FRACTURE TOUGHNESS OF OXIDE-DISPERSION STRENGTHENED COPPER -

D. J. Alexander, Oak Ridge National Laboratory

OBJECTIVE

The fracture toughness of an oxide-dispersion strengthened copper alloy was examined to determine the suitability of such alloys as candidate materials for first wall and divertor structural applications for ITER.

SUMMARY

The fracture toughness of an oxide-dispersion strengthened copper alloy AL-15 has been examined at room temperature and 250°C, in air and in vacuum (< 10^{-6} torr). Increasing test temperature causes a significant decrease in the fracture toughness of this material, in either air or vacuum environments. In addition, specimens oriented in the T-L orientation (crack growth parallel to the extrusion direction) show significantly lower toughness than those in the L-T orientation (crack growth perpendicular to the extrusion direction).

PROGRESS AND STATUS

Introduction

High-strength copper alloys with high thermal conductivity are attractive candidates for some structural applications in ITER. One type of copper alloys are dispersion-strengthened by internal oxidation. An early version of this alloy, called GLIDCOP AL-15, contains 0.15 wt % Al that has been internally oxidized to produce small Al_2O_3 particles in a copper matrix. Testing of unirradiated material was conducted to determine the fracture toughness as a function of test temperature and specimen orientation. Preliminary testing [1] had shown that the toughness of the AL-15 material decreased significantly as the test temperature increased from 22 to 250°C, although the tensile properties showed only a slight change over the same temperature range [2]. This suggested that an environmental effect might be responsible for the decrease in toughness at higher temperatures. Therefore, tests were carried out in vacuum to determine whether this could mitigate the decrease in toughness observed at higher temperatures.

Experimental Procedure

Specimens of the AL-15 material were fabricated from an as-wrought plate measuring 165 mm wide by 12.7 mm thick by approximately 3 m long that was produced by SCM Metals for the ORNL Fusion Energy Division in 1987 [3]. This plate had been warm worked during the consolidation of the -20 mesh powder. The plate was then extruded at about 820°C with an extrusion ratio of 25:1. Specimens were oriented in the T-L orientation so that crack growth was in the extrusion direction, or in the L-T orientation for crack growth perpendicular to the extrusion direction.

Small disk compact specimens 12.5 mm in diameter by 4.62 mm thick (0.492 by 0.182 in.) [designated 0.18 T DC(T) specimens] were fabricated from the middle of the plate thickness. All specimens were fatigue precracked at room temperature and then side grooved 10% of their thickness on each side prior to testing. Testing was conducted on an 89-kN (20-kip) capacity servohydraulic test machine in laboratory air, or on a 223-kN (50-kip) servohydraulic machine equipped with a vacuum chamber. The vacuum tests were conducted with a vacuum of better than 10^{-6} torr. A thermocouple was spotwelded to the specimen to monitor the temperature during each test. Testing was conducted in general accordance with ASTM E 813-89, Standard Test Method for J_{Ic}, A Measure of Fracture Toughness, and ASTM E 1152-87, Standard Test Method for Determining J-R Curves, using a computer-controlled data acquisition and analysis system operating in strain control. The J-integral equations from E 1152-87 were used for the calculations. Tensile properties used in the analyses were taken from the literature [2].

