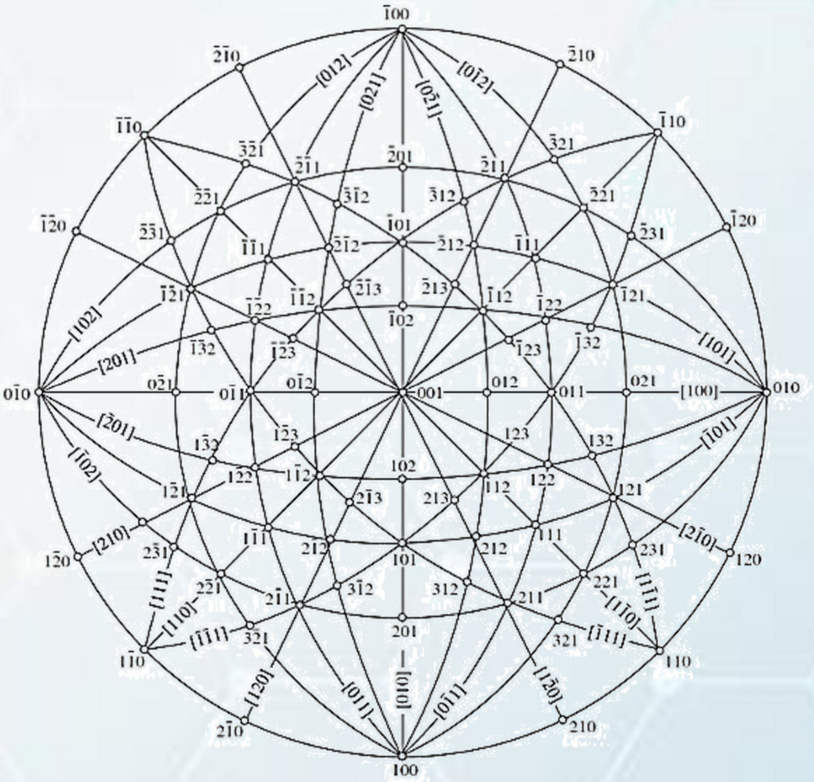
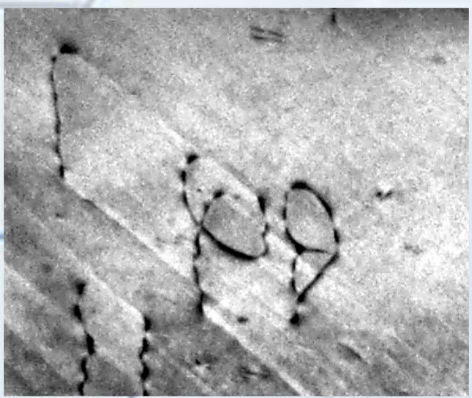
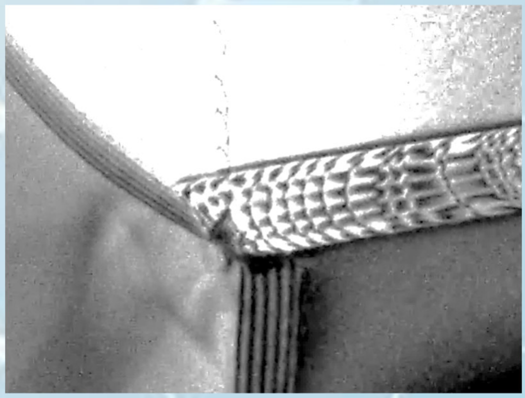


Physical Metallurgy

Crystal Defects - Dislocations in metals



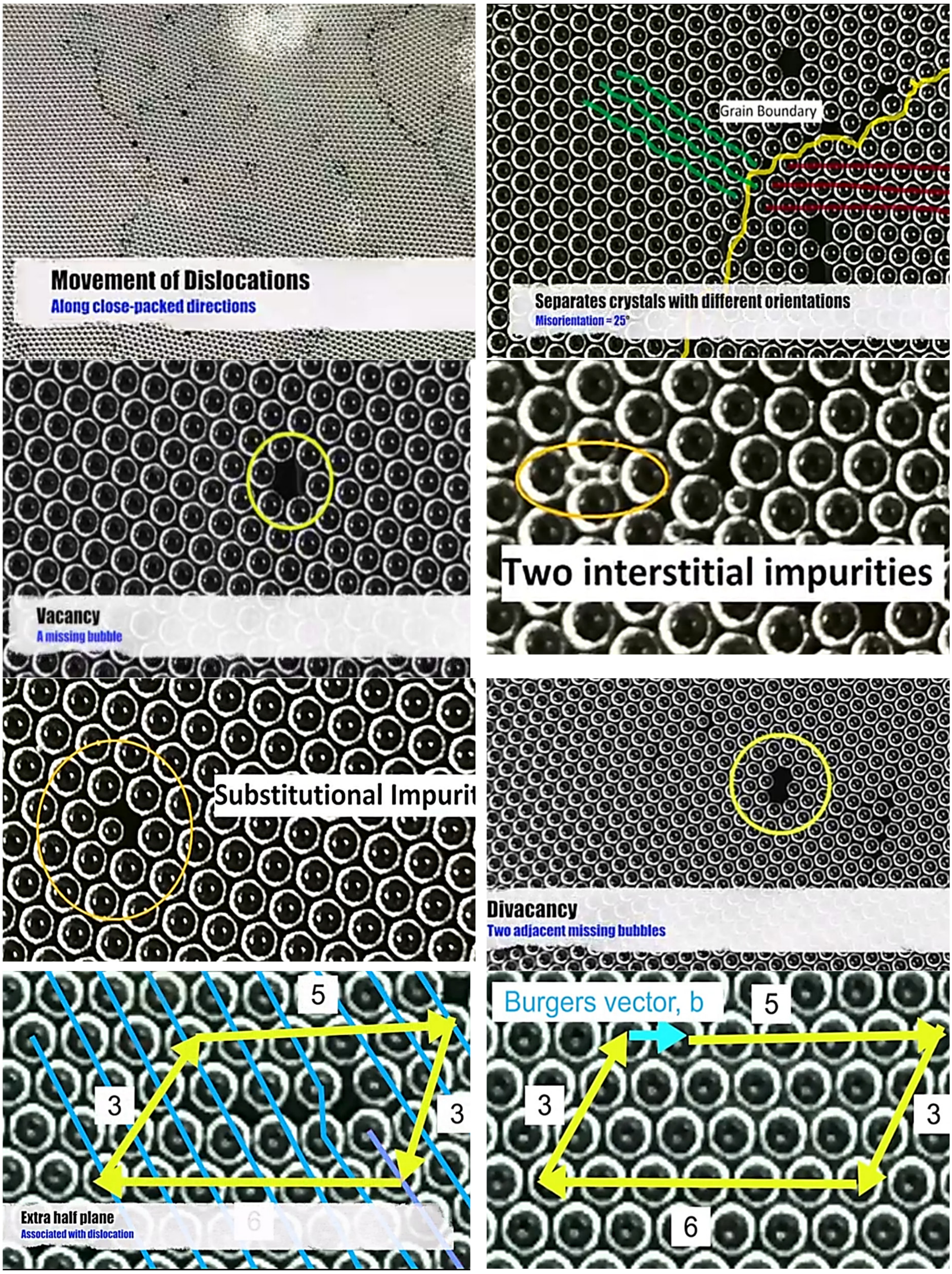


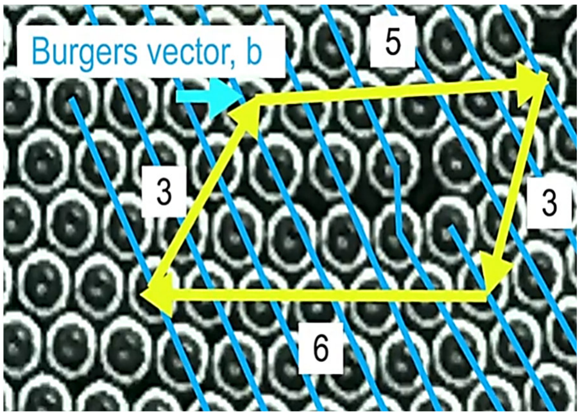
Dr. Sc. Dževad Hadžihafizović

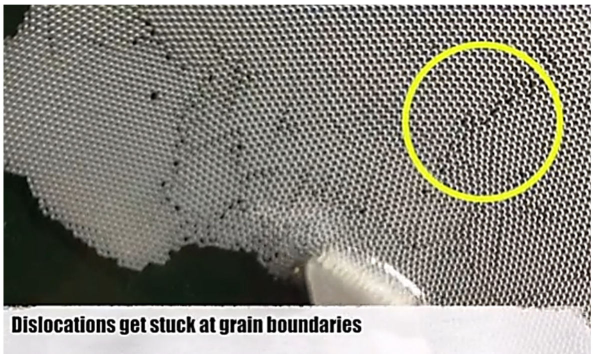
Sarajevo. 2023.

APPENDICES

Bubble Raft Experiment – Plivajući mjehurići eksperiment







As part of our materials science experiment analysis, we made a video that demonstrates all the interesting aspects of our bubble raft.

The bubble raft acts as an excellent analogy for the crystallographic structure and defects in a material.

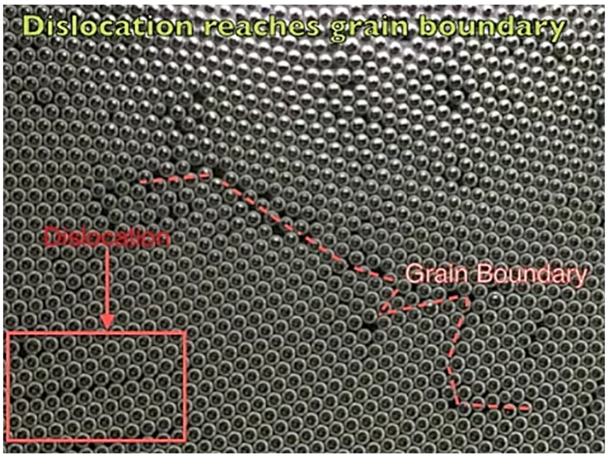
Kao dio naše analize eksperimenata nauke o materijalima, napravili smo video koji pokazuje sve zanimljive aspekte našeg splava.

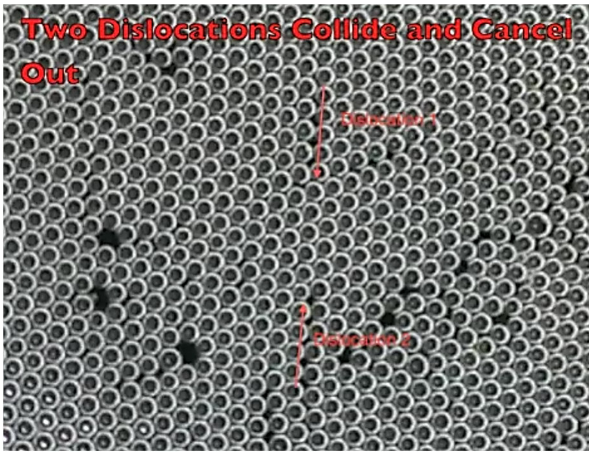
Splav s mjehurićima djeluje kao odlična analogija za kristalografsku strukturu i defekte u materijalu.

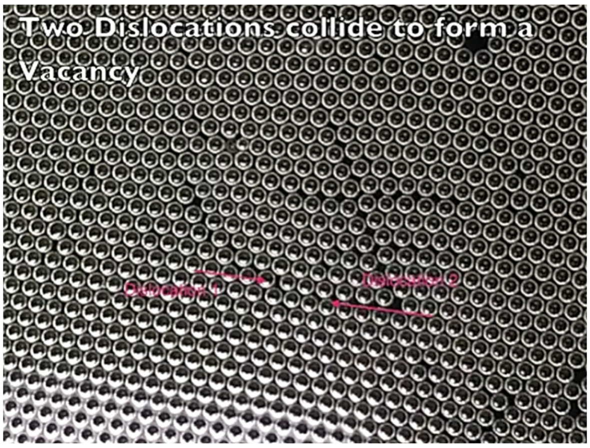
https://www.youtube.com/watch?v=TW2k1TYKAEk&ab_channel=JessWen

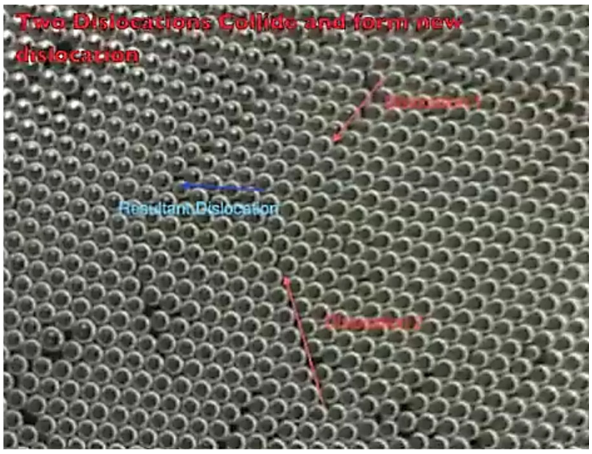
Bubble Raft and Dislocations Practical 1P5

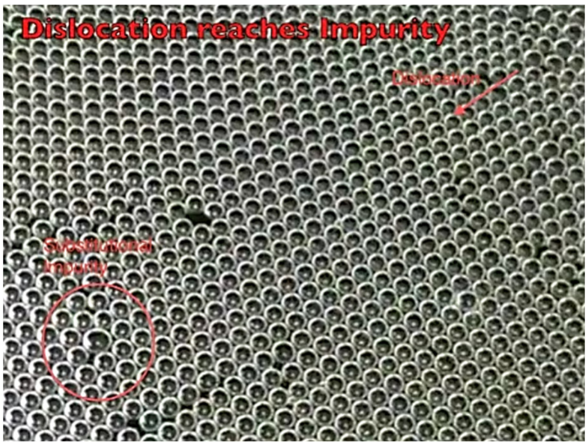
Plivajući mjehurići eksperiment - Praktične dislokacije 1P5

