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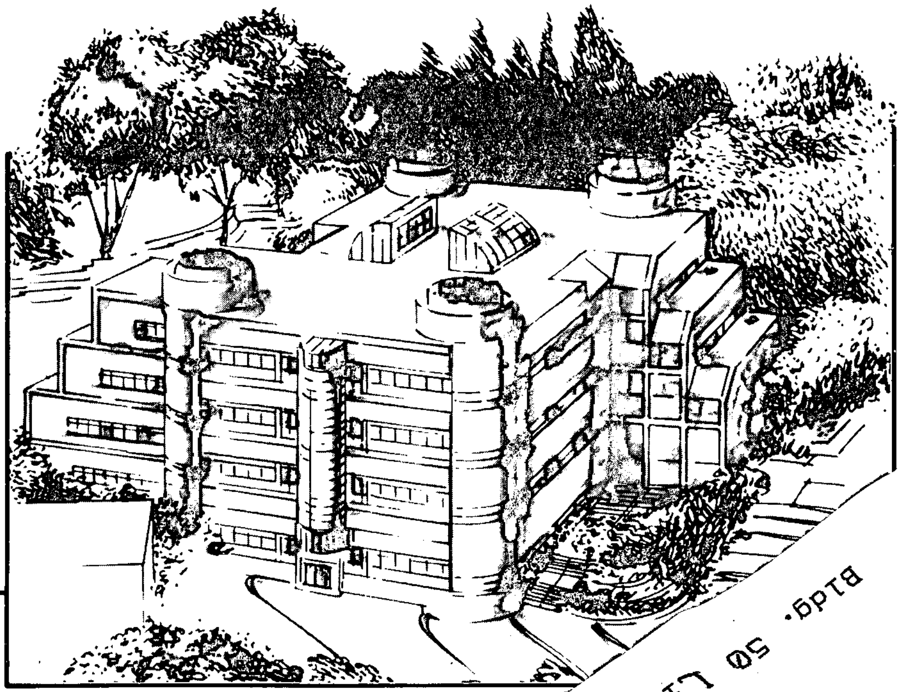

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The fracture behavior of austenitic stainless steels of differing stability, AISI310S, 304, and 304L, in a 4.2 K, 8T magnetic field environment are examined. 304L specimens with different amounts of work at different rolling temperatures are also examined. The different rolling conditions are used to produce stability differences independent of those inherent to chemistry differences. The application of an 8T magnetic field at 4.2K leads to measured fracture toughness above and below that without an applied field in the metastable alloys, with the amount and direction of change a function of the stability of the alloy. Stable 310S alloy does not exhibit significant fracture toughness changes. This difference in fracture behavior is attributed to the enhancement of martensitic transformation about the crack tip during the fracture process in a magnetic field.

INTRODUCTION

Austenitic stainless steels have been used as structural alloys in high field superconducting magnets. Some of the candidate structural alloys for the next generation of magnetic confinement fusion reactors are of this type. In this application the alloys sustain high stresses in high strength magnetic fields at 4.2K. It is known that plastic deformation at low temperatures induces martensitic transformation in some of these alloys and that the presence of a strong magnetic field enhances the transformation. If the structural alloys selected for this application undergo martensitic transformation under service conditions, there may be unanticipated effects, such as changes in the tensile, fatigue, and fracture properties that can potentially degrade the performance of the device. Even if the base alloys remain austenitic under service conditions, there remains the possibility that welds, which commonly suffer from chemical inhomogeneities because of segregation during solidification, can in some regions be metastable. This necessitates complete characterization of the mechanical behavior: tensile, fatigue, and fracture toughness properties of these metastable alloys at the anticipated operating conditions to better understand the controlling mechanisms. Previous work demonstrates that the presence of a strong magnetic field can influence both tensile[1-3] and fracture properties[4,5] of AISI304 stainless steels at 4.2K. The change in 4.2K mechanical properties of these metastable alloys with the application of a magnetic field is associated with a martensitic transformation during deformation. Both increases[5,6] and decreases[4] in 4.2K fracture toughness were observed in an 8T magnetic field. Some of the mechanisms affecting fracture toughness that arises because of the in situ transformation were identified in previous work[5]. In this work, AISI310S, an alloy stable with respect to deformation at 4.2 K, and AISI304L, a metastable alloy, with various prior processing conditions are examined to help further clarify the role of alloy stability on the direction and magnitude of fracture toughness change in an applied magnetic field.

EXPERIMENTAL

The amount of transformation that can occur during the J_{IC} test is varied both through changes in chemistry and through prior deformation and transformation. Matched sets of specimens were tested at 4.2 K with 0 T and 8 T applied fields.

Chemistry-related stability changes were accomplished by using 304L and 310S. AISI 304L is metastable while 310S is a stable alloy at 4.2 K. The compositions of the 304L and 310S plates used in this work are listed in Table 1.

Table 1. Alloy Compositions in wt%.

	Cr	Ni	Mn	Si	C	N	O	P	S	Mo
304L	18.90	8.29	1.84	0.33	0.019	0.087	0.011	0.024	0.015	0.43
310S	24.66	19.11	1.84	0.52	0.025	0.062	0.010	0.024	0.012	0.41

The amount of transformation available during crack initiation and propagation was controlled independently of chemistry by using 304L specimens with different prior deformation. Heavy prior deformation reduces the amount of in situ transformation by both causing a prior transformation and by stabilizing the austenite. 304L plates were given a 20% reduction (31.8mm to 25.4mm) at 300 K and at 993 K. The 993 K treatment is well above the reversion temperature for 304L, so the plate remains austenitic. Deformation at that temperature will, however, stabilize the alloy against subsequent transformation.[7] In addition, 304L plates were given a 13% (31.8mm to 27.6mm) rolling reduction at 77 K, reducing its stability. Thus the order of the alloys in terms of increasing stability is 304L processed at 77 K, 304L, 304L processed at room temperature, 304L processed at 993 K, and 310S. Compact tension (CT) and tensile specimens were then machined from these plates.

J_{IC} tests were performed in an 8 T magnetic field at 4.2 K in the bore of a NbTi superconducting solenoid and without an applied magnetic field at 4.2 K. A single specimen compliance technique, in which load line displacement measurements are made using a clip gage, was used. The specimens were precracked at room temperature to a nominal a/w of 0.6. J_{IC} tests were conducted according to ASTM 813-88.

conditions indicates that in situ martensitic transformation is the proximate cause of the observed changes in an 8T magnetic field. Rolling of the 304L plates at different temperatures produces differences in the amount of transformation that occurs during deformation and fracture. This is seen more clearly in Figure 2, where the data in Figure 1 is replotted as a percentage change in 4.2 K fracture toughness with the application of an 8T magnetic field. The least stable alloy, the 77 K-rolled 304L, has the largest percentage reduction while the fully stable alloy has not changed significantly. The alloys with intