Status of ITER Task T213 Collaborative Irradiation Screening Experiment on Cu/SS Joints in the Russian Federation SM-2 Reactor - D.J. Edwards (PNNL), S.A. Fabritsiev (D.V. Efremov Institute, St. Petersburg, Russia), A.S. Pokrovsky (SRIAR, Dimitrovgrad, Russia), S.J. Zinkle (ORNL), R.F. Mattas (ANL), R.D. Watson (SNL)

OBJECTIVE

This report summarizes the current status of specimen fabrication and details of the U.S. participation in the planned irradiation experiment in the R.F. SM-2 reactor.

SUMMARY

Specimen fabrication is underway for an irradiation screening experiment planned to start in January 1996 in the SM-2 reactor in Dimitrovgrad, Russia. The purpose of the experiment is to evaluate the effects of neutron irradiation at ITER-relevant temperatures on the bond integrity and performance of Cu/SS and Be/Cu joints, as well as to further investigate the base metal properties of irradiated copper alloys. Specimens from each of the four ITER parties (U.S., E.U., Japan, and R.F.) will be irradiated to a dose of ~0.2 dpa at two different temperatures, 150 and 300°C. The specimens will consist of Cu/SS and Be/Cu joints in several different geometries, as well as a large number of specimens from the base materials. Fracture toughness data on base metal and Cu/SS bonded specimens will be obtained from specimens supplied by the US. Due to a lack of material, the Be/Cu specimens supplied by the US will only be irradiated as TEM disks.

INTRODUCTION

ITER has begun to investigate the possible methods by which the first wall and divertor assemblies can be fabricated to produce a viable structure of Be/Cu/SS. This work is being conducted under ITER Tasks T212 and T221, and is concerned primarily with the fabrication of large full scale panels produced by a variety of methods, including hot isostatic pressing (HIP), explosion bonding, and brazing. All four of the ITER home teams are involved in the production of these panels and joints. In the United States the production, nondestructive evaluation (NDE), and evaluation of the properties of the bonded panels are being pursued through a collaboration between DOE national laboratories, industry, and universities.

The effects of neutron irradiation on Cu/SS and Be/Cu joints has never been investigated to the knowledge of the authors, which causes serious concern since the fabrication method chosen to produce the panels may be strongly influenced by how the bonds perform under irradiation during ITER operation. To address this concern ITER Task T213 has been given the responsibility of irradiating specimens from the panels and joints produced under Tasks T212 and T221.

A series of low dose (≤0.3 dpa) irradiation screening experiments are being planned through 1997 to help evaluate the effects of neutron irradiation on the properties of joints produced by the methods mentioned earlier. Later experiments will irradiate joints deemed to be acceptable by the earlier evaluations, and at doses up to 3-5 dpa to investigate the irradiation effects at dose levels representative of the ITER Basic Physics Phase.

The first experiment is scheduled to start in January 1996, and will include specimens from each of the four home teams. Details of the irradiation conditions, choice of materials, and specimen geometries are discussed in the following sections.

IRRADIATION CONDITIONS

Specimens of each type of joint and material will be irradiated to ~0.2 dpa in two separate capsules. The two capsules will be irradiated in succession in the Channel 5 position of the SM-2 reactor core. The fast neutron fluence in this position is 3 x 10^{21}n/cm^2 (E>0.1 MeV), with a corresponding thermal neutron fluence of 3 x 10^{21}n/cm^2 (E<0.67 eV). The first capsule will be irradiated at a temperature of 150°C ±10°C, the second capsule at 300°C ±10°C. The capsules will be irradiated in a closed water loop (Channel 5), where the temperature of the water is controlled by varying the water pressure and flow rate of the water through the loop. The specimens will be enclosed in He-filled stainless steel subcapsules to protect them from the reactor coolant water.

