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1 VANADIUM ALLOYS

1.1 MICROSTRUCTURAL EXAMINATION OF DEFORMATION IN IRRADIATED V-4CR-4TI COMPRESSION SPECIMENS – D. S. Gelles (Pacific Northwest National Laboratory) **1**

Microstructural examinations have been performed on a series of V-4Cr-4Ti cylindrical compression specimens in order to provide understanding of the observed deformation behavior. Compression testing showed that unirradiated specimens exhibited upper and lower yield points whereas following irradiation the yield stresses were much higher and no yield drop behavior was observed. Both conditions showed evidence of serrated yielding during testing at ~420°C. Microstructural examination of irradiated conditions revealed extensive precipitation making it difficult to observe dislocation structures. Interstitial Impurities were found to form a fine distribution of precipitates following irradiation at ~420°C. Interaction between these precipitates and glide dislocations is apparent.

1.2 ADDITIONAL CHARACTERIZATION OF V-4Cr-4Ti EXPOSED TO FLOWING Li – B. A. Pint (Oak Ridge National Laboratory) **11**

The high temperature tensile behavior of V-4Cr-4Ti specimens was evaluated at 500°C in vacuum with a strain rate of 10-3s-1 after exposure to flowing Li at 400°-700°C. Specimens exposed in the loop exhibited increased strength and decreased ductility and the effect increased with decreasing temperature at the various locations in the loop. Thus, the specimens from the bottom of the hot and cold legs of the loop with exposure temperatures near 450°C showed the highest tensile strength, lowest ductility and also the least dynamic strain aging. For comparison, the tensile behavior of unexposed as-annealed V-4Cr-4Ti specimens from the same batch of specimens also was measured as well as specimens (1) exposed to Li for 1000h at 800°C in a capsule and (2) annealed for 2,350h at 700°C in an evacuated quartz capsule. The present results were compared to similar studies in the literature.

2 CERAMIC COMPOSITE MATERIALS

2.1 DETAILED 3D STRUCTURE OF {111} TETRAHEDRAL VOIDS AND ITS UNIDIRECTIONAL FORMATION IN CUBIC SIC - S. Kondo, Y. Katoh, and L.L. Snead (Oak Ridge National Laboratory) **16**

The {111} tetrahedral voids induced by neutron-irradiation in 3C-SiC were found to be spatially oriented in only one of two possible directions. The tetrahedral shape was unexpected as the surface-to-volume ratio is larger than the alternative {111} octahedral void common in both metals and ceramics. From a geometric viewpoint, all faces of the observed voids are either Si- or C-terminated surfaces. By comparing the surface area with the octahedral void (composed of the both Si- and C-surfaces) of the same volume, the considerable difference of surface energy between the Si(111) and C($\bar{1}\bar{1}\bar{1}$) was implicated.

2.2 MECHANICAL CHARACTERIZATION OF SILICON CARBIDE COMPOSITES FOR HFIR-18J EXPERIMENT IN UNIRRADIATED CONDITION — Y. Katoh, K. Ozawa, L.L. Snead (Oak Ridge National Laboratory), Y.B. Choi (Hiroshima University), T. Hinoki (Kyoto University), and A. Hasegawa (Tohoku University) **21**

A suite of silicon carbide ceramics and composite materials were prepared in various specimen types for the purpose of evaluating irradiation performance at high to very high temperatures in the HFIR RB-18J experiment. Detailed information of the materials prepared is provided. Properties including tensile strength, dynamic elastic modulus, interlaminar shear strength, and trans-thickness tensile strength were determined in an unirradiated condition.