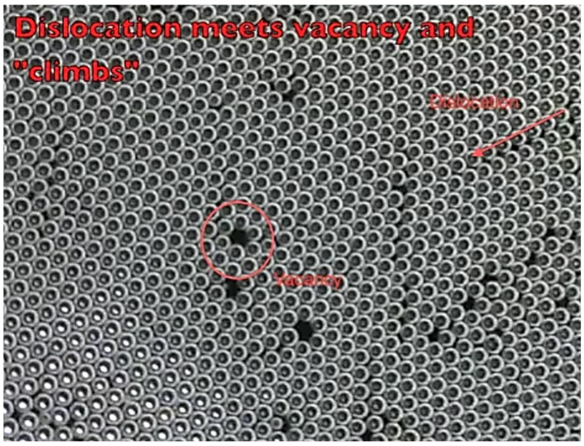












https://www.youtube.com/watch?v=4Kp3_KINBdg&ab_channel=DeruJ

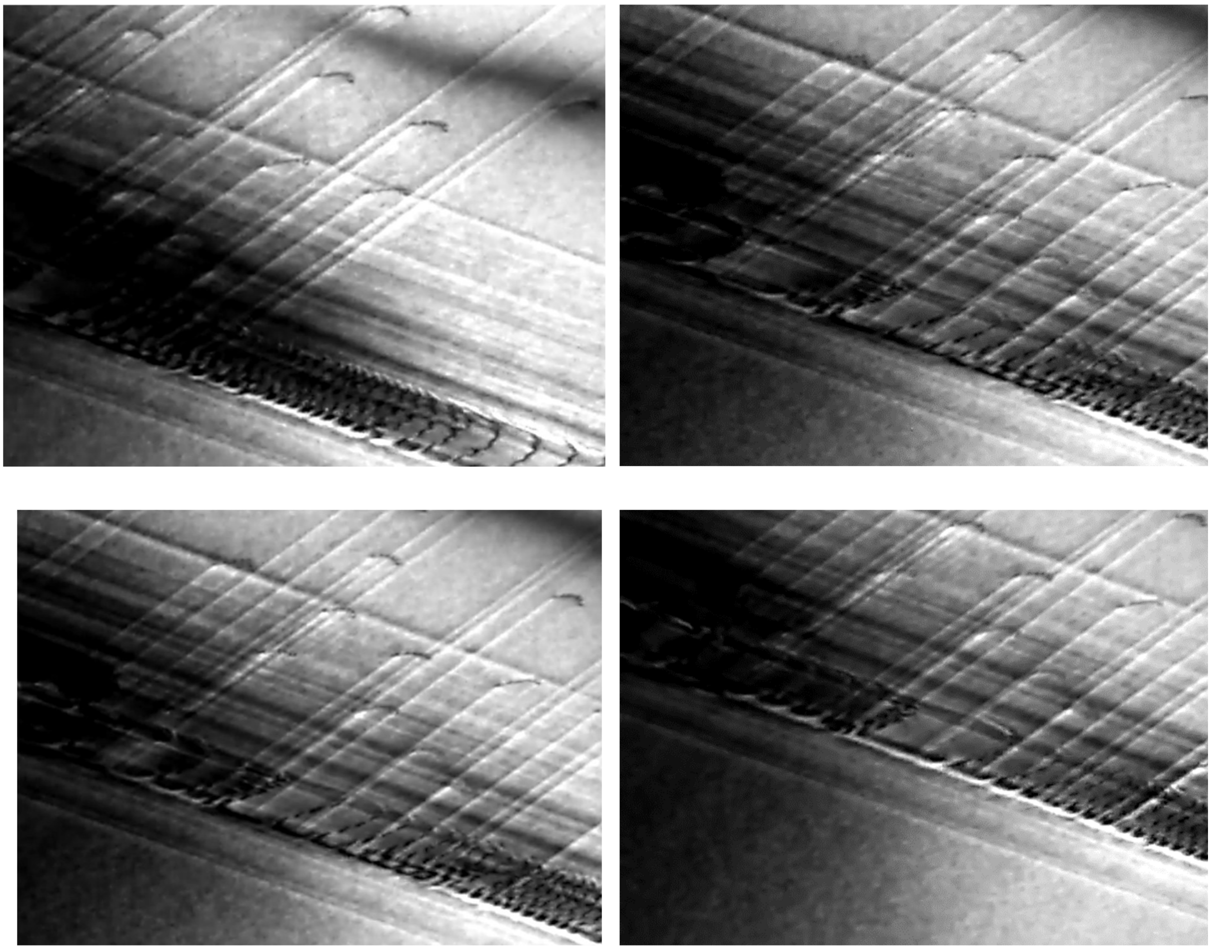
Bubble raft - moving dislocations, Materials Science, Oxford

As I blew into the draft, stress was generated on the structure and we were able to observe defects moving rapidly along the closepacked directions within each grain. These defects are dislocations. As bubble draft is a 2D approximation of 3D model, we can't observe screw dislocation, but only edge dislocation. The motion of dislocation can be derived from Burgers vector. As these dislocations meet a point defects such as vacancy we can see that they interact with them and remove them. However as it can be seen at 00:15 new point defects can also be created by moving dislocations (in this case several vacancies). When the moving dislocation meets graind boundary or edge of the raft it is disrupted. Also interesting, and important, effect can be observed at 00:26 when several dislocation ran into each other. At this point they got stuck and cumulate creating a large defect. They can't move from this place and the material can't be further bent. This is in fact representation of what is happening when stress is applied on material causing it breaks at this point.

Naprezanje je stvoreno na strukturi i mogli smo uočiti defekte koji se brzo kreću duž zbijenih smjerova unutar svakog zrna. Ovi defekti su dislokacije. Kako je mjehurić promaja 2D aproksimacija 3D modela, ne možemo uočiti dislokaciju vijka, već samo ivicu dislokacije. Kretanje dislokacije može se izvesti iz Burgersovog vektora. Kako se ove dislokacije susreću sa tačkastim nedostacima kao što je praznina, možemo vidjeti da one stupaju u interakciju s njima i uklanjaju ih. Međutim, kao što se može vidjeti u 00:15, novi tačkasti defekti mogu se stvoriti i pomicanjem dislokacija (u ovom slučaju nekoliko slobodnih mjesta). Kada pokretna dislokacija naiđe na granicu zrna ili ivicu splava, ona je prekinuta. Takođe zanimljiv i važan efekat se može uočiti u 00:26 kada je nekoliko dislokacija naletelo jedna na drugu. U ovom trenutku su se zaglavili i nagomilali stvarajući veliki defekt. Ne mogu se pomjeriti sa ovog mjesta i materijal se ne može dalje savijati. Ovo je u stvari prikaz onoga što se dešava kada se na materijal primeni naprezanje zbog čega se u ovom trenutku lomi.

https://www.youtube.com/watch?v=ppRis7vQarY&ab_channel=Josef

Dislocation cross slip - Poprečno dislokaciono klizanje



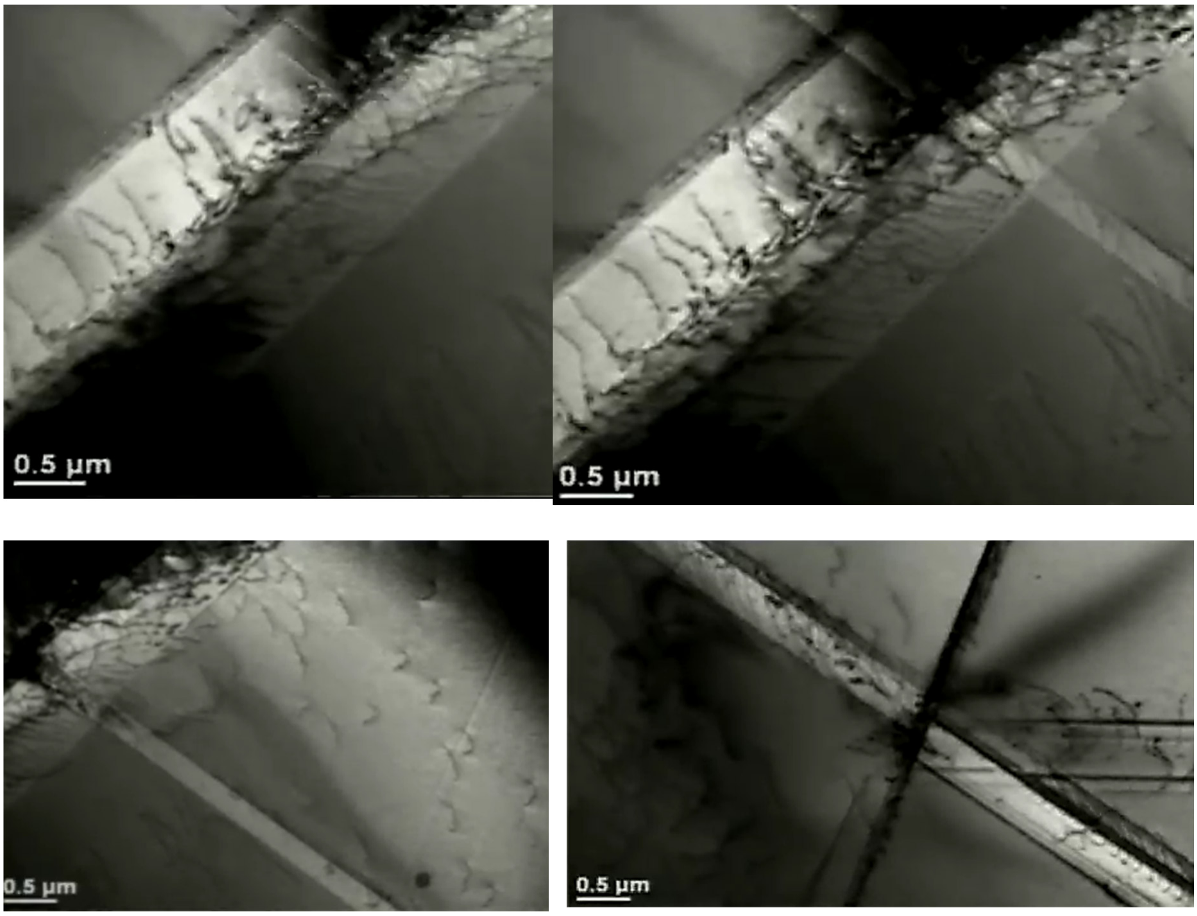
Dislocation cross slip seen during in situ TEM straining at 400 ^{0}C of a 304 stainless steel sample. Video speed is increased 5x.

Poprečno klizanje dislokacije uočeno tokom in situ TEM naprezanja na 400 ^{0}C uzorka od nerđajućeg čelika 304. Brzina videa je povećana 5x.

https://www.youtube.com/watch?v=VDbVxhRfChw&ab_channel=JoshKacher

Dislocation activity in irradiated materials

Aktivnost dislokacije u ozračenim materijalima



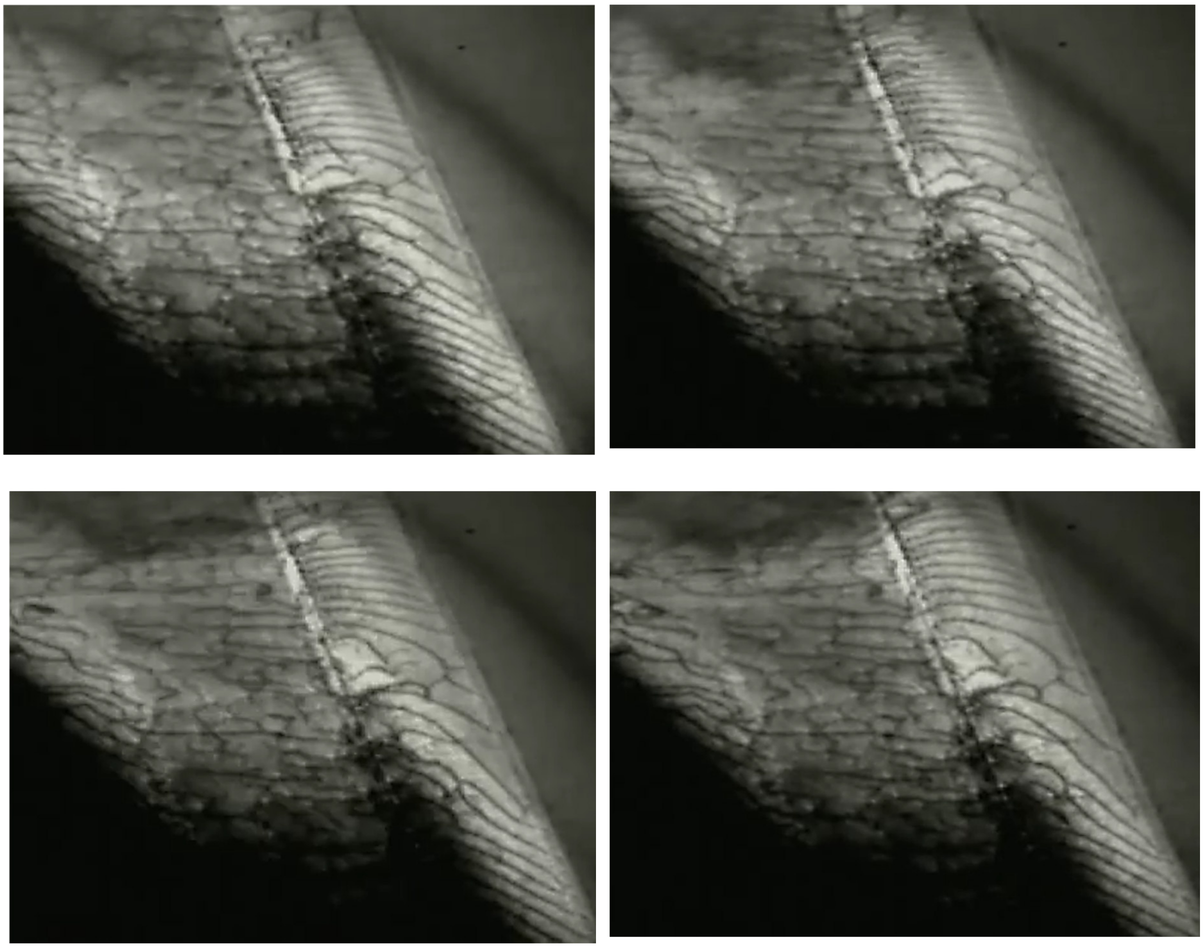
In situ TEM straining of irradiated stainless steel sample. Sample was ion irradiated with Kr ions in situ at Argonne's IVEM facilities. Massive cross-slip, dislocation generation, and increasing complexity of dislocation/dislocation interactions are observed over the course of the experiment. Video speed increased 5x.

In situ TEM naprezanje ozračenog uzorka nerđajućeg čelika. Uzorak je ioniziran Kr ionima in situ u Argonneovim IVEM objektima. Masivno poprečno klizanje, stvaranje dislokacija i sve veća složenost interakcija dislokacija/dislokacija su uočeni tokom eksperimenta. Brzina videa je povećana 5x.

https://www.youtube.com/watch?v=weK7gTAmTb4&ab_channel=JoshKacher

https://www.sciencedirect.com/science/article/abs/pii/S0968432812000182

Dislocation cross slip 2 - Poprečno klizanje dislokacije 2



Dislocation cross slip in ion-irradiated stainless steel during in situ TEM deformation at 400 ^{0}C.