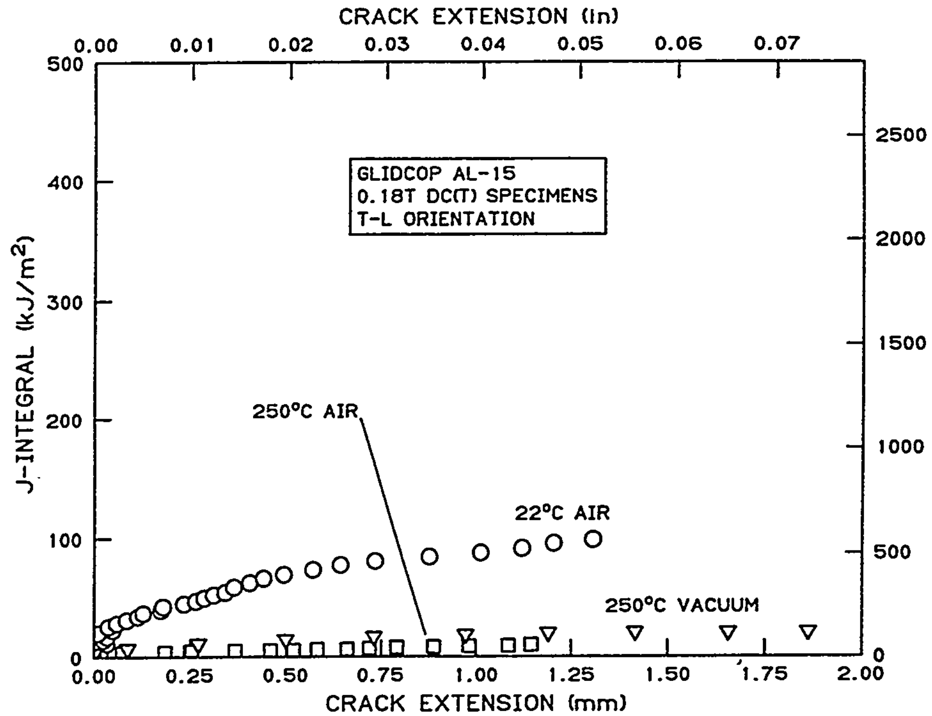
Crack growth was monitored by the unloading compliance technique for all tests. An outboard clip gage was used that seated in grooves machined on the outer diameter of the disk, above and below the loading holes. The experimental techniques developed for testing the small DC(T) specimens have been described elsewhere [4].

To mark the extent of crack growth for some of the preliminary testing the specimens were heat tinted by placing them on a hot plate and heating them until a noticeable color change had occurred. The specimens were cooled to room temperature and then broken open to allow the initial and final crack lengths to be measured. Later tests used fatigue crack extension at room temperature after the tests were completed to mark the final crack front. The crack lengths were measured from the fracture surfaces with a measuring microscope.

Results and Discussion

The results of the fracture toughness testing are shown in Fig. 1 and are summarized in Table 1. The fracture toughness decreased markedly as the test temperature increased, as Fig. 1 shows. The toughness was also quite different depending on the specimen orientation, with specimens from the L-T orientation being much tougher than the T-L specimens. The toughness was only slightly improved by testing in vacuum, and the increase in test temperature from 25 to 250°C caused a significant decrease in the fracture toughness in either air or vacuum.

The significant decrease in the toughness as the test temperature increases is a surprising response, as there is no indication of a significant change in the tensile properties over this same range of temperatures [2]. These results are similar to data for the AL-25 alloy [5], a more recent variant of oxide-dispersion strengthened copper which has 0.25 wt % Al. Interestingly, impact tests of notched specimens of AL-25 [5] do not show a decrease in absorbed energy over a similar range of test temperatures. The fact that the toughness is degraded in the quasistatic fracture toughness test but not under dynamic conditions suggests that an environmental effect such as oxygen embrittlement of grain boundaries may be responsible for the drop in toughness at higher temperature. It was thought that the fracture toughness may not be so impaired in a vacuum environment. However, although there is a slight improvement in the toughness at 250°C under vacuum conditions as compared to air, the toughness is still much lower than one would expect on the basis of the small changes in the tensile properties over the same temperature range.