2.3 MODELING THE ELECTRICAL CONDUCTIVITY OF SiC_F/SiC FOR FCI-APPLICATION 35
– G. E. Youngblood and E. Thomsen (Pacific Northwest National Laboratory)

Using a combination 2/4-probe method to measure the electrical resistance across a disc-shaped CVD-SiC sample with evaporated gold electrodes, the average specific contact resistances at 200ºC and 500ºC were determined to be 12±2 and 7±1 Ωcm^2, respectively. The measured transverse electrical conductivity values for a high quality 2D-SiC/CVI-SiC composite made with Nicalon™ type S fabric were much lower than similar values measured for the same material with its SiC seal coat removed. This observation suggests that the pyrocarbon fiber coatings form an interconnected, highly conductive carbon network within the interior regions of the composite, and are largely responsible for the overall transverse electrical conductivity of the composite. At lower temperatures, the composite SiC seal coat should be an effective electrical insulator in the transverse direction across such 2D-SiC/SiC composites. However, the effectiveness becomes less as the temperature increases due to the rapidly increasing conductivity of SiC with increasing temperature. Nevertheless, the seal coat thickness (and type) can easily be adjusted during the composite fabrication to control the overall transverse electrical conductivity, an important parameter in the design of a FCI-structure. A simple three-layer series electrical conduction model fails to explain the unexpected low electrical conductivity values observed for the 2D-Nic S/CVI-SiC composite with a CVD-SiC seal coat. Importantly, up to 700ºC the transverse EC-values for a Nic S/CVI composite (with or without seal coat) appear to meet the desired criteria for FCI-application of < 20 S/m.

2.4 MECHANICAL PROPERTIES OF TRI-AXIALLY BRAIDED CARBON FIBER COMPOSITE - K. Ozawa, Y. Katoh, L.L. Snead, J.W. Klett (Oak Ridge National Laboratory), and W.E. Windes (Idaho National Laboratory) 43

Tensile, inter-laminar shear and trans-thickness tensile properties of tri-axially braided carbon fiber-reinforced carbon matrix (C/C) composites were evaluated. The C/C composites exhibited the quasi-ductile behaviors with initial elastic behavior, second linear portion and non-linear region. Tensile properties of the C/C composites such as ultimate tensile strength, elastic tensile modulus, and proportional limit stress depended on the axial fiber volume fraction. Relatively low inter-laminar shear (2.2 MPa) and quite low trans-thickness tensile

3 FERRITIC/MARTENSITIC STEELS

3.1 RESULTS OF FRACTURE TOUGHNESS TESTS OF SEVERAL RAFM STEELS IRRADIATED IN JP-27 CAPSULE IN HFIR — M. A. Sokolov (Oak Ridge National Laboratory) 49

Large number of 3-point bend multi-notch specimens of several RAFM steels was irradiated at 300°C and 400°C in capsule JP-27 up to ~22 dpa. These specimens were tested in the hot cell and results are reported here.

4 COPPER ALLOYS
No contributions this period

5 REFRACTORY METALS AND ALLOYS
No contributions this period

6 AUSTENITIC STAINLESS STEELS

6.1 PRECIPITATE EVOLUTION IN LOW-NICKEL AUSTENITIC STAINLESS STEELS DURING NEUTRON IRRADIATION AT VERY LOW DOSE RATES - Y. Isobe, M. Sagisaka (Nuclear Fuels Limited), F. A. Garner (Pacific Northwest National Laboratory) and T. Okita (University of Tokyo) **52**

Neutron-induced microstructural evolution in response to long term irradiation at very low dose rates was studied for a Russian low-nickel austenitic stainless steel designated X18H9 that is analogous to AISI 304. The irradiated samples were obtained from an out-of-core support column for the pressure vessel of the BN-600 fast reactor with doses ranging from 1.7 to 20.5 dpa generated at 3.8×10^{-9} to 4.3×10^{-8} dpa/s. The irradiation temperatures were in a very narrow range of 370-375°C. Microstructural observation showed that in addition to voids and dislocations, an unexpectedly high density of small G-phase precipitates was formed that are not usually observed at higher dpa rates in this temperature range.

A similar behavior was observed in a Western stainless steel, namely AISI 304 stainless steel, irradiated at similar temperatures and somewhat higher dpa rates in the EBR-II fast reactor, indicating that irradiation at low dpa rates for many years can lead to a different precipitate microstructure and therefore different associated changes in matrix composition than are generated at higher dpa rates. The contribution of such radiation-induced precipitation to changes in electrical resistivity was measured in the X18H9 specimens and was shown to cause significant deviation from predictions based only on void swelling.