The temperature of the specimens will determined indirectly by measuring the water temperature at various positions within the water loop. The ratio of capsule temperature to coolant temperature has been calibrated in previous experiments, so that the water temperature and pressure inside the closed loop can be varied to maintain the desired specimen temperature. Heat transfer analysis codes will then be used to calculate the temperature of the specimens. Gamma heating in this channel position is relatively low (10 W/gm), so the heating will occur by thermal transfer from the coolant water. The temperature inside the capsule will be passively monitored using materials with different melting temperatures to establish the temperature limits of the irradiation experiment. No Cd-shielding will be used in this experiment as the low irradiation dose will yield low levels of the transmutants nickel and zinc. Fast and thermal neutron fluence monitors will be used in this experiment to measure the dose.

STATUS OF SPECIMEN FABRICATION IN U.S.

1. Materials

The first panels of Cu/SS produced by ITER Task T212 were GlidCop™ Al15 bonded to 316L by two methods - explosive bonding and hot isostatic pressing (HIP). Although CuAl25, which is produced by SCM Metal Products, is considered to be the prime ITER candidate copper alloy, at the time the panels were produced (Fall 1994) only two panels of stress-relieved CuAl15 were available from SCM Metal Products. The small size of the two CuAl15 panels (0.64 cm x 25.4 cm x 106.7 cm, 1.27 cm x 50.8 cm x 121.9 cm) resulted in only a small section of each subsequent Al15/316L panel (5.08 cm x 20.3 cm) being made available for this first irradiation experiment; the remainder was used to evaluate the two bonding techniques. The composition of the starting materials is provided in Table 1.

The Be/Cu joints were supplied by Dr. R. Watson from Sandia National Laboratories. Four types of joints were to be included in the irradiation experiment, however, some of the materials did not survive the electrical discharge machining (EDM) into test specimens. Joints of electroplated copper to beryllium and explosively bonded beryllium to copper withstood the EDM specimen machining, but Be/Cu joints formed by inertia welding or brazing broke apart during the machining. For the available Be/Cu joints only TEM disks were fabricated due to the small size of the joints.

Because of the lack of available bonded material, base metal specimens from CuAl25 in the cross rolled and annealed condition (CR & A) and in the as-HIPped condition were included in the matrix. The two separate CuAl25 conditions were made from the same starting powder, LOX-80. This powder has been boron deoxidized to remove any free Cu_2O, and the powder was screened to below 80 mesh to narrow the size range of the starting powders. The screening eliminated or reduced the

Table 1 Composition of Materials (wt%)

CuAl15	99.65 Cu	0.15 Al	0.01 Fe	0.01 Pb	0.13 O	~250 ppm B	--------	--------
CuAl25*	99.65 Cu	0.25 Al	0.01 Fe	0.01 Pb	0.22 O	~250 ppm B	--------	--------
CuNiBe	99.5 Cu	0.5 Be	1.8 Ni	0.2 Al	0.2 Si	--------	--------	--------
Be/Cu	50.0 Be	50.0 Cu	--------	--------	--------	--------	--------	--------
316L	68.0 bal Fe	2.0 Mn	1.0 Si	17 Cr	12 Ni	0.045 P	0.03 S	0.03 C

* LOX -80 CuAl25 powder, ITER Grade 0 (IG0)

number of large copper powder particles that tended to have large particles of α-Al_2O_3 (~1 μm) attached to their surfaces, thereby achieving a more uniform distribution of the small Al_2O_3 particles responsible for the properties of this alloy.

The as-HIPped plate was consolidated at ~14:1 reduction ratio at 980°C. No further thermomechanical treatments were given to the plate, simulating the condition of CuAl25 powder HIPped directly to stainless steel, which is one processing route being considered for the ITER first wall.

The cross-rolled and annealed CuAl25 is the result of improved thermomechanical processing that, in conjunction with the LOX-80 starting powder, yields better elongation up to temperatures as high as 350°C [1]. The extruded plate is given an additional warm rolling treatment perpendicular to the original extrusion direction, yielding approximately 60% reduction. The plate is then annealed at 1000°C for 1 hour to stress relieve the plate, producing strength levels closer to that of the as-extruded plate. The final properties of the cross-rolled and annealed plate at room temperature are: σ_{UTS}= 421 MPa, σ_{YS}= 331 MPa, ε_{total} = 27%, and an electrical conductivity 86% IACS. The properties of the as-HIPped plate are almost identical at room temperature. This composition and powder processing has been unofficially designated as ITER Grade 0 (IG0) by SCM Metals.