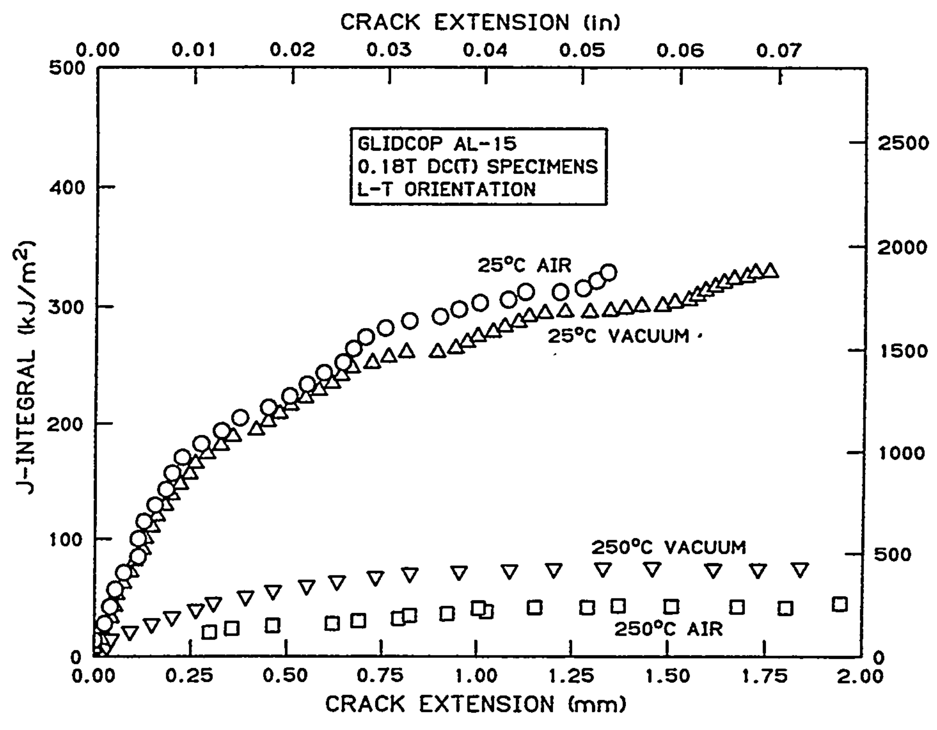


Fig. 1. J-integral resistance curves for AL-15 oxide-dispersion strengthened copper. Top: T-L orientation; bottom: L-T orientation. The L-T specimens have much higher toughness than the T-L specimens.

Table 1. Fracture toughness values of GLIDCOP AL-15

Orientation	Specimen	Temperature (°C)	Environment	J_Q (kJ/m^2)	K_{JQ} (MPa$\sqrt{m}$)	T
T-L	FJ4	22	air	51	78	42
	FJ1	250	air	3	20	9
	GC1	250	vacuum	11	34	13
L-T	GC5	25	air	241	168	87
	GC11	25	vacuum	220	161	75
	GC6	250	air	19	46	30
	GC7	250	vacuum	48	72	37

The results show that the toughness of L-T specimens is much greater than that of T-L specimens. The processing used in the fabrication of this material results in the alignment of particles and the creation of an aligned grain structure parallel to the rolling or extrusion direction. Specimens in the T-L orientation will have crack extension parallel to this microstructure. This will result in a greatly reduced resistance to crack extension by providing a path that favors crack growth, whether by a ductile fracture mechanism, as will occur at room temperature, or by an intergranular mechanism, as may be occurring at high temperature. Preliminary fractography indicates this change in fracture mode occurs for the T-L specimens tested in air. Additional examination of the specimens tested in vacuum and in the L-T orientation is needed.

REFERENCES

1. D. J. Alexander and B. G. Gieseke, "Fracture Toughness and Fatigue Crack Growth of Oxide-Dispersion Strengthened Copper," in Fusion Materials Semiannual Progress Report for Period ending December 31, 1995, DOE/ER-0313/19, 1996, pp. 189-94.

2. T. J. Miller, S. J. Zinkle, and B. A. Chin, "Strength and Fatigue of Dispersion-Strengthened Copper," J. Nuc. Mat., 1991, Vol. 179-181, pp. 263-66.

3. S. J. Zinkle, Oak Ridge National Laboratory, personal communication, 1995.

4. D. J. Alexander, "Fracture Toughness Measurements with Subsize Disk Compact Specimens," in Small Specimen Test Techniques Applied to Nuclear Vessel Thermal Annealing and Plant Life Extension, ASTM STP 1204, W. R. Corwin, F. M. Haggag, and W. L. Server, Eds., American Society for Testing and Materials, Philadelphia, 1993, pp. 130-42, also published in Fusion Reactor Materials Semiannual Progress Report for Period Ending March 31, 1992, DOE/ER-0313/12, pp. 35-45.

5. R. R. Solomon, A. V. Nadkarni, and J. D. Troxell, SCM Metal Products, Inc., unpublished information presented at ITER Workshop, Gatlinburg, Tenn., November 7, 1995