Dislokacijsko poprečno klizanje u nerđajućem čeliku zračenom jonima tokom in situ TEM deformacije na 400 ^{0}C.

https://www.youtube.com/watch?v=HbnSHmzqhTg&ab_channel=JoshKacher

https://www.sciencedirect.com/science/article/abs/pii/S0968432812000182

In situ and tomographic observations of defect free channel formation in ion irradiated stainless steels

Author links open overlay panelJ.KacherG.S.LiuI.M.Robertson

Abstract

The effects of heavy-ion irradiation on dislocation processes in stainless steels were investigated using in situ irradiation and deformation in the transmission electron microscope as well as post mortem electron tomography to retrieve information on the three-dimensional dislocation state. Irradiation-induced defects were found to pose a strong collective barrier to dislocation motion, leading to dislocation pileups forming in grain interiors and at grain boundaries. The passage of multiple dislocations along the same slip plane removes the irradiation defects and leads to the eventual formation of a defect-free channel. These channels are composed of densely tangled dislocation networks which line the channel-matrix walls as well as residual dislocation debris in the channel interiors. The structures of the dislocation tangles were found to be similar to those encountered in later stages of deformation in unirradiated materials, with the exception that they developed earlier in the deformation process and were confined to the defect free channels. Also, defect free channels were found to widen through both source widening as well as complex cross-slip mechanisms.

Highlights

► Irradiation-produced defects present strong barriers to dislocation motion. ► Dislocation motion creates defect free channels. ► Channels widen through cross-slip mechanisms and source widening. ► Channels consist of dense tangles and elongated dislocations lining channel walls. ► In situ microscopy and electron tomography allow full characterization of system.

Introduction

The degradation of the mechanical properties of pure metals and alloys by irradiation with energetic particles is well established (Makin and Minter, 1959, Victoria et al., 2000, Kirk et al., 2003). Irradiation leads to a loss of ductility as well as an increase in the yield and tensile strength and the appearance of a distinct yield point drop. This degradation occurs irrespective of the energetic particles used for irradiation, including neutron, proton, and heavy-ion irradiation. It is also independent of crystal structure, having been observed in BCC, FCC, and HCP materials. In order to understand the macroscopic response to irradiation and subsequent deformation, a fundamental understanding of the material response at the microscale where deformation mechanisms are governed by dislocation interactions is necessary.

The purpose of studying deformation of irradiated materials is to gain a fundamental understanding of the mechanisms responsible for the degradation of mechanical properties compared to unirradiated materials. This knowledge is needed to inform and validate models as well as to direct innovative approaches to overcome degradation issues. Two areas central to this goal that are clarified in this study are the evolution of the dislocations in the cleared channel, including the formation of dislocation pileups at invisible obstacles and the mechanism of channel widening.

Understanding the details of these channels has implications beyond the mechanical response as they are also thought to have a critical role in the irradiation-assisted stress corrosion process (Was and Busby, 2005).

Dislocation interactions with irradiation-induced defects have been investigated in real time by conducting deformation experiments of irradiated metals in situ in the transmission electron microscope (TEM) (Suzuki et al., 1991, Robach et al., 2003, Briceno et al., 2011), by post mortem investigation of bulk deformed metals (Eyre and Bartlett, 1965, Sharp, 1967) and by molecular dynamics computer simulations as well as by dislocation dynamics simulations (Rodney and Martin, 1999, Diaz de la Rubia et al., 2000, Victoria et al., 2000, Ghoniem et al., 2002, Khraishi et al., 2002). In all cases, the formation of channels cleared of defects by dislocation motion was identified as a central feature dictating the mechanical response of the material. These channels act to concentrate the plasticity, leading to high stress concentrations and an overall loss in ductility. In situ TEM straining and irradiation investigations of stainless steel aimed at discovering the source of the dislocations responsible for creating these defect-free channels have shown that dislocations mobile during straining before irradiation has taken place are effectively locked in place by defects created during the irradiation process (Briceno et al., 2011). The dislocation sources at grain boundaries and stress concentration sites, however, remain active and unaffected by the irradiation, indicating that dislocation propagation, not nucleation, determines the mechanical response. Dislocation propagation is obstructed by the collective barrier strength of the irradiation defects, leading to jerky and segmented motion through the matrix as well as the formation of dislocation pileups near dislocation sources, resulting in an increased stress state at grain boundaries. Dislocation dynamics models similarly show that dislocations are pinned locally by irradiation-produced defects (Li et al., 2011).

After the defect free channels are formed, dislocations should be able to propagate at velocities approaching those observed in unirradiated materials. Barriers to dislocation motion in the form of residual dislocation debris from previous dislocation/irradiation defect interactions still exist, however, causing congestion in the defect free channels and impeding the motion of dislocations. Studies on the evolving structure of these channels have shown that they can widen both through source widening (Briceno et al., 2011) as well as through double cross-slip mechanisms (Diaz de la Rubia et al., 2000) or dislocation absorption of the point defects on annihilation of stacking-fault tetrahedra (Ghoniem et al., 2001). The latter mechanism relates the channel width to the height of jogs, which is determined by the number of tetrahedra with which the dislocation interacts. Computational methods have been able to show how defect absorption can act to pin dislocations, but the hypothesized mechanisms for channel widening have yet to be experimentally verified (Azevedo, 2011). It has also been shown experimentally that the channel width increases with increasing deformation temperature, suggesting a thermal component in the mechanisms governing channel widening (Sharp, 1967).

Part of the difficulty in understanding the effects of irradiation on dislocation behavior is due to limitations in experimental methods. Computational models can simulate both the time-resolved and the three-dimensional spatial relations of the dislocation interactions, but experimental methods are still often limited to a two-dimensional snapshot in time approach. While in situ straining experiments, as described briefly above, have resolved many of the issues related to the changes with time in dislocation interactions, they are still limited to two dimensions. In this paper, in situ TEM observations of dislocation propagation and channel formation and evolution in heavy-ion irradiated stainless steels are combined with three-dimensional post mortem analysis of the defect free channel structure using electron tomography. Both the irradiation and deformation were conducted in situ using the IVEM-accelerator facility at Argonne National Laboratory (Allen et al., 1996).

Section snippets

Materials and methods

In this study, two stainless steel alloys with different compositions, and consequently differing stacking-fault energies, were investigated. The compositions are reported in Table 1. Preparation for in situ TEM observation was achieved by first cutting the samples to stage specific dimensions for in situ straining (11.5 mm × 2.5 mm), drilling holes at either end of the specimens for attachment to the straining stage, and mechanically thinning them to approximately 150 μm thickness. The samples were

Results

Although two alloys with different composition were used in this study, the response for the most part was independent of composition. For the remainder of this section, it should be assumed that the results pertain to both systems unless explicitly stated otherwise.

Dislocation motion through the obstacle field was observed to be jerky, segmented and discontinuous, which is consistent with dislocations progressing through a medium with irregularly spaced obstacles. Dislocation progression

Discussion

Here the formation of defect-free channels by the passage of dislocations was investigated in two stainless steel alloys with different compositions (stacking-fault energies). Differences in response between the two alloys were minimal, which might reflect the irradiation-produced defects restricting the formation of partial dislocations. The collective effect of a high density of irradiation-produced defects is to provide a strong barrier opposing dislocation mobility. Manifestations of the

Conclusions

Irradiation produced defects present strong barriers to dislocation motion, leading to anomalous dislocation distributions including dislocation pileups in grain interiors and dislocation sources as well as conventional pileups formed at grain boundaries. The passage of multiple dislocations leads to the formation of defect free channels which provide a path of lower resistance for further dislocation flow. These channels are composed of dense dislocation tangles lining the borders between the

Acknowledgements

This work was supported by the US Department of Energy, Office of Basic Energy Sciences, Division of Materials Science, under award No. DEFG-02-08ER46525. The authors thank Dr. M.A. Kirk for his assistance and fruitful discussion as well as May Martin for her assistance with the FIB lift-out. This document was prepared by the University of Illinois at Urbana-Champaign as a result of the use of facilities in the US Department of Energy (DOE), which are managed by UChicago Argonne, LLC, acting

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In situ i tomografska promatranja stvaranja kanala bez defekata u ionski ozračenim nehrđajućim čelicima

Kacher G.S. Liu I.M. Robertson

Sažetak

Učinci zračenja teškim ionima na procese dislokacije u nehrđajućem čeliku istraživani su korištenjem in situ zračenja i deformacije u transmisijskom elektronskom mikroskopu, kao i post mortemelektronska tomografija za dobivanje informacija o trodimenzionalnom stanju dislokacije. Utvrđeno je da defekti izazvani zračenjem predstavljaju snažnu zajedničku prepreku kretanju dislokacija, što dovodi do stvaranja nakupina dislokacija u unutrašnjosti zrna i na granicama zrna. Prolaz višestrukih dislokacija duž iste ravnine klizanja uklanja nedostatke zračenja i dovodi do konačnog stvaranja kanala bez defekata. Ovi kanali se sastoje od gusto zapetljanih dislokacijskih mreža koje oblažu stijenke kanala-matrice kao i zaostalog dislokacijskog otpada u unutrašnjosti kanala. Utvrđeno je da su strukture dislokacijskih spletova slične onima koje se susreću u kasnijim fazama deformacije u neozračenim materijalima, s iznimkom da su se razvili ranije u procesu deformacije i bili su ograničeni na kanale bez defekata. Također je otkriveno da se kanali bez defekata šire kroz širenje izvora kao i kroz složene mehanizme poprečnog klizanja.

Ključne riječi:

► Defekti nastali zračenjem predstavljaju snažnu prepreku kretanju dislokacija.

► Kretanje dislokacije stvara kanale bez oštećenja.

► Kanali se proširuju pomoću mehanizama poprečnog klizanja i proširenja izvora.

► Kanali se sastoje od gustih spletova i izduženih dislokacija koje oblažu stijenke kanala.

► In situ mikroskopija i elektronska tomografija omogućuju potpunu karakterizaciju sustava.

Uvod

Degradacija mehaničkih svojstava čistih metala i legura zračenjem energetskim česticama dobro je utvrđena (Makin i Minter, 1959., Victoria i sur., 2000., Kirk i sur., 2003.). Zračenje dovodi do gubitka duktilnosti kao i povećanja razvlačenja i vlačne čvrstoće te pojave izrazitog pada granice tečenja. Ova degradacija se događa bez obzira na energetske čestice koje se koriste za zračenje, uključujući zračenje neutronima, protonima i teškim ionima. Također je neovisan o kristalnoj strukturi, primijećen je u BCC, FCC i HCP materijalima. Kako bi se razumio makroskopski odgovor na zračenje i naknadnu deformaciju, neophodno je temeljno razumijevanje odgovora materijala na mikroskali gdje su mehanizmi deformacije upravljani interakcijama dislokacija.

Svrha proučavanja deformacije ozračenih materijala je steći temeljno razumijevanje mehanizama odgovornih za degradaciju mehaničkih svojstava u usporedbi s neozračenim materijalima. Ovo je znanje potrebno za informiranje i provjeru valjanosti modela, kao i za usmjeravanje inovativnih pristupa prevladavanju problema degradacije. Dva središnja područja za ovaj cilj koja su razjašnjena u ovoj studiji su evolucija dislokacija u očišćenom kanalu, uključujući formiranje nakupina dislokacija na nevidljivim preprekama i mehanizam širenja kanala. Razumijevanje detalja ovih kanala ima implikacije izvan mehaničkog odgovora jer se također smatra da imaju ključnu ulogu u procesu korozije uz pomoć zračenja (Was i Busby, 2005.).

Interakcije dislokacija s defektima izazvanim zračenjem istražene su u stvarnom vremenu provođenjem eksperimenata deformacije ozračenih metala in situ u transmisijskom elektronskom mikroskopu (TEM) (Suzuki et al., 1991., Robach et al., 2003., Briceno et al., 2011), obdukcijomistraživanje masovnih deformiranih metala (Eyre i Bartlett, 1965., Sharp, 1967.) i računalnim simulacijama molekularne dinamike, kao i simulacijama dinamike dislokacija (Rodney i Martin, 1999., Diaz de la Rubia et al., 2000., Victoria et al. , 2000., Ghoniem i sur., 2002., Khraishi i sur., 2002.). U svim slučajevima, stvaranje kanala očišćenih od defekata kretanjem dislokacija identificirano je kao središnja značajka koja diktira mehanički odgovor materijala. Ovi kanali djeluju tako da koncentriraju plastičnost, što dovodi do visokih koncentracija naprezanja i ukupnog gubitka duktilnosti. In situIstraživanja TEM naprezanja i zračenja nehrđajućeg čelika s ciljem otkrivanja izvora dislokacija odgovornih za stvaranje ovih kanala bez defekata pokazala su da su dislokacije pokretne tijekom naprezanja prije ozračivanja učinkovito zaključane na mjestu defektima nastalim tijekom procesa zračenja (Briceno i sur., 2011). Međutim, izvori dislokacija na granicama zrna i mjestima koncentracije naprezanja ostaju aktivni i na njih ne utječe zračenje, što ukazuje da širenje dislokacija, a ne nukleacija, određuje mehanički odgovor.

Širenje dislokacija ometa kolektivna čvrstoća barijere defekata zračenja, što dovodi do trzaja i segmentiranog gibanja kroz matricu, kao i do stvaranja nakupina dislokacija u blizini izvora dislokacija, što rezultira povećanim stanjem naprezanja na granicama zrna. Modeli dinamike dislokacija na sličan način pokazuju da su dislokacije lokalno pričvršćene defektima nastalim zračenjem (Li et al., 2011.).

Nakon što se formiraju kanali bez defekata, dislokacije bi se trebale moći širiti brzinama koje se približavaju onima koje se opažaju u neozračenim materijalima. Prepreke kretanju dislokacija u obliku zaostalog dislokacijskog otpada iz prethodnih interakcija dislokacije/defekta zračenja, međutim, još uvijek postoje, uzrokujući zagušenje u kanalima bez defekata i ometajući kretanje dislokacija. Studije o evolutivnoj strukturi ovih kanala pokazale su da se oni mogu proširiti kroz širenje izvora (Briceno et al., 2011.) kao i kroz mehanizme dvostrukog poprečnog klizanja (Diaz de la Rubia et al., 2000.) ili dislokacijsku apsorpciju točkasti defekti pri anihilaciji tetraedra s greškom slaganja (Ghoniem et al., 2001). Potonji mehanizam povezuje širinu kanala s visinom trčanja, što je određeno brojem tetraedara s kojima dislokacija međudjeluje. Računalne metode uspjele su pokazati kako apsorpcija defekata može djelovati na dislokacije iglama, ali pretpostavljene mehanizme za širenje kanala tek treba eksperimentalno potvrditi (Azevedo, 2011.). Također je eksperimentalno pokazano da se širina kanala povećava s povećanjem temperature deformacije, što ukazuje na toplinsku komponentu u mehanizmima koji upravljaju širenjem kanala (Sharp, 1967.).

