material shall not be placed over previously applied material to build up to the required thickness.
- In a multilayer-lining, the hot face shall be removed without removing or disturbing the backup lining.
- The contractor shall prepare records identifying and locating all repaired areas and field joints (e.g. a map).
- The record shall include the reason for all repairs and the means of repair along with the refractory used.



Installation/Execution

b)Repair Procedures

General

- All proposed materials and methods of repair shall be approved by the owner before the repair is made.
- Immediately before placement of the new refractory, the sound refractory material adjacent to the repair area shall be cleaned of debris, roughened, and completely prewetted with potable water, membrane curing compound, phosphate-bonded mortar, or a weak phosphoric acid.
- Anchors and shell shall be cleaned of refractory or other debris and new anchor leg coverings installed on the anchors where applicable.
- If the anchors or the attachment weld are damaged, the anchor shall be replaced in accordance with the original installation.



Installation/Execution

c) Monolithic Lining

- With the exception of surface bubble defects , unacceptable refractory lining shall be cut at a right angle to the shell and laterally to the acceptable lining and removed. The shell shall not be damaged.
- Areas removed for repair shall have at least one anchor completely exposed. If not, a new anchor shall be installed.
- The recommended area to be removed for repair shall be sufficient to expose three, noncontinuous anchors.
- Corners shall be rounded to a smooth, generous contour throughout the depth of the refractory.
- When repair of surface bubble defects is required, they shall be repaired by packing with a phosphate- bonded castable.
- Metal fibers shall not be used in this type of repair. The surface shall be screed flush with the adjacent refractory surface.

Installation/Execution

d) Thin Erosion-resistant Lining

- Defective refractory in hexmetal lining shall require complete removal and replacement of all affected biscuits.



Dryout

a) Dryout Procedure

- The contractor shall develop a dryout procedure and submit it to the owner for approval.
- The dryout s dryout requirements and the requirements of this standard. In the absence of refractory manufacturer requirements.
- The dryout procedure shall include heat up/cool down rates for all control temperature indicators, location of and maximum temperature difference between temperature indicators, and shall ensure adequate flow of heated air over the entire refractory surface.
-



Dryout

- The dryout plan for complex vessels or vessel/duct/pipe systems which involve more than one burner, more than two flue gas exit points or eight or more thermocouples, shall be reviewed by an engineer experienced in dryout of complex systems.
- Initial heating of refractory linings shall be performed by temporary equipment such as portable burners or electric heating elements.
- When temporary heating devices are not practical, process heating devices are an acceptable alternative. Flame impingement and radiant heating are prohibited.
- Cold wall refractory lined components shall be dried out by heating from the refractory hot face only, in accordance with the approved dryout procedures.



Dryout

- Hot wall refractory lined components shall be dried out by application of heat from either the inside or outside surface or by placement within an oven and heating from both sides, in accordance with the approved dryout procedures.
- Heating shall be controlled using temporary thermocouples to monitor gas temperatures throughout the lined area(s).
- Thermocouples shall be located within 1 / 2 in. (13 mm) of the refractory surface. Place thermocouples to detect any stagnant area(s).
- When temporary thermocouples are not practical (e.g. dryout performed as part of startup), process thermocouples may be an acceptable alternative if they are capable of low temperature accuracy and located in appropriate areas.



Dryout

- Heating rates shall be monitored by thermocouples closest to the heat source. The hold temperatures and durations shall be achieved at all thermocouples including those at gas exits of the installed refractory.
- Thermocouples shall also be provided to protect design temperature limits of the unit and/or components
- When cool-down is included in the dryout work scope, cooling rates shall not exceed 100°F/h (56°C/h).



Dryout

b) Dryout Schedule

- Generally it is the provisions for determining safe and cost effective dryout schedules for conventional cement bonded castables.
- Dryout is the initial heating of castable refractory linings in order to remove retained water from within the refractory without adversely affecting its structure or physical properties.
- The procedure shall be efficient and provide for cost effective execution with minimal impact on the service factor of the process unit in which the refractory is installed.