Two large plates of Brush Wellman's CuNiBe Hycon 3HP™ were purchased, one plate in the HT condition (fully hardened temper, 69% IACS, hardness R_B= 92) and the second in the AT condition (solution annealed and aged, 65% IACS, R_B= 92). Additional mechanical tests are planned to better establish the starting mechanical properties of the CuNiBe alloys. A small amount of Hycon 3HP overaged to produce a higher conductivity/lower strength condition was also included in the irradiation matrix on a limited basis. The conductivity of this material was 74% IACS, with a σ_{YS}= 633 MPa. In addition to the copper alloys, a limited number of specimens of the 316L stainless steel used to make the Cu/SS panels were included in the matrix.

2. Specimen Geometry

At the time the specimen matrix was set up, no data were available from the evaluations on the Cu/SS panels being performed under Task T212. Consequently, the choice of specimen geometries was made based on the necessity of testing in hot cells and using geometries considered somewhat standard for testing materials. Unfortunately, the small size of the Cu/SS panels (5.08 cm x 20.3 cm) restricted the type of specimens that could be included in the irradiation experiment. It was decided to use miniature bend bars (Fig. 1) to evaluate the fracture behavior of the Cu/SS interface, lap shear specimens (Fig. 2) of different overlaps to measure the shear strength of the interface, and butt tensile specimens (Fig. 3) to provide additional data on the interface properties. The complete matrix of specimens for the Cu/SS, Be/Cu joints, and base materials is provided in Tables 2 & 3, respectively.

Note that in Figure 1 the bend bar configuration was varied to change the orientation of the interface with respect to the notch. The idea was to observe the behavior of the crack as it approached the interface, to see whether it deflected away from the interface into the base material, or propagated across or along the interface. TEM disks were also included in the irradiation experiment, and are illustrated in Figure 4 for the base materials, Cu/SS, and the Cu/Be joints.

The bend bars for the Cu/SS specimens are too small to allow significant precracks to be grown into the specimen. Therefore the specimens were precracked a total of 0.76 mm as measured from the outside edge of the specimen (notch + crack length = 0.76 mm). Details of the precracking will be presented in a later report.

Table 2 Bonded Cu/SS matrix for RBT-10 Task T213 irradiation experiment. Specimens listed are for one irradiation temperature only.

	TEM Disks	Butt Tensile	Lap Tensile W = 1.5 mm	2mm	3-Point Bend Bars Angle/Notch entry 0	45/Cu	45/SS
GlidCop Al15/316L Explosively Bonded	5	4	4	4	2	2	2
GlidCop Al15/316L HIP	5	4	4	4	2	2	2
Be/Cu Explosion Bonded	5	---------	---------	---------	--------	--------	--------
Be/Cu Electroplated Cu	5	---------	---------	---------	--------	--------	--------
Total	20	8	8	8	4	4	4

Table 3 Base materials matrix for RBT-10 Task T213 irradiation experiment. Specimens listed are for one irradiation temperature only.

	TEM disks	STS Tensile	LTS Fatigue	Disk Compact Tension	3 Point Bend Bars
GlidCop Al25 CR & Annealed	5	4	6	2	2
GlidCop As-HIPped	5	4	---------	2	2
CuNiBe HT (CW & aged)	5	4	---------	2	2
CuNiBe AT (SA & aged)	5	4	6	2	2
CuNiBe High Cond. (74% IACS)	5	4	---------	---------	---------
316SS	5	4	---------	---------	---------
Total	30	24	12	8	8

Data on the fracture toughness of irradiated GlidCop CuAl25 and CuNiBe are almost nonexistent, so two types of fracture toughness specimens were included in this experiment. The bend bars and disk compact tension (DCT) specimens (Figs. 5 & 6) are based on geometries and sizes used in other parts of the U.S.
fusion program [2-4]. The bend bars and DCT specimens will be precracked according to ASTM Standard E399-90.