Dio poteškoća u razumijevanju učinaka zračenja na ponašanje dislokacija uzrokovan je ograničenjima eksperimentalnih metoda. Računalni modeli mogu simulirati i vremenski razlučene i trodimenzionalne prostorne odnose međudjelovanja dislokacija, ali eksperimentalne metode još uvijek su često ograničene na dvodimenzionalni pristup snimci u vremenu. Dok su eksperimenti naprezanja in situ , kao što je ukratko gore opisano, riješili mnoga pitanja povezana s promjenama s vremenom u interakcijama dislokacija, oni su još uvijek ograničeni na dvije dimenzije. U ovom radu, in situ TEM promatranja širenja dislokacija i formiranja kanala i evolucije u nehrđajućem čeliku ozračenom teškim ionima kombinirana su s trodimenzionalnim post mortemanaliza strukture kanala bez defekata pomoću elektronske tomografije. I zračenje i deformacija provedeni su in situ korištenjem IVEM-akceleratora u Nacionalnom laboratoriju Argonne (Allen et al., 1996).

Isječci odjeljaka

Materijali i metode

U ovoj studiji ispitane su dvije legure nehrđajućeg čelika s različitim sastavima i posljedično različitim energijama greške pri slaganju. Sastav je prikazan u tablici 1. Priprema za in situ TEM promatranje postignuta je prvim rezanjem uzoraka na specifične dimenzije za in situ naprezanje (11,5 mm × 2,5 mm), bušenjem rupa na oba kraja uzoraka za pričvršćivanje na naprezanje. fazi, te ih mehanički stanjiti na debljinu od približno 150 μm. Uzorci su bili

Rezultati

Iako su u ovom istraživanju korištene dvije legure različitog sastava, odgovor je najvećim dijelom bio neovisan o sastavu. U ostatku ovog odjeljka treba pretpostaviti da se rezultati odnose na oba sustava osim ako nije izričito navedeno drugačije.

Uočeno je da je kretanje dislokacija kroz polje prepreka trzavo, segmentirano i diskontinuirano, što je u skladu s napredovanjem dislokacija kroz medij s nepravilno raspoređenim preprekama. Progresija dislokacije

Rasprava

Ovdje je istraženo stvaranje kanala bez defekata prolaskom dislokacija u dvije legure nehrđajućeg čelika s različitim sastavima (energije greške slaganja). Razlike u odgovoru između dviju legura bile su minimalne, što bi moglo odražavati defekte nastale zračenjem koji ograničavaju stvaranje djelomičnih dislokacija. Zajednički učinak velike gustoće defekata nastalih zračenjem je stvaranje snažne barijere koja se suprotstavlja pokretljivosti dislokacija. Manifestacije

Zaključci

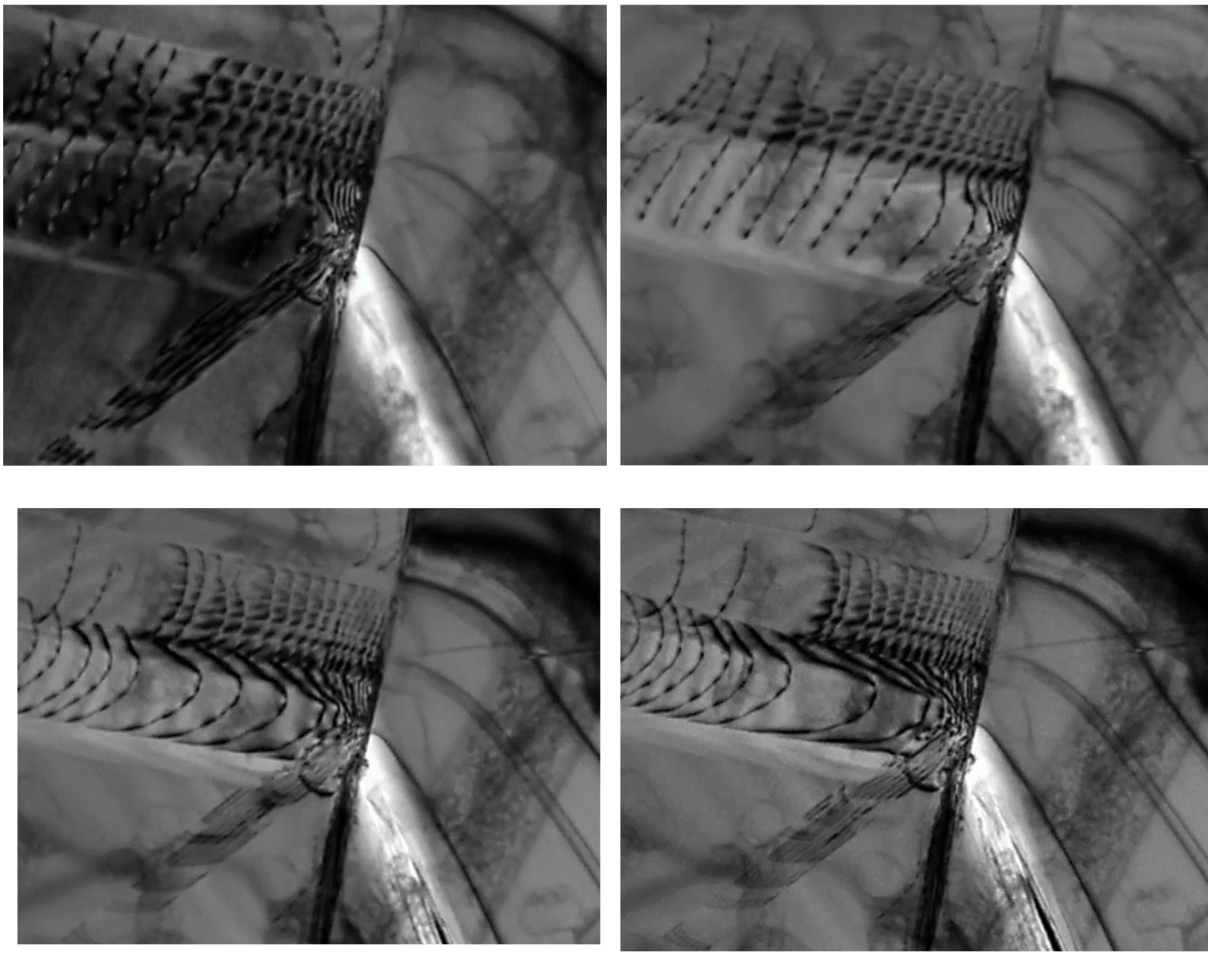
Defekti uzrokovani zračenjem predstavljaju snažnu prepreku kretanju dislokacija, što dovodi do nenormalne distribucije dislokacija uključujući gomile dislokacija u unutrašnjosti zrna i izvore dislokacija, kao i konvencionalne nakupine formirane na granicama zrna. Prolazak višestrukih dislokacija dovodi do stvaranja kanala bez defekata koji osiguravaju put manjeg otpora za daljnji tok dislokacija. Ti su kanali sastavljeni od gustih dislokacijskih spletova koji oblažu granice između

Priznanja

Ovaj je rad podržalo Ministarstvo energetike SAD-a, Ured za osnovne energetske znanosti, Odjel za znanost o materijalima , pod brojem DEFG-02-08ER46525 . Autori zahvaljuju dr. MA Kirku na njegovoj pomoći i plodonosnoj raspravi, kao i May Martin.

Dislocation emission from crack tip

Emisija dislokacije iz vrha pukotine

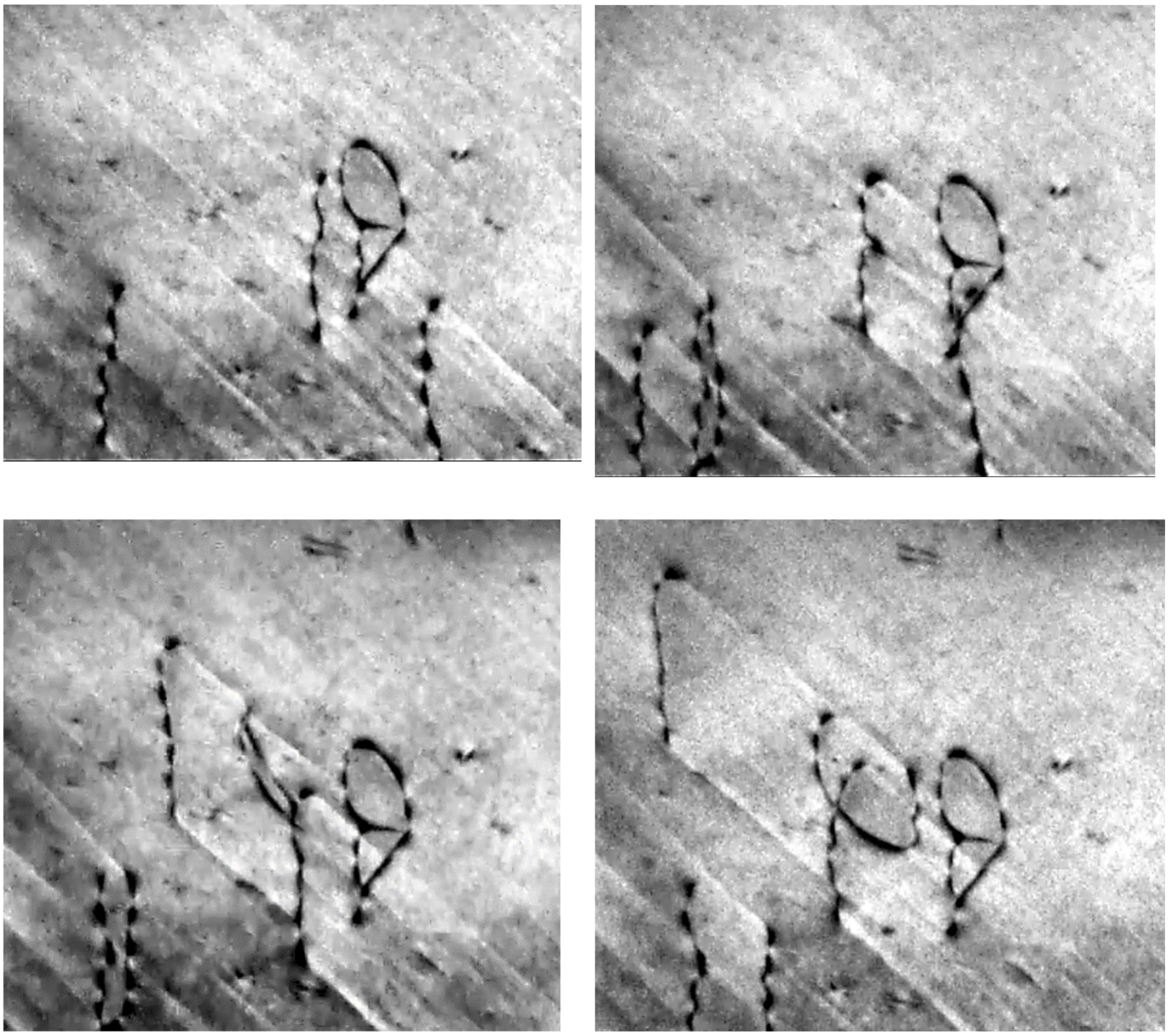


Dislocation emission from a crack tip/grain boundary intersection during in situ TEM deformation of 304 stainless steel at 300 ^{0}C. Crack tip reaches the boundary just before the 1 minute mark.

Emisija dislokacije iz raskrsnice vrha pukotine/granične granice zrna tokom in situ TEM deformacije nehrđajućeg čelika 304 na 300 ^{0}C. Vrh pukotine dostiže granicu neposredno prije oznake od 1 minute.

https://www.youtube.com/watch?v=j0P3kdpKH90&ab_channel=JoshKacher

Dislocation generation - Generacija dislokacija



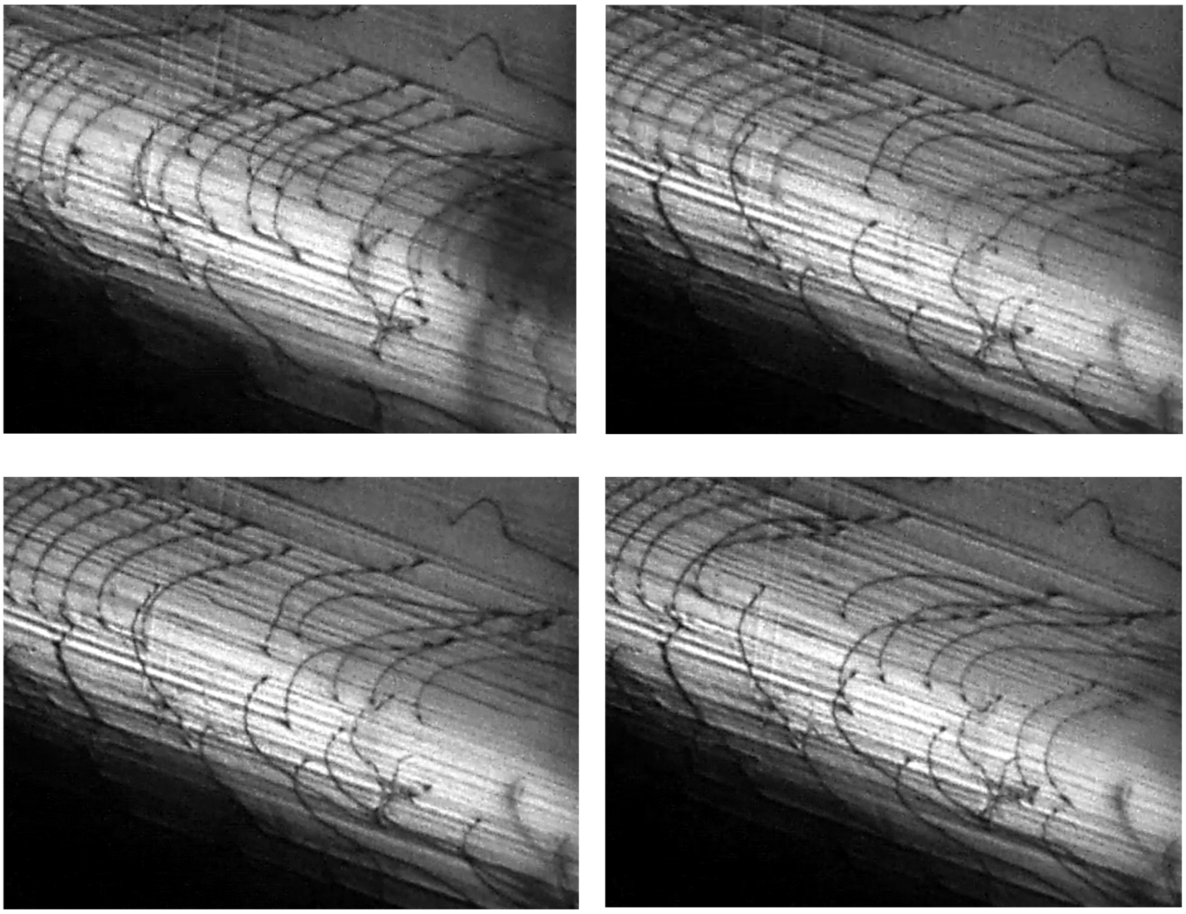
Dislocation generation through cross slip mechanism during in situ TEM deformation of alpha-titanium. J Kacher, I.M. Robertson, "In situ TEM characterization of dislocation interactions in alpha-Ti." Phil Mag. 96(14) 2016

https://www.tandfonline.com/doi/abs/10.1080/14786435.2016.1170222?journalCode=tphm20

In situ naprezanje u transmisijskom elektronskom mikroskopu i difrakcijsko-kontrastna elektronska tomografija primijenjeno je za istraživanje interakcija dislokacija u α -Ti. Uočeno je da dislokacijski ostaci, u obliku malih petlji, nastaju iz uzastopnih događaja poprečnog klizanja. Elektronska tomografija omogućila je izravnu trodimenzionalnu vizualizaciju dislokacijskih struktura, omogućujući točnu identifikaciju ravnina klizanja, smjerova linija dislokacija i prostornih odnosa između dislokacija.

https://www.youtube.com/watch?v=iD8QkWnRWQM&ab_channel=JoshKacher

Dislocation glide - Dislokacijsko klizanje



Dislocation glide during in situ TEM straining at 400 ^{0}C of 304 stainless steel. Video speed is increased 5x.