7 FUNCTIONAL MATERIALS – INCLUDING MHD INSULATORS, COATINGS, INSULATING CERAMICS, AND OPTICAL MATERIALS

7.1 COMPATIBILITY OF MATERIALS EXPOSED TO ISOTHERMAL Pb-Li – B. A. Pint (Oak Ridge National Laboratory) **61**

Specimens from six Pb-Li capsule experiments exposed for 1000h at 700° or 800°C were further characterized to determine the extent of attack. The LiAlO2 reaction product appeared to spall in some cases, although this may be due to the Pb-Li cleaning process after exposure. The most unusual result was the large Al loss from the coating on Fe-9Cr-2W after 1000h at 700°C in Pb-Li. If this result indicates the rate of Al loss, it has strong implications for the coating lifetime at this temperature. Also, the mass loss from type 316 stainless steel and resulting microstructure were compared for commercial Pb-Li and high purity Pb-Li. The experimental plan is outlined for the next series of 1000h capsule experiments beginning in January 2009.

7.2 IRRADIATION EFFECTS ON DIELECTRIC MIRRORS IN INERTIAL FUSION POWER REACTOR APPLICATION - L. L Snead and K. Leonard (Oak Ridge National Laboratory), G. E. Jellison Jr. (Fusion Technology Institute), Mohamed Sawan (University of Wisconsin-Madison), and Tom Lehecka (Penn State University) **68**

This paper discusses the neutron exposure expected in the HAPL dielectric mirrors and an experimental program comprised of fabrication of advanced dielectric mirrors and testing of these mirrors exposed to prototypical irradiation environment. Specifically, three dielectric mirror types were fabricated to reflect in the KrF laser wavelength of 248 nm and these mirrors irradiated at ~ 175°C in the dose range of 0.001 to 0.1 x 10^{25} n/m^2 (E>0.1 MeV.) This dose range spans the range calculated with a recently developed 3-D Monte Carlo code. Mirrors were visually inspected following irradiation and reflectivity and laser induced damage threshold measured. All mirrors were intact following irradiation and did not appear to degrade significantly either in reflectivity or damage threshold. This finding is somewhat in contradiction to earlier work on dielectric mirrors, which suggested poor performance of dielectric mirrors at an order of magnitude lower neutron dose. Moreover, the current finding suggests the possibility for using dielectric mirrors to much high dose levels.

8 BREEDING MATERIALS

No contributions this period

9 RADIATION EFFECTS, MECHANISTIC STUDIES, AND EXPERIMENTAL METHODS

9.1 MODELLING THERMODYNAMICS OF ALLOYS FOR FUSION APPLICATION - A. Caro, P. Erhart, M. Serrano de Caro, B. Sadigh (Lawrence Livermore National Laboratory), S.G. Srinivasan, and C. Jiang (LANL). L. Malerba (Belgium), J. Wallenius (Sweden), A. Stukowski (Germany) **81**

We develop a strategy to model radiation damage in FeCr alloys, system in which magnetism introduces an anomaly in the heat of formation of the solid solution that is at the basis of its unique behavior. Magnetism has implications for the precipitation of excess Cr in the *a*' phase in the presence of heterogeneities. These complexities pose many challenges for atomistic (empirical) methods. To address such issues we develop a modified, many-body potential by rigorously fitting thermodynamic properties, including free-energy. Multi-million atom displacement Monte Carlo simulations in the transmutation ensemble, using both our new potential and our new MC code, are able to predict properties of non equilibrium processes like heterogeneous precipitation, and dislocation – precipitate interactions, enabling the study of hardening and embrittlement under irradiation.

9.2 ATOMISTIC STUDIES OF PROPERTIES OF HELIUM IN BCC IRON: COMPARISON OF FE–HE AND FE MATRIX POTENTIALS—David M. Stewart, Stanislav Golubov (Oak Ridge National Laboratory and the University of Tennessee), Yuri Ostesky, Roger E. Stoller, Tatiana Seletskaia, and Paul Kamenski (Oak Ridge National Laboratory) **92**