The STS tensile and LTS fatigue specimens shown in Figs. 7 & 8, respectively, are Russian specimen geometries that have been used in previous irradiation experiments.

All specimens included in the irradiation experiment are being laser engraved.

FUTURE WORK

The control specimens need to be engraved, and afterwards a fraction of them will be shipped to Russia for testing. Both the unirradiated and irradiated tensile and fatigue specimens will tested in Russia. Fracture toughness testing on the unirradiated control specimens will begin shortly, as well as characterization of the various materials and joints. Post-irradiation testing will commence six weeks after the specimens are removed from reactor to allow sufficient cooling times. U.S. fracture toughness specimens will be shipped to the United States for testing in existing facilities.

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Bend bar (Cu/SS joints)

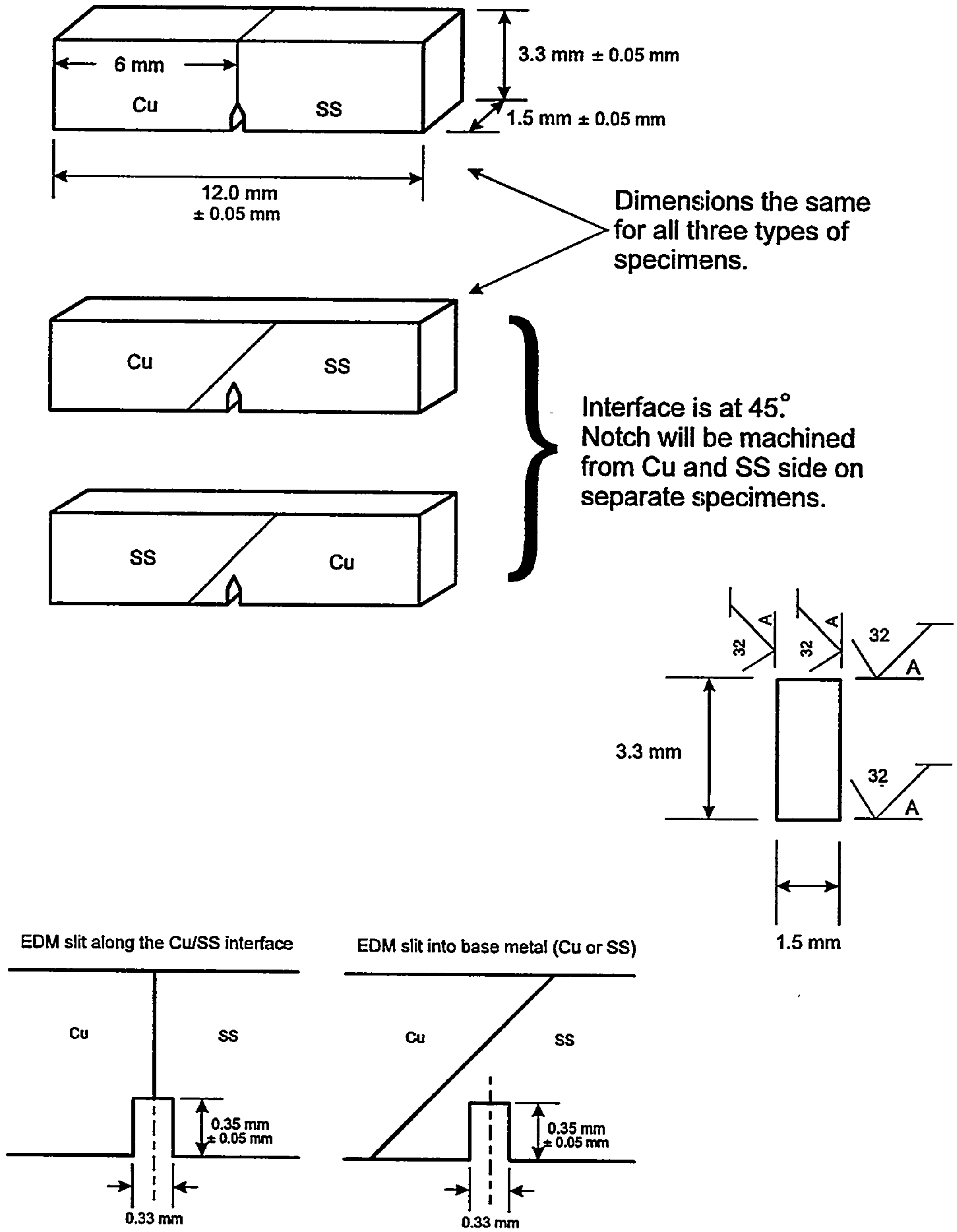

Figure 1 Bend bar configuration for the Cu/SS joints. Note the variation of the interface with respect to the notch.