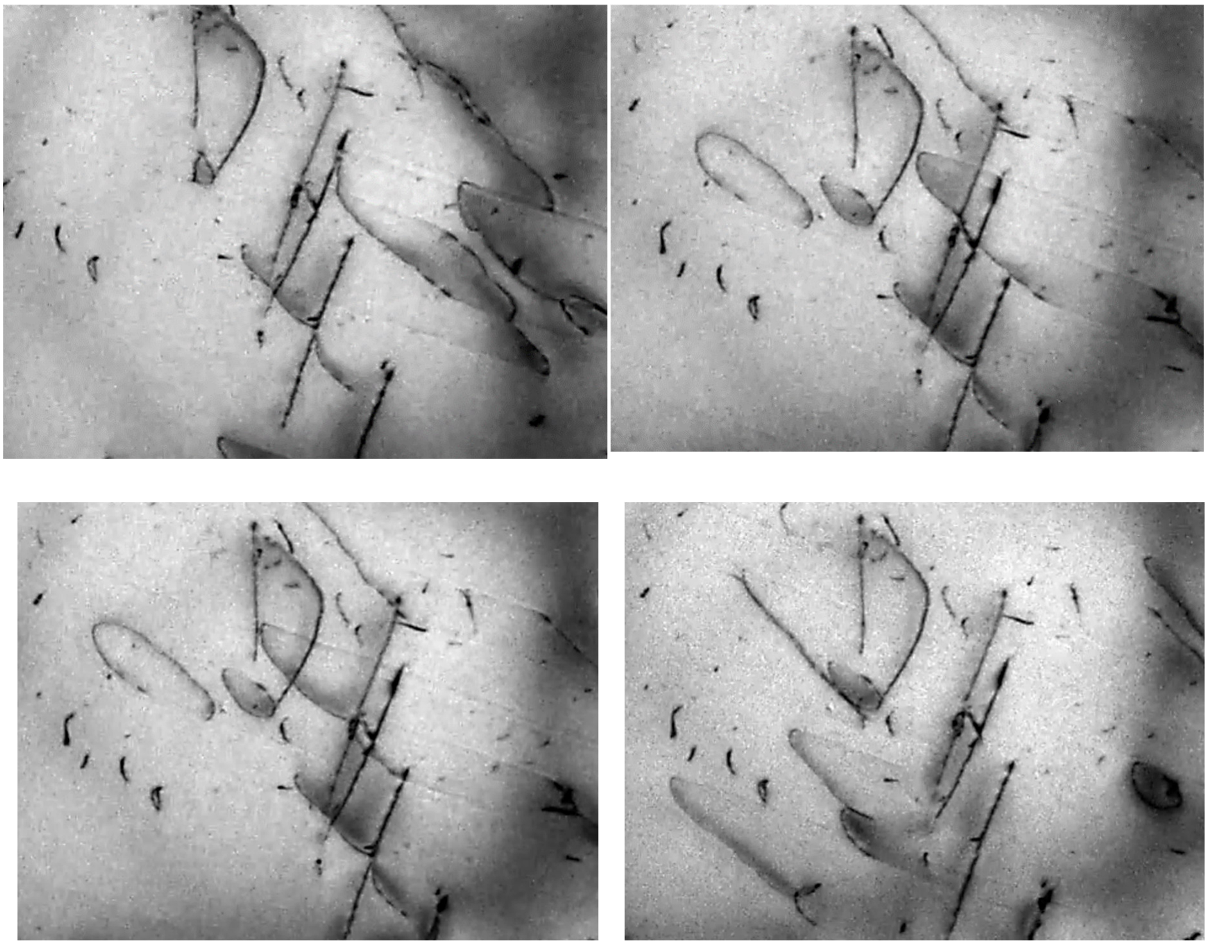
Dislokacija klizi tokom in situ TEM naprezanja na 400 ^{0}C od nerđajućeg čelika 304. Brzina videa je povećana 5x.

https://www.sciencedirect.com/science/article/abs/pii/S1359645412005757

https://www.youtube.com/watch?v=EXbiEopDJ_g&ab_channel=JoshKacher

Dislocation interactions in alpha Ti

Interakcije dislokacija u alfa Ti



Dislocation behavior during in situ TEM straining of alpha titanium. Glissile screw dislocations interact with sessile mixed-character dislocations. Cross-slip of the glissile dislocations leads to dislocation multiplication.

J Kacher, I.M. Robertson, "In situ TEM characterization of dislocation interactions in alpha-Ti." Phil Mag. 96(14) 2016

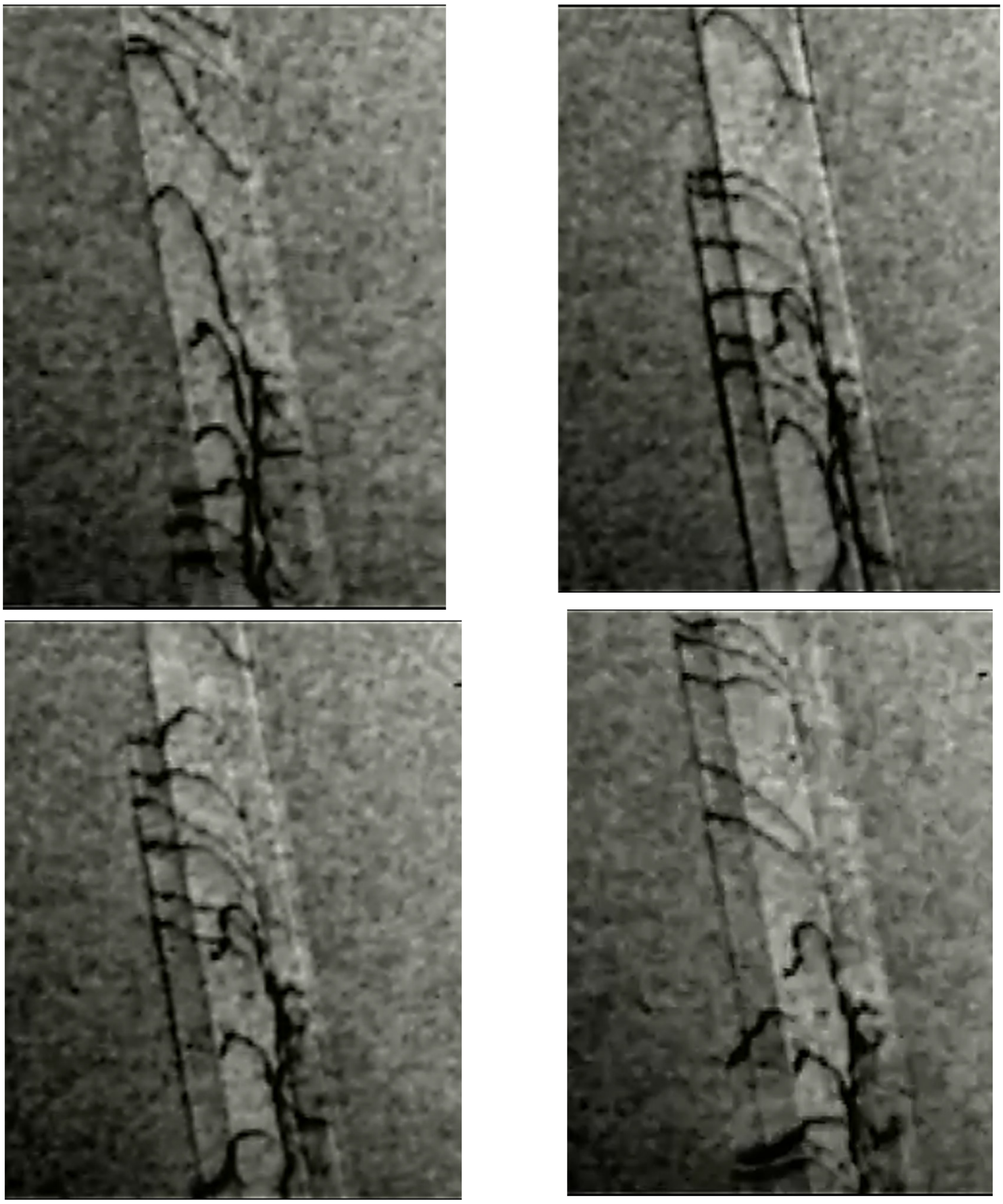
Ponašanje dislokacije tokom in situ TEM naprezanja alfa titanijuma. Glisilne vijčane dislokacije su u interakciji sa sjedećim dislokacijama mješovitog karaktera. Unakrsno klizanje glisilnih dislokacija dovodi do umnožavanja dislokacija.

J Kacher, I.M. Robertson, "In situ TEM karakterizacija dislokacijskih interakcija u alfa-Ti." Phil Mag. 96(14) 2016

https://www.youtube.com/watch?v=50Q8UxTMMqY&ab_channel=JoshKacher

Dislocation motion through a defect field

Kretanje dislokacije kroz defektno polje



In situ TEM straining experiment showing dislocations propagating through an irradiation-induced defect field in stainless steel. This video illustrates dislocation pinning and release from the distributed defects. More details can be found in:

Kacher, J., G.S. Liu, I.M. Robertson "In situ and tomographic observations of defect free channel formation in ion irradiated stainless steels." Volume 43, Issue 11, November 2012, Pages 1099-1107

In situ TEM eksperiment naprezanja koji pokazuje dislokacije koje se šire kroz polje defekta izazvano zračenjem u nehrđajućem čeliku. Ovaj video ilustruje pričvršćivanje dislokacija i oslobađanje od distribuiranih defekata. Više detalja možete pronaći na:

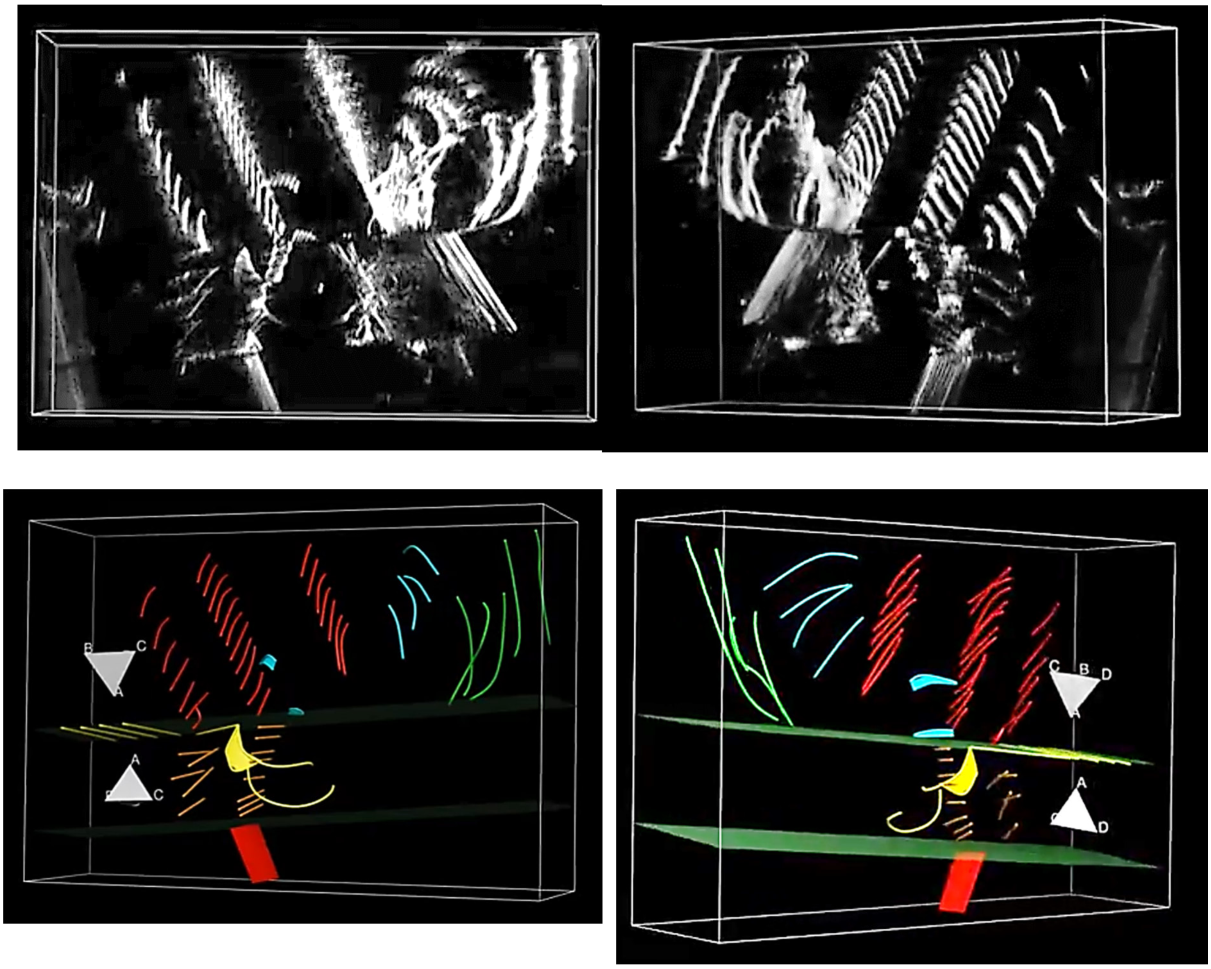
Kacher, J., G.S. Liu, I.M. Robertson "In situ i tomografska zapažanja formiranja kanala bez defekata u nerđajućim čelicima zračenim jonima." Svezak 43, broj 11, novembar 2012, stranice 1099-1107

https://www.sciencedirect.com/science/article/abs/pii/S0968432812000182

https://www.youtube.com/watch?v=8D9NaXYGwsc&ab_channel=JoshKacher

Dislocation tomography - 3D dislocation model

Tomografija dislokacije - 3D model dislokacije



Tomogram of the dislocation interaction shown in a previous video (https://www.youtube.com/watch?v=oBt45...). The tomogram was constructed using a weighted back projection algorithm. A 3D dislocation model constructed from the tomogram can be seen at https://www.youtube.com/watch?v=K8Via....