In fusion applications, helium caused by transmutation plays an important role in the response of RAFM steels to neutron radiation damage. We have performed atomistic simulations using a new 3-body Fe–He inter-atomic potential combined with the Ackland iron potential. The results are compared with older (Wilson) and more recent (Juslin-Nordund) Fe-He pair potentials, and with alternate iron matrices. With the ORNL potential, interstitial helium is very mobile and coalesces together to form interstitial clusters. We have investigated the mobility of these clusters. If the He cluster is sufficiently large the cluster can push out an Fe interstitial, creating a Frenkel pair. The resulting helium-vacancy cluster is not mobile. The ejected SIA is mobile, but is weakly trapped by the He–V cluster. If more helium atoms join the He–V cluster, more Fe interstitials can be pushed out, and they combine to form an interstitial dislocation loop. The reverse process is also studied. Multiple helium atoms can be trapped in a single vacancy, and if there are few enough, the vacancy can recombine with an Fe interstitial to create a helium interstitial cluster. These mechanisms are investigated together in larger simulations that examine the nucleation of He defects. Results are compared based on temperature, interatomic potentials used and helium concentration.

9.3 IMPLEMENTATION OF A Fe-He 3-BODY INTERATOMIC POTENTIAL - R. E. Stoller (Oak Ridge National Laboratory), S. I. Golubov (Oak Ridge National Laboratory and the University of Tennessee), P. J. Kamenski (University of Wisconsin, Madison), T. Seletskaia and Yu. N. Osetsky (Oak Ridge National Laboratory) **97**

The implementation of a recently-developed interatomic potential describing the interactions of helium in bcc iron is described. This He-Fe potential was based on an empirical fit to the results of *ab initio* calculations of both the formation and relaxation energies of small helium defect structures in iron. The fitting database included substitutional and interstitial helium, as well as small helium and helium-vacancy clusters. In contrast to previous He-Fe pair potentials, fitting the *ab initio* forces and energies required the use of a three-body interaction term. The implementation of this potential for atomistic simulations using molecular dynamics presented certain challenges which are discussed here to facilitate its further use in materials research, particularly to investigate the behavior of iron-based alloys that may be employed in fusion energy systems.

9.4 STEADY-STATE SIZE DISTRIBUTION OF VOIDS IN METALS UNDER CASCADE IRRADIATION - A.V. Barashev (The University of Liverpool), S.I. Golubov (Oak Ridge National Laboratory, University of Tennessee) **108**

The steady state of the void population predicted by the theory under cascade-irradiation conditions has been analyzed. The following conclusions have been drawn.

1) The theoretical steady-state SDF of voids is described by a Gaussian distribution, which is quite narrow, in contrast to much bigger spread of void sizes observed.
2) At high void density, when $\alpha >> 1$, the irradiation dose required to reach the steady state is higher than those at which void lattices are observed. Hence, the void size saturation of randomly distributed voids and in the lattice are not related to each other.
3) At low void density, when $\alpha \leq 1$, the irradiation dose required to reach the steady state is relatively small and might be a reason for the incubation period of swelling frequently observed.

9.5 KINETICS OF SELF-INTERSTITIAL CLUSTER AGGREGATION NEAR DISLOCATIONS AND THEIR INFLUENCE ON HARDENING - Ming Wencor (University of California-Los Angeles), Akiyuki Takahashi (Tokyo Univ. of Science) and Nasr M. Ghoniem (University of California-Los Angeles) **114**

Kinetic Monte Carlo (KMC) computer simulations are performed to determine the kinetics of SIA cluster "clouds" in the vicinity of edge dislocations. The simulations include elastic interactions amongst SIA clusters, and between clusters and dislocations. Results of KMC simulations that describe the formation of "SIA clouds" during neutron irradiation of bcc Fe and the corresponding evolution kinetics are presented, and the size and spatial distribution of SIA clusters in the cloud region are studied for a variety of neutron displacement damage dose levels. We then investigate the collective spatio-temporal dynamics of SIA clusters in the presence of internal elastic fields generated by static and mobile dislocations. The main features of the investigations are: (1) determination of the kinetics and spatial extent of defect clouds near static dislocations; (2) assessment of the influence of localized patches of SIA clouds on the pinning-depinning motion of dislocations in irradiated materials; and (3) estimation of the radiation hardening effects of SIA clusters. The critical stress to unlock dislocations from self-interstitial atom (SIA) cluster atmospheres and the reduced dislocation mobility associated with cluster drag by gliding dislocations are determined.