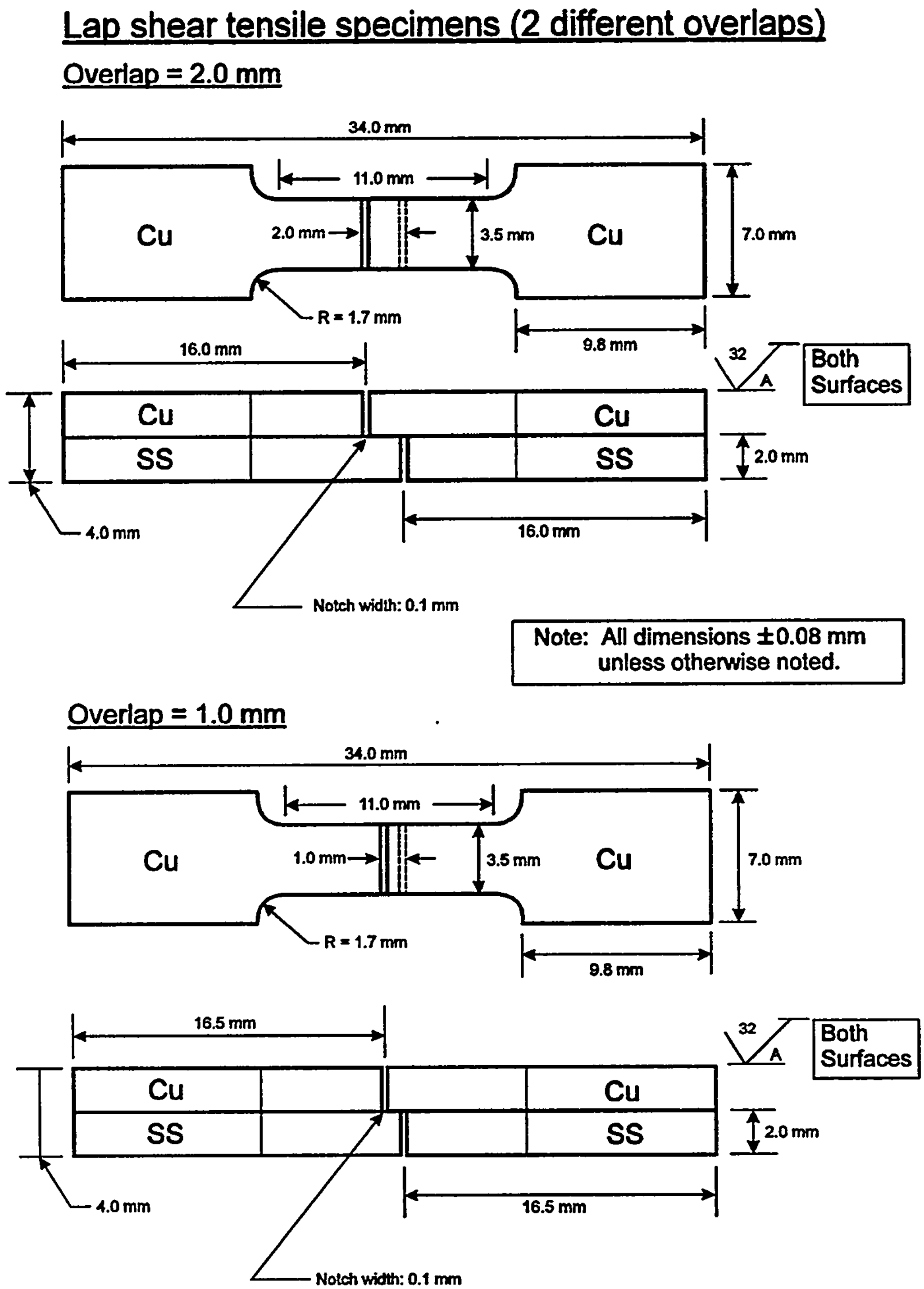

Figure 2 Lap shear geometry for testing the Cu/SS joints.

Tensile specimens for Cu/SS joints

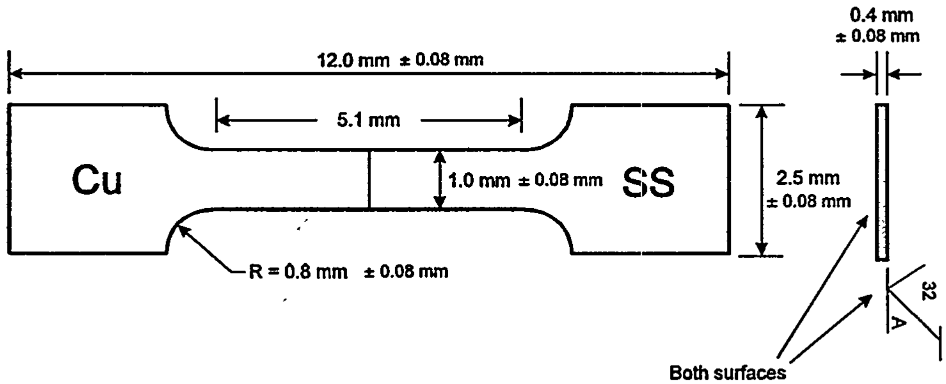

Figure 3 Butt tensile specimen geometry for the Cu/SS joints.

TEM Disks

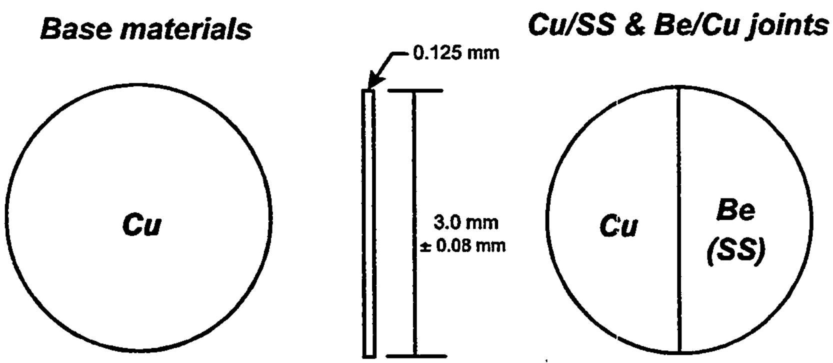

Figure 4 TEM disk geometry for the Cu/SS, Be/Cu, and base materials.

Bend bar (base material)