3D dislocation model constructed from a tomogram (seen here https://www.youtube.com/watch?v=VAPsY..., image sequence shown here https://www.youtube.com/watch?v=oBt45...) showing dislocations interacting with a pair of twin plains in 304 stainless steel. The green planes represent twin planes and the dislocations are color coded according to the Burgers vector (red = +-a/2[-110], blue = +-a/2[101], yellow = +-a/2[-110]). Thompson tetrahedra are included in each region to provide the coordinate system.

Tomogram interakcije dislokacije prikazan u prethodnom videu Tomogram je konstruiran korištenjem algoritma ponderirane povratne projekcije. 3D model dislokacije konstruiran iz tomograma može se vidjeti

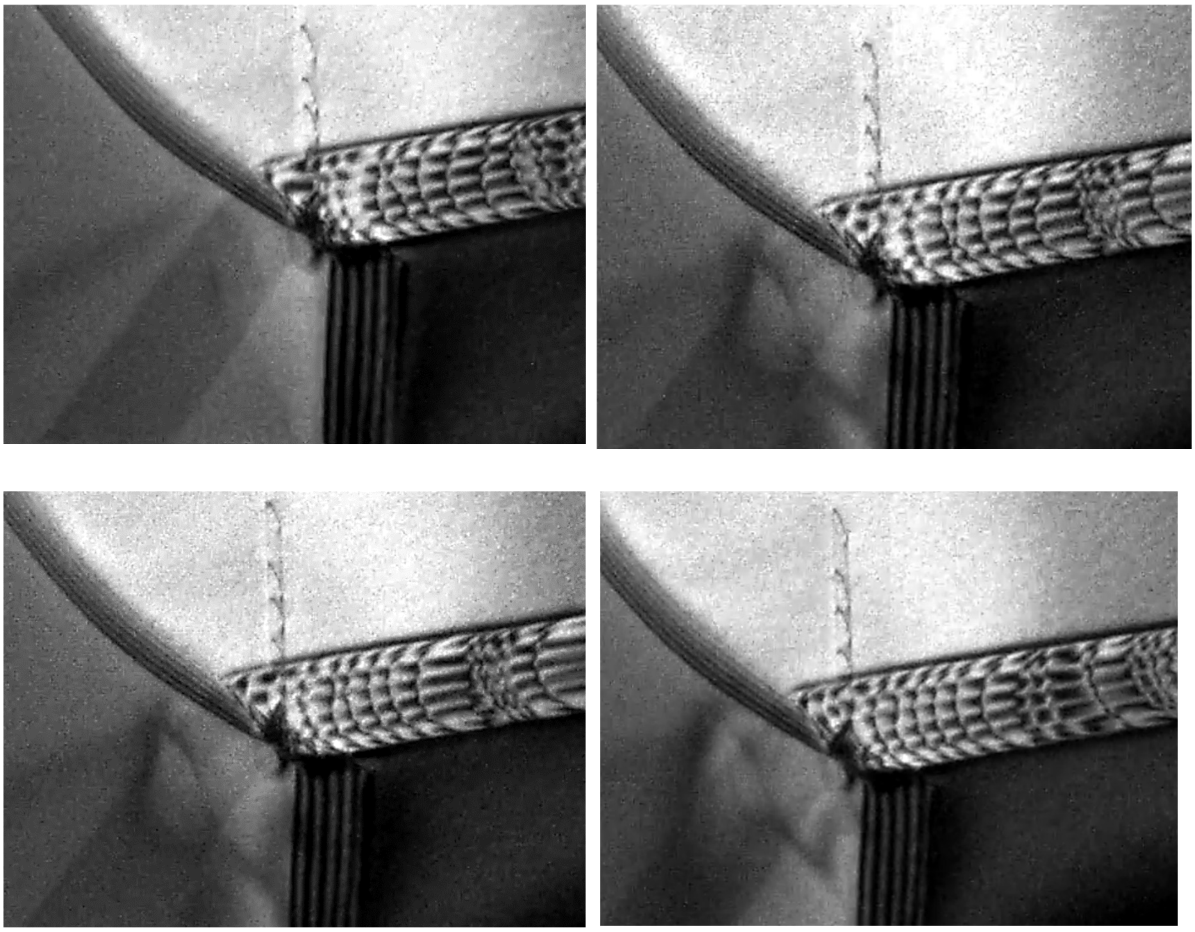
3D model dislokacije konstruiran iz tomograma prikazuje dislokacije koje stupaju u interakciju s parom ravnih blizanaca od nehrđajućeg čelika 304. Zelene ravni predstavljaju ravni blizanaca, a dislokacije su kodirane bojom prema Burgersovom vektoru (crvena = +-a/2[-110], plava = +-a/2[101], žuta = +-a/2[- 110]). Thompsonovi tetraedri su uključeni u svaku regiju kako bi se obezbijedio koordinatni sistem.

https://www.youtube.com/watch?v=VAPsYjGOH_w&ab_channel=JoshKacher

https://www.youtube.com/watch?v=K8Viaz4_E7s&ab_channel=JoshKacher

Dislocation/grain boundary interaction - back emission

Interakcija dislokacija/granica zrna - povratna emisija



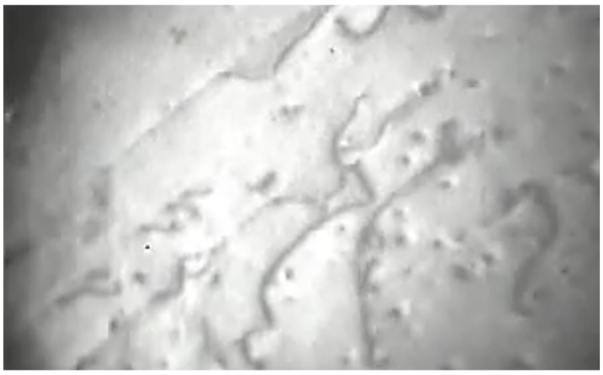
Dislocation/grain boundary interaction seen during in situ TEM straining at 400 ^{0}C of a 304 stainless steel sample. Partial dislocations impinge on a high angle grain boundary. Some partial dislocations are nucleated in the neighboring grain, but the majority of the dislocations are emitted back into the original grain. (http://www.sciencedirect.com/science/...)

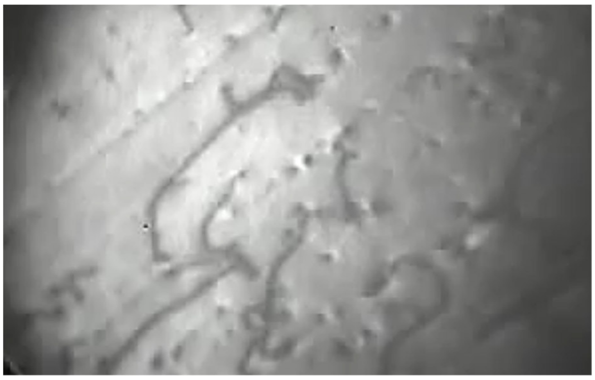
Interakcija dislokacija/granica zrna viđena tokom in situ TEM naprezanja na 400 ^{0}C uzorka od nerđajućeg čelika 304. Djelomične dislokacije zadiru u granicu zrna pod velikim uglom. Neke djelomične dislokacije nastaju u susjednom zrnu, ali većina dislokacija se emituje natrag u originalno zrno.

https://www.sciencedirect.com/science/article/abs/pii/S1359645412005757

https://www.youtube.com/watch?v=FjljUOG88D8&ab_channel=Onera-ComputationalSolidMechanics

Dislocations in motion - Dislokacije u pokretu



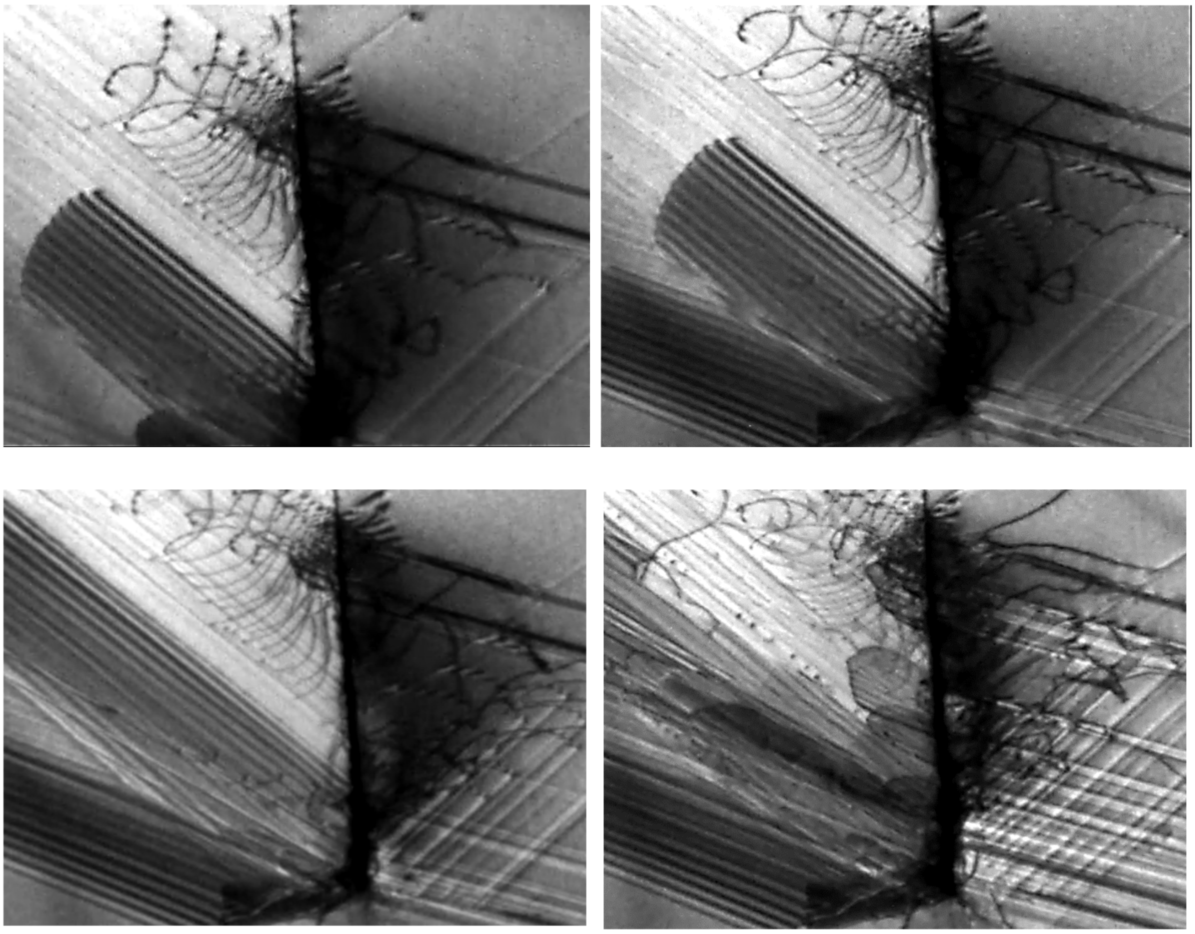
In materials science, a dislocation or Taylor's dislocation is a linear crystallographic defect or irregularity within a crystal structure that contains an abrupt change in the arrangement of atoms. The movement of dislocations **allow atoms to slide over each other at low stress levels and is known as glide or slip**.

U nauci o materijalima, dislokacija ili Taylorova dislokacija je linearni kristalografski defekt ili nepravilnost unutar kristalne strukture koja sadrži naglu promjenu u rasporedu atoma. **Kretanje dislokacija omogućava atomima da klize jedan preko drugog na niskim nivoima naprezanja i poznato je kao klizanje ili klizanje.**

https://www.youtube.com/watch?v=BV1cxwxnhPs&ab_channel=OndrejKotecky

Dislocation/twin boundary interaction

Interakcija dislokacija/granica blizanaca



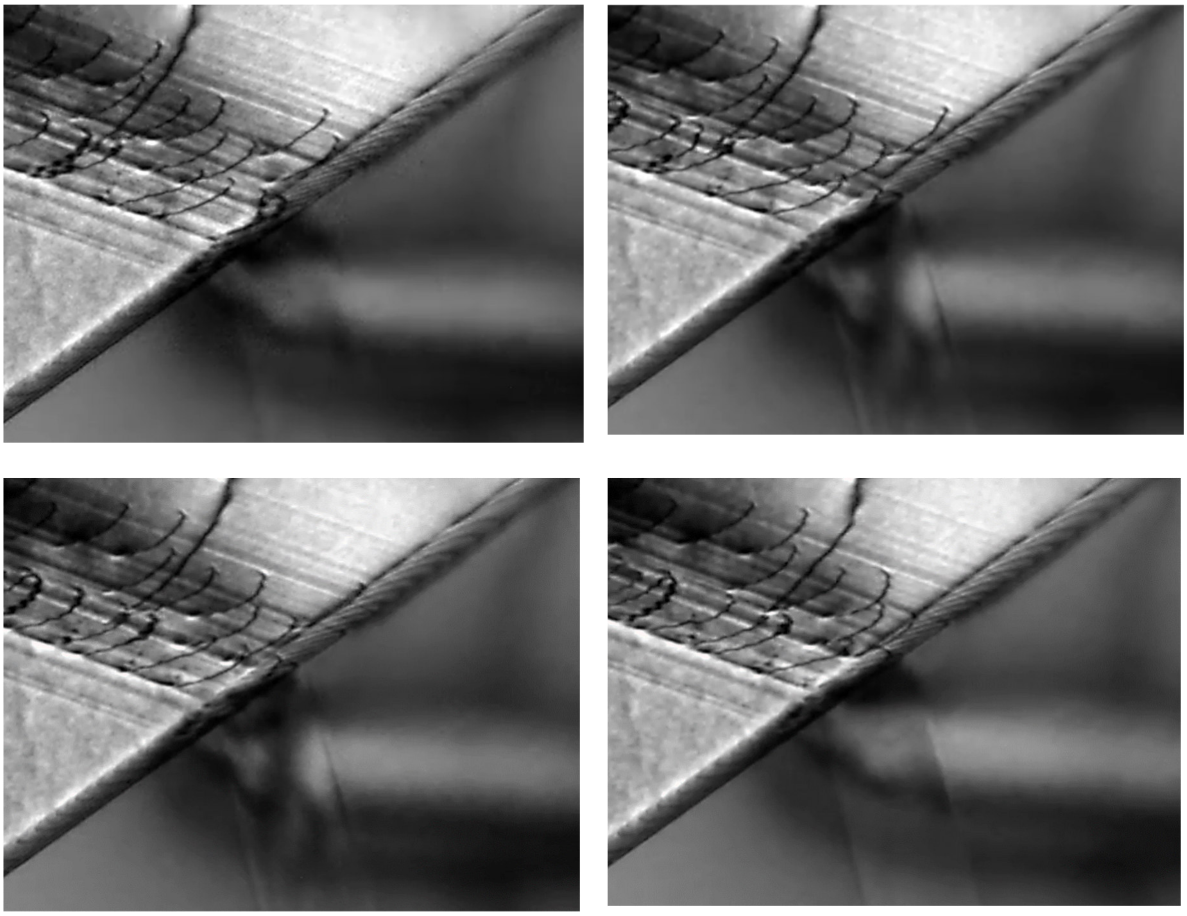
Dislocation/twin boundary interaction seen during in situ TEM straining at 400 ^{0}C of a 304 stainless steel sample. Perfect dislocations are seen impinging on a twin boundary from the left side and the bottom right. Multiple dislocation systems are emitted rapidly from the boundary.