9.6 LENGTH-SCALE EFFECTS IN CASCADE DAMAGE PRODUCTION IN IRON - R. E. Stoller (Oak Ridge National Laboratory), P. J. Kamenski (University of Wisconsin, Madison) and Yu. N. Osetsky (Oak Ridge National Laboratory) **131**

Molecular dynamics simulations provide an atomistic description of the processes that control primary radiation damage formation in atomic displacement cascades. An extensive database of simulations describing cascade damage production in single crystal iron has been compiled using a modified version of the interatomic potential developed by Finnis and Sinclair. This same potential has been used to investigate primary damage formation in nanocrystalline iron in order to have a direct comparison with the single crystal results. A statistically significant number of simulations were carried out at cascade energies of 10 keV and 20 keV and temperatures of 100 and 600K to make this comparison. The results demonstrate a significant influence of nearby grain boundaries as a sink for mobile defects during the cascade cooling phase. This alters the residual primary damage that survives the cascade event. Compared to single crystal, substantially fewer interstitials survive in the nanograined iron, while the number of surviving vacancies is similar or slightly greater than the single crystal result. The fraction of the surviving interstitials contained in clusters is also reduced. The asymmetry in the survival of the two types of point defects is likely to alter damage accumulation at longer times.

10 DOSIMETRY, DAMAGE PARAMETERS, AND ACTIVATION CALCULATIONS
No contributions this period

11 MATERIALS ENGINEERING AND DESIGN REQUIREMENTS
No contributions this period

12 IRRADIATION FACILITIES AND TEST MATRICES

12.1 TITAN TASK 2-3 SILICON CARBIDE BEND STRESS RELAXATION CREEP EXPERIMENT - Y. Katoh (Oak Ridge National Laboratory), Y.B. Choi (Hiroshima University), and T. Hinoki (Kyoto University) **140**

A study on transient irradiation creep deformation of silicon carbide is being undertaken as a part of Task 2-3 of the US/Japan TITAN collaboration on fusion materials and blanket technology. The Phase-IA program is the first of the two irradiation campaigns planned for studying the bend stress relaxation (BSR) creep of ceramics and composites under neutron irradiation. The objective of experiment is to gain understanding of the stress relaxation and transient creep behavior of SiC composites and constituents under neutron irradiation at elevated temperatures. The neutron irradiation will be performed using hydraulic and fixed rabbit facilities of the High Flux Isotope Reactor. The Phase-IA program irradiates 8 rabbit capsules; 5 in hydraulic and 3 in fixed facility. Target irradiation temperatures in the Phase-I are 300, 500, 800, and 1200ºC. The minimum number of rabbit capsules to be irradiated in entire Phase-I campaign will be 15. The present schedule assumes the initiation of irradiation in early 2009.

12.2 IRRADIATION EXPERIMENT DESIGN FOR TITAN RABBITS WITH FERRITIC STEEL, TUNGSTEN, AND NICKEL SPECIMENS - E. Popov, J. McDuffee, M. Sokolov, (Oak Ridge National Laboratory) **146**

Several designs of capsules for irradiating different specimens are described in this work. The specimens are of tensile, disk, or plate configurations from ferritic steels (FS), tungsten, and nickel. Some designs are complete, and others are still in the temperature evaluation phase. Two capsules (T9A1 and T9A2) are currently being irradiated in the hydraulic tube of HFIR as of January 2009

12.3 PULSED E-BEAM THERMO-FATIGUE SYSTEM (PETS)—Chad Duty, Lance Snead (Oak Ridge National Laboratory), John Sethian (Naval Research Laboratory) **155**

A unique pulsed electron beam system has been developed for the thermo-mechanical fatigue testing of potential first wall materials for inertial fusion energy program. The Pulsed E-beam Thermo-fatigue System (PETS) is a high perveance system that pulses a 70 kV, 74 A electron beam at rates up to 100 Hz. The pulse width ranges from 0.5 to 1.5 μs and is confined to an area of 1 cm^2. Following design and fabrication of the PETS system, it was installed at ORNL in the fall of 2007. Several technical challenges have precluded its use as a thermo-fatigue system, but plans are in place to resolve many of these issues and move toward a fully-operational system by the summer of 2009.