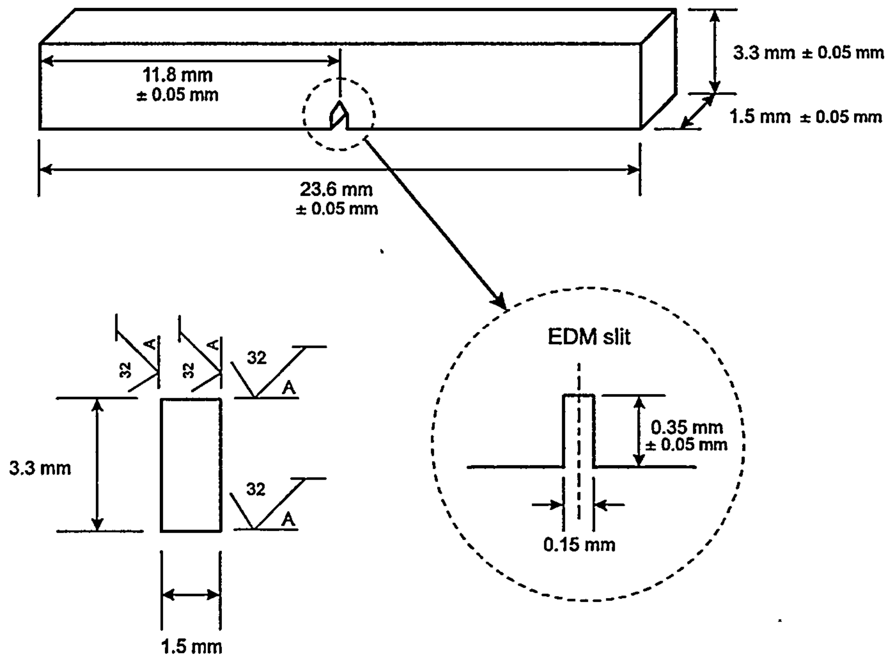

Figure 5 Bend bar for base materials. Based on ASTM standards, but scaled down proportionally in size for the irradiation experiment.