Interakcija dislokacija/dvostruka granica viđena tokom in situ TEM naprezanja na 400 ^{0}C uzorka od nerđajućeg čelika 304. Savršene dislokacije se vide kako zadiru u granicu blizanaca s lijeve i donje desne strane. Višestruki dislokacijski sistemi se brzo emituju sa granice.

https://www.youtube.com/watch?v=IyM7-fjE7mY&ab_channel=JoshKacher

Dislocation/twin boundary interaction

Interakcija dislokacija/granica blizanaca



Dislocations interacting with a sigma 3 twin boundary in 304 stainless steel. Two different dislocation systems interact with the twin boundary, but one is in a g.b=0 condition so is not visible in the video. Video recorded during in situ deformation in the TEM at 400 C. More information can be found at:

Kacher, J., I.M. Robertson. "Quasi-four-dimensional analysis of dislocation interactions with grain boundaries in 304 stainless steel." Acta Mater. 2012, 60 (19), pp. 6657-6672

Abstract

The application of diffraction contrast electron tomography to dynamic experiments involving dislocation interactions with grain boundaries is demonstrated for the first time. Two applications are shown: the first is concerned with post-mortem analysis of dislocation interactions with grain boundaries and illustrates the usefulness of the tomography technique for defect analysis; the second is in conjunction with in situ straining experiments in which the dynamics of dislocation interactions with grain boundaries are observed directly and the resulting structure visualized three-dimensionally. The in situ straining experiments were conducted at room and elevated temperatures to determine the influence, if any, of thermal

processes on the slip transfer mechanism. It was found that increasing the temperature lowers the barrier for dislocation absorption and emission from the boundary and increases the complexity of the interactions, but does not change the fundamental mechanisms governing slip transmission. Previous experimentally determined criteria for slip transmission across boundaries were extended to interactions involving partial dislocations, where it was found that the reaction continues to be governed predominately by reduction of the Burgers vector of the residual grain boundary dislocation left after slip transfer.

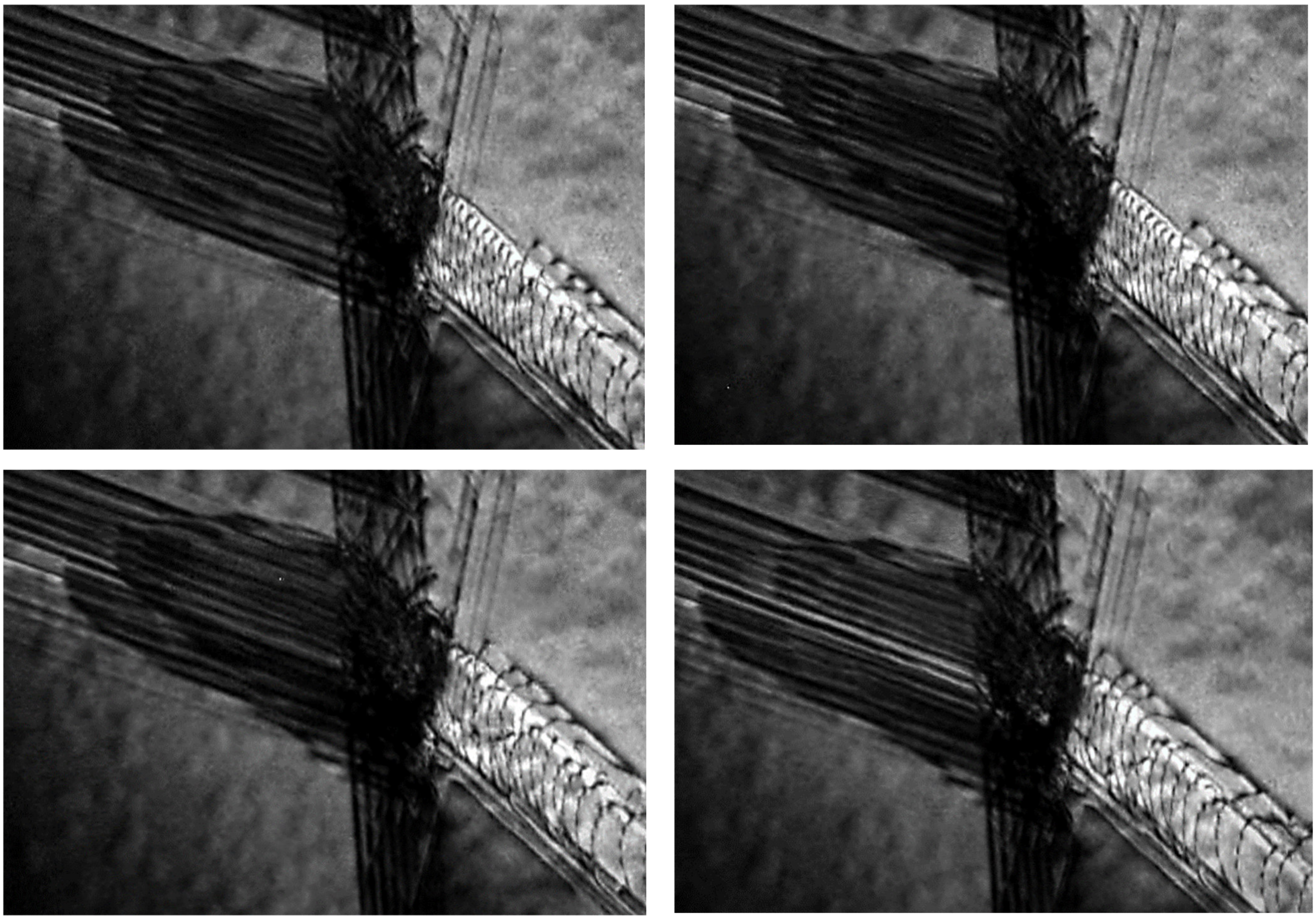
Sažetak

Prvi put je prikazana primjena difrakcijske kontrastne elektronske tomografije u dinamičkim eksperimentima koji uključuju interakcije dislokacija s granicama zrna. Prikazane su dvije primjene: prva se bavi post mortem analizom interakcija dislokacija s granicama zrna i ilustrira korisnost tehnike tomografije za analizu nedostataka; drugi je u sprezi s eksperimentima naprezanja in situ u kojima se izravno promatra dinamika interakcija dislokacija s granicama zrna, a rezultirajuća struktura vizualizira trodimenzionalno. Pokusi naprezanja in situ provedeni su na sobnoj i povišenoj temperaturi kako bi se odredio utjecaj, ako ga ima, toplinskih procesa na mehanizam prijenosa klizanja. Utvrđeno je da povećanje temperature snižava barijeru za apsorpciju i emisiju dislokacija s granice i povećava složenost međudjelovanja, ali ne mijenja temeljne mehanizme koji upravljaju prijenosom klizanja. Prethodno eksperimentalno utvrđeni kriteriji za prijenos klizanja preko granica prošireni su na interakcije koje uključuju djelomične dislokacije, gdje je utvrđeno da je reakcija i dalje pretežno vođena smanjenjem Burgersovog vektora zaostale dislokacije granica zrna koja je ostala nakon prijenosa klizanja.

https://www.sciencedirect.com/science/article/abs/pii/S1359645412005757

Dislocation/grain boundary interaction - absorption and nucleation

Interakcija dislokacija/granica zrna - apsorpcija i nukleacija



Dislocation/grain boundary interaction seen during in situ TEM straining at 400°C of a 304 stainless steel sample. Dislocations are seen impinging on a high angle grain boundary. Partial dislocations nucleate from the boundary into the neighboring grain. The large strain buildup at the boundary results in some dislocations cross-slip.

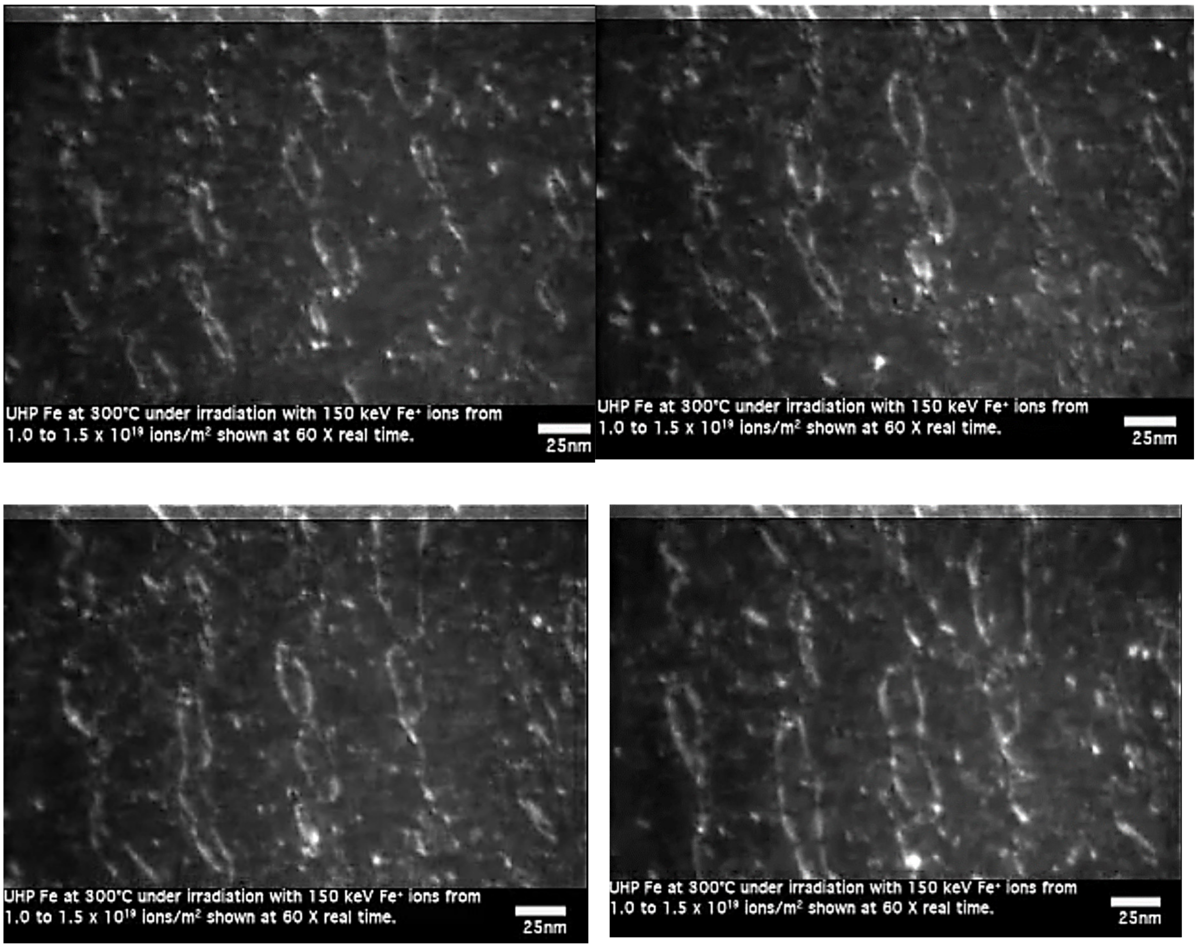
Quasi-four-dimensional analysis of dislocation interactions with grain boundaries in 304 stainless steel.

Interakcija dislokacija/granica zrna viđena tokom in situ TEM naprezanja na 400°C uzorka od nerđajućeg čelika 304. Dislokacije se vide kako zadiru u granicu zrna pod velikim uglom. Djelomične dislokacije nastaju s granice u susjedno zrno. Veliko nakupljanje naprezanja na granici dovodi do poprečnog klizanja nekih dislokacija. Kvazi-četvorodimenzionalna analiza interakcija dislokacija s granicama zrna u nehrđajućem čeliku 304.

https://www.youtube.com/watch?v=JjWdEj_LjZo&ab_channel=JoshKacher

Irradiation Defect Dynamics in Fe

Dinamika zračenja defekta u Fe



In situ movie of defect formation, motion, and coalescence to form extended dislocation structures in Fe under ion irradiation. These structures lead to degradation of the mechanical properties in irradiated metals.

M.Hernandez-Mayoral, Z. Yao, M. Jenkins, M. Kirk, Phil Mag 88(21), 2881 (2008).

For more information: Intermediate Voltage Electron Microscopy (IVEM)-Tandem Facility at Argonne National Laboratory

https://www.anl.gov/ivem

The IVEM Tandem Facility at Argonne National Laboratory is part transmission electron microscope—part ion beam accelerators.

It's also one of about a dozen instruments in the world that lets researchers look at material changes caused by ion irradiation as it happens.

IVEM-Tandem Facility koristi se za in situ TEM studije defektnih struktura u materijalima pod kontroliranim ionskim zračenjem i uvjetima uzorka.

IVEM-Tandem Facility je partnerska ustanova Nuclear Science User Facilities (NSUF) koju podržava Ministarstvo energetike SAD-a, Ured za nuklearnu energiju. To je postrojenje s dvostrukom ionskom zrakom za in situ TEM studije defektnih struktura u materijalima pod kontroliranim ionskim zračenjem/implantacijom i uvjetima uzorka.

Postrojenje IVEM-Tandem jedinstveno je po svojoj sposobnosti da prikaže promjene u strukturi atoma i formiranje defekata tijekom zračenja pri velikom povećanju. Važne prednosti IVEM-a uključuju:

Promatranje stvaranja i razvoja defekata tijekom zračenja u stvarnom vremenu.

Dobro kontrolirani eksperimentalni uvjeti (konstantna orijentacija i površina uzorka, temperatura uzorka, vrsta iona, energija iona, brzina doze, doza i primijenjeno naprezanje).

Usavršiti i potvrditi simulacije računalnih modela defektnih stanja zračenja.