Dryout

c) Dryout Index

- Dryout is described in schedules or procedures by heating rates, target temperatures, and hold times. For the purpose of this standard, these requirements are based upon gas temperatures at the surface of the lining that will see the greatest heat during service.
- Heat sources and monitoring of gas temperatures affecting the dryout



Dryout

- Refractory products with dryout requirements differing from those defined by Table 5 shall be rated by the dryout index.
- To provide a comparative basis, the dryout index shall be defined as the duration time in hours that is required for initial heating from 50°F to 1300°F (10°C to 710°C), including recommended heating rates and holding times.
- The Index shall be based on single-layer linings 5 in. (127 mm) thick, applied and dried out in accordance with this standard.
- Details of actual heating rates and holding times within the overall duration defined by the dryout Index shall be determined prior to installation work



Dryout

- Modifications to account for greater thickness and/or dual-layer designs shall be resolved at that time.
- When drying out a unit or vessel that has multiple refractories, schedules shall be based on the refractory or lining system that has the longest duration requirement for the maximum thickness at each stage of the dryout.
- typical dryout schedules for conventional castable refractories with a density of 140 lb/ft³ (2240 kg/m³) or less is as follows.



Dryout

Heating Stage	Refractory Density		
	Less Than 75 lb/ft ³ (1200 kg/m ³)	75 lb/ft ³ to 100 lb/ft ³ (1200 kg/m ³ to 1600 kg/m ³)	101 lb/ft ³ to 140 lb/ft ³ ^d (1601 kg/m ³ to 2240 kg/m ³)
Initial temperature to first hold ^e	Heat at 100°F/h (56°C/h) Hold at 250°F to 300°F (122°C to 150°C) Hold 1 h/in. (1 h/25 mm) of refractory thickness	Heat at 75°F/h (42°C/h) Hold at 250°F to 300°F (122°C to 150°C) Hold 1 h/in. (1 h/25 mm) of refractory thickness	Heat at 50°F/h (28°C/h) Hold at 250°F to 300°F (122°C to 150°C) Hold 1 h/in. (1 h/25 mm) of refractory thickness
Ramp to next hold	Heat at 100°F/h (56°C/h) Hold at 600°F to 700°F (318°C to 374°C) Hold 1 h/in. (1 h/25 mm) of refractory thickness	Heat at 75°F/h (42°C/h) Hold at 600°F to 700°F (318°C to 374°C) Hold 1 h/in. (1 h/25 mm) of refractory thickness	Heat at 50°F/h (28°C/h) Hold at 600°F to 700°F (318°C to 374°C) Hold 1 h/in. (1 h/25 mm) of refractory thickness
Ramp to next hold	Heat at 100°F/h (56°C/h) to operating temperature	Heat at 75°F/h (42°C/h) Hold at 1000°F to 1050°F (542°C to 565°C) Hold 1 h/in. (1 h/25 mm) of refractory thickness	Heat at 50°F/h (28°C/h) Hold at 1000° to 1050°F (542°C to 565°C) Hold 1 h/in. (1 h/25 mm) of refractory thickness
Ramp to next hold		Heat at 75°F/h (42°C/h) to operating temperature	Heat at 75°F/h (42°C/h) to operating temperature
Dryout index ^f	23 hours	31 hours	40 hours

^a See 10.1.1.

^b These rates only apply when the curing temperature is between 50°F (10°C) and 90°F (32°C).

^c Conventional castable refractories having a "normal" cement content, i.e. greater than 2.5% CaO.

^d For refractories with densities higher than 140 lb/ft³ (2240 kg/m³) consult manufacturer.

^e Initial temperature not to exceed 200°F (94°C).

^f The dryout index is based on a refractory thickness of 5 in. (127 mm), an operating temperature of 1300°F (710°C), and heating from the refractory side only. It is further based on standard accepted dry out practice in a well exhausted configuration.