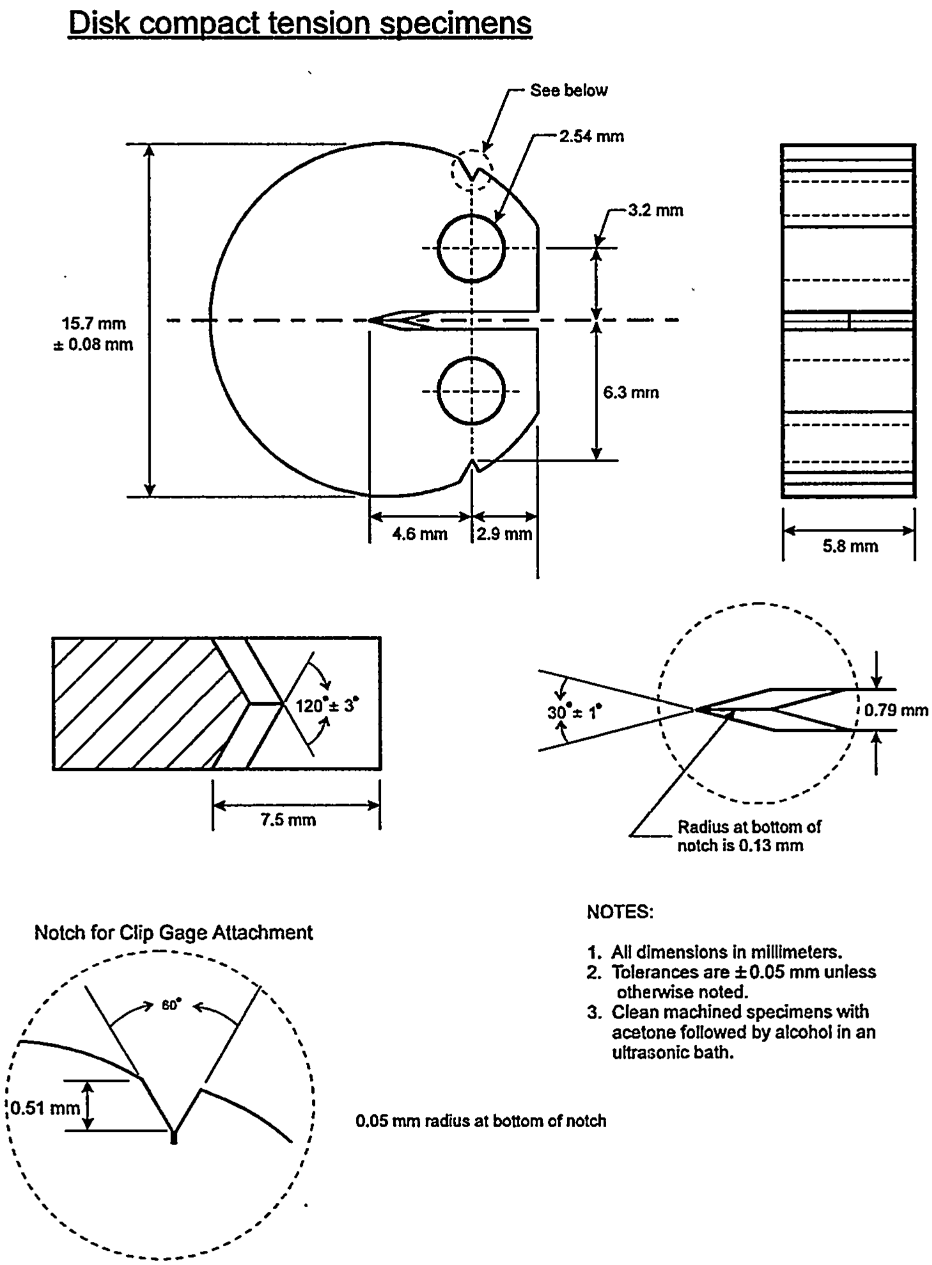

Figure 6 Disk compact tension specimen geometry for the base materials.

STS specimen dimensions

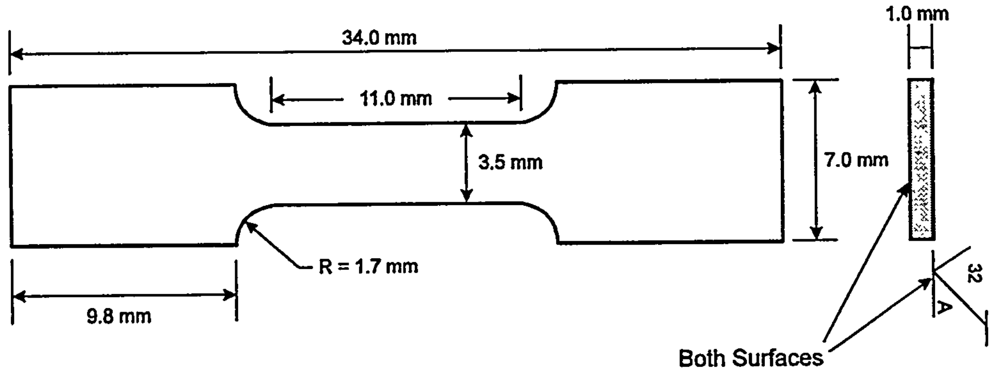