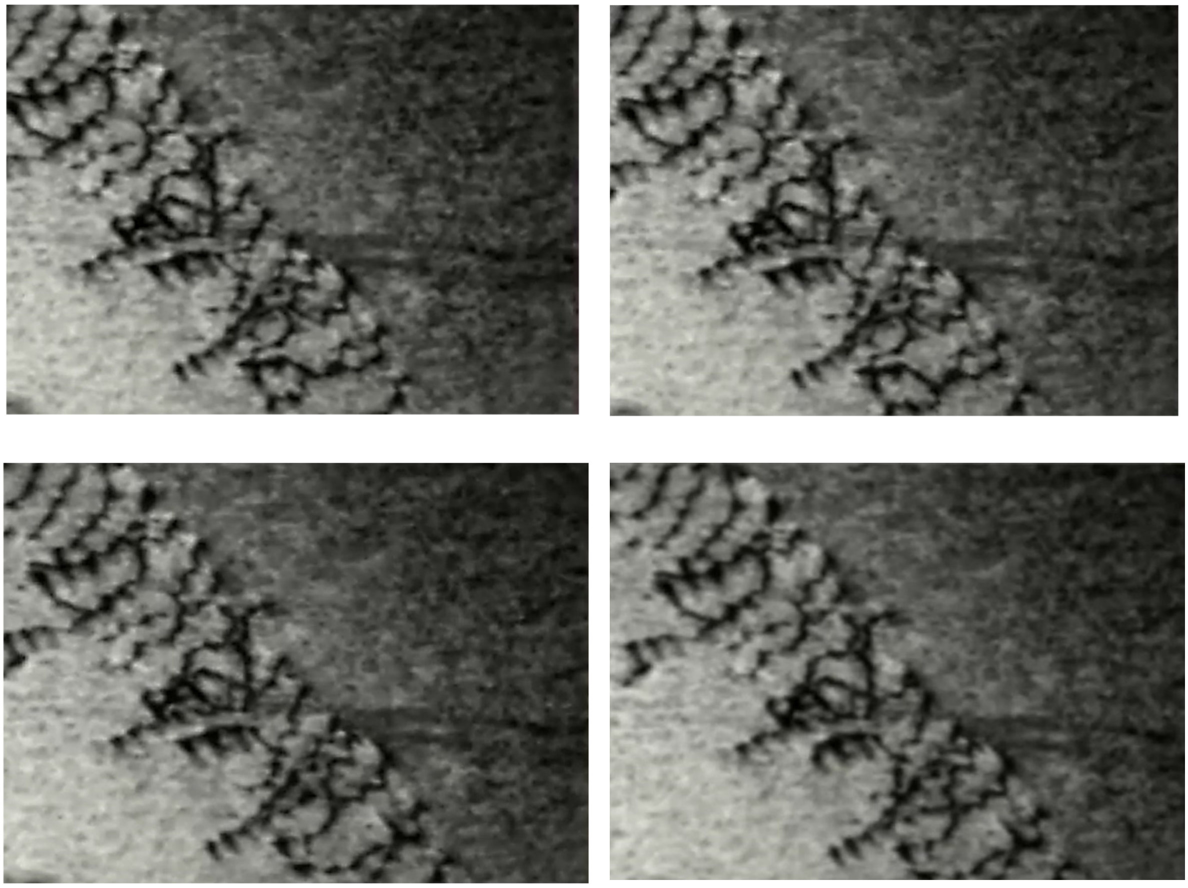
Oštećenje visokim dozama iona nastaje u satima, a ne u godinama koje bi zahtijevale takvo oštećenje u nuklearnom reaktoru, podupirući studije odgovora materijala na visoke doze zračenja česticama (iona i neutrona).

In situ ionsko zračenje ne stvara nikakvu radioaktivnost u uzorcima.

https://www.youtube.com/watch?v=7TkxCJiHtBU&ab_channel=NuclearEngineeringatArgonne

Irradiation Embrittlement in 304 SS with ion irradiation

Kretanje dislokacije u 304 SS sa ionskim zračenjem



Movie illustrating dislocation motion with in situ straining and with ion irradiation. Material is 304 stainless steel held in situ at 400°C. Irradiation was with 1 MeV Kr ions to dose of $3x10^{13}$ ions/cm^2. Note the pinning of dislocations by irradiation defects impedes motion in the irradiated material, which results in its embrittlement.

J. Kacher, I. M. Robertson (U. Illinois at Urbana-Champaign), “Quasi-four-dimensional analysis of dislocation interactions with grain boundaries in 304 stainless steel,”Acta Materialia 60 (2012) 6657.

M. Briceño et al. (U. Illinois at Urbana-Champaign), “Effect of ion irradiation-produced defects on the mobility of dislocations in 304 stainless steel, J. Nucl. Mater. 409 (2011) 18.

(size bar is 100 nm and is 1/3 the width of the ion irradiated panel)

Movie Courtesy of: Ian M. Robertson Research Group, Dept. Of Materials Science & Engineering, U. of Illinois at Urbana-Champaign, http://robertson.matse.illinois.edu

For more information: Intermediate Voltage Electron Microscopy (IVEM)-Tandem Facility at Argonne National Laboratory, http://www.ne.anl.gov/ivem/

Film koji ilustruje kretanje dislokacije i naprezanjem i sa ionskim zračenjem. Materijal je nerđajući čelik 304 koji se drži in situ na 400°C. Ozračenje je bilo sa 1 MeV Kr jona do doze od $3x10^{13}$ jona/cm^2. Imajte na umu da pričvršćivanje dislokacija defektima zračenja ometa kretanje u ozračenom materijalu, što rezultira njegovom krhkošću.

J. Kacher, I. M. Robertson (U. Illinois u Urbana-Champaign), “Kvazi-četvorodimenzionalna analiza interakcija dislokacija s granicama zrna u nehrđajućem čeliku 304,” Acta Materialia 60 (2012) 6657.

M. Briceño i dr. (U. Illinois u Urbana-Champaign), “Utjecaj defekata uzrokovanih ionskim zračenjem na pokretljivost dislokacija u 304 nehrđajućem čeliku, J. Nucl. Mater. 409 (2011) 18.

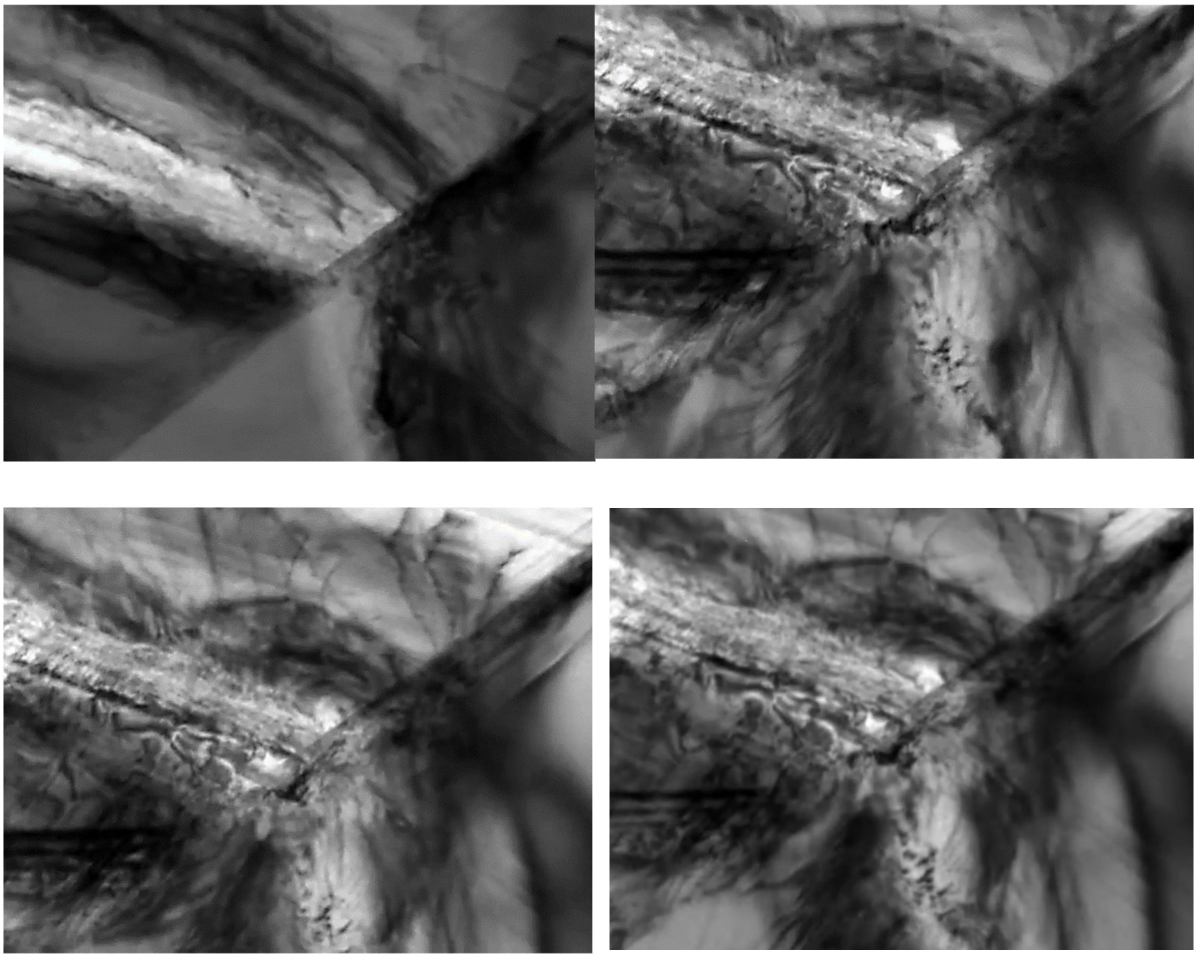
(veličina trake je 100 nm i iznosi 1/3 širine panela ozračenog jonom)

Film ljubaznošću: Ian M. Robertson Research Group, Dept. of Material Science & Engineering, U. of Illinois at Urbana-Champaign, http://robertson.matse.illinois.edu

Za više informacija: Elektronska mikroskopija srednjeg napona (IVEM) - Tandem Facility u Argonne National Laboratory, http://www.ne.anl.gov/ivem/

https://www.youtube.com/watch?v=vOtBwrTYkvA&ab_channel=NuclearEngineeringatArgonne

Twin boundary rupturing - Puknuće u blizini granice



Twin boundary 'breaking' after the passage of many dislocations. Video taken during in situ TEM straining of 304 stainless steel at 400°C. For analysis of dislocation interaction at earlier point, see:

Kacher, J., I.M. Robertson. “Quasi-four-dimensional analysis of dislocation interactions with grain boundaries in 304 stainless steel.” Acta Mater. 2012, 60 (19), pp. 6657-6672

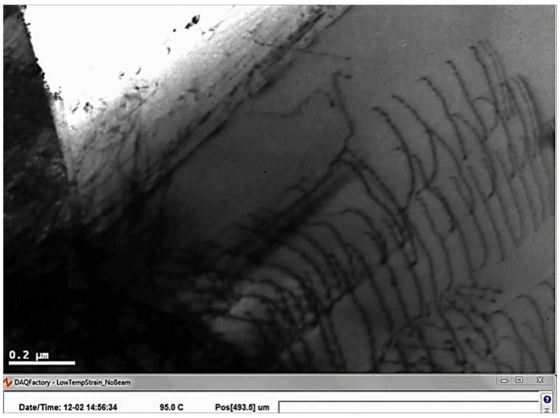
Granica blizanaca 'kidanja' nakon prolaska mnogih dislokacija. Video snimljen tokom in situ TEM naprezanja nehrđajućeg čelika 304 na 400°C. Za analizu interakcije dislokacija u ranijoj tački, pogledajte:

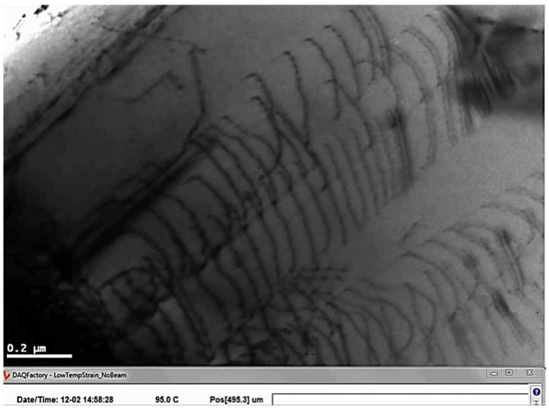
Kvazi-četvorodimenzionalna analiza interakcija dislokacija s granicama zrna u nehrđajućem čeliku 304

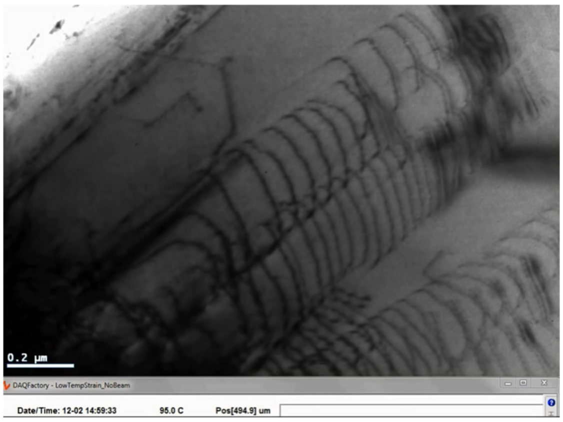
https://www.youtube.com/watch?v=9vTbO-0iYnI&ab_channel=JoshKacher

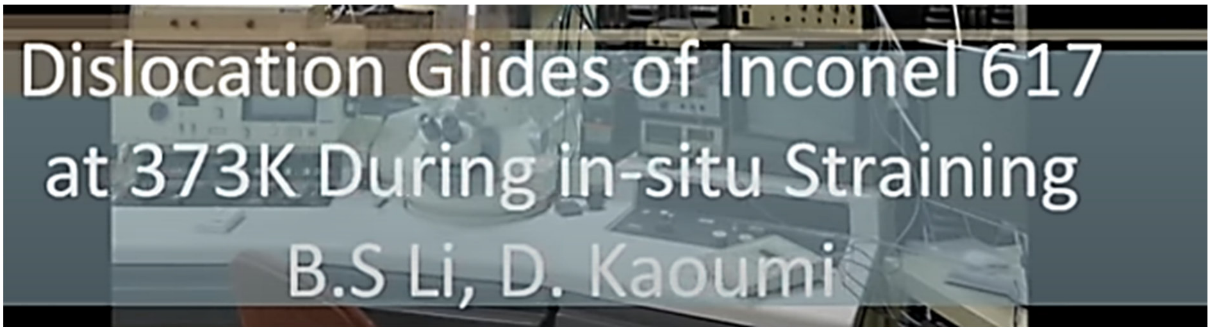
Inconel 617 dislocation glide at 373K

Inconel 617 klize dislokacije na 373K









https://www.youtube.com/watch?v=r-geDwE8Z5Y&ab_channel=Bo-ShiuanLi