Color Coding for Metallic Anchors

1. Scope

- The purpose of this color coding guideline is to provide a method for visual identification of metallic anchors used in refractory linings by a general alloy classification.
- Only submerged anchors made of rods and castings shall be color coded. Hexmet al and hexalt anchors used in thin erosion-resistant linings and various designs of stud and washer anchors for ceramic fiber linings are not included in this specification as they can be best identified by stamping.
- Identification by this method is not a substitute for PMI (positive material identification) or other permanent manufacturer's markings or labeling t so, it is not intended that the color coding will be resistant to fading under all conditions including exposure to high-temperature operations.



Color Coding for Metallic Anchors

- The principal purpose is to ensure identification of the alloy of the anchor to facilitate proper installation, inspection, and storage for future usage.
- Many people are lacking color discrimination.
- Users of this specification shall therefore ensure that personnel involved in color identification are able to discriminate colors.
- Marking Material Requirements
- Paint shall be used for the marking of color codes. Paint is specified for efficiency and cost effectiveness. Other marking materials, such as dye, ink, and colored labels, are permissible provided the marking material meets the durability, identification, chemistry, and safety requirements



Color Coding for Metallic Anchors

- Paints used for identification markings shall be durable and of identifying colors. Markings of the color-coded anchors shall not fade when stored indoors in a standard warehouse.
- Paint material shall be acrylic, alkyd modified acrylic, or alkyd enamels capable of fast drying.
- Paint shall be free of cadmium, chromium, and lead. Also, the paint shall not contain copper, tin, zinc, chloride, sulfide, and other undesirable elements in any significant quantities.



Color Coding for Metallic Anchors

- The marking requirements described in this color codification shall be applied by the manufacturer (supplier or vendor as applicable) and are supplemental to any other marking and labeling standards and specifications under which the materials may be manufactured.
- The marking(s) shall be applied after completion of all anchor heat treatments (e.g. solution annealing).
- Paints contain solvents that pose safety and health hazards. Therefore, paint shall be applied in fire protected, well ventilated areas.
- Applicators shall wear proper respirators and other safety gear.
- The surface to be color coded shall be cleaned and free of dirt, loose scale, and oil.



Color Coding for Metallic Anchors

- Color Code Requirements
- Marking for color coding shall be by painting one or more stripes onto the top part of each anchor leg.
- Each stripe shall be of single solid color
- For two-component anchors, such as a V screwed or welded onto a stud, each part of the anchor shall be color coded.



Anchor Material	Color of Stripe ^a
Carbon steel	None
Carbon steel, killed	2 solid green
304	1 solid black
304L	2 solid black
309	1 solid black, 1 solid brown
310	1 solid green, 1 solid orange
316	1 solid gray
316L	2 solid gray
321	1 solid pink
347	1 solid brown
405	1 solid green, 1 solid black
410S	1 solid green, 1 solid brown
Inconel 600	2 solid blue
Incoloy 800	1 solid black, 1 solid orange

^a In accordance with Pipe Fabrication Institute (PFI) ES22, *Recommended Practices for Color Coding of Piping Materials*, 511 Avenue of America's, Suite 601, New York, New York 10011, www.pfi-institute.org.



Color Coding for Metallic Anchors

Table B.2—Dimension of Color Stripe

Color Stripe	Anchor Length	
	2 in. (50 mm) or Less	Greater Than 2 in. (50 mm)
Single Stripe	Full top half of the anchor.	1 in. to 2 in. (25 mm to 50 mm) wide in top half of the anchor.
Double Stripe	Two equal size bands with $\frac{1}{8}$ in. (3 mm) minimum gap between bands and at least $\frac{1}{2}$ in. (13 mm) above the bottom of the anchor.	Two equal-size bands with $\frac{1}{4}$ in. (6 mm) minimum gap between bands in the top half of the anchor.