Figure 7 STS tensile specimen geometry for the base materials.

LTS fatigue specimen dimensions

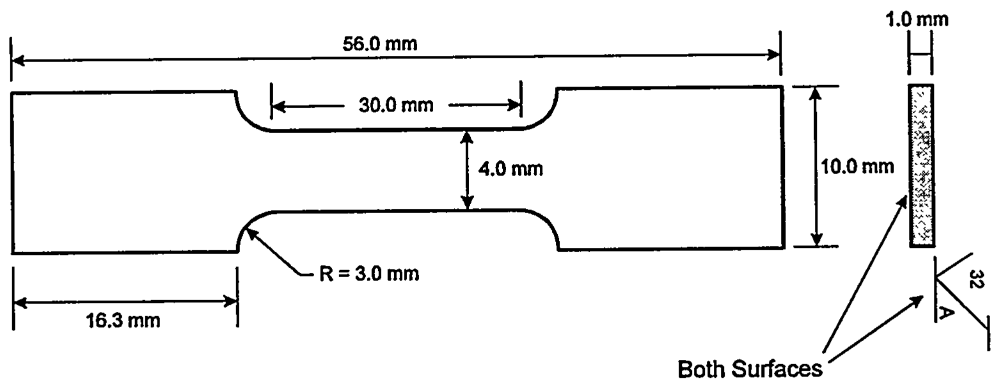

Figure 8 LTS bending fatigue specimen geometry for base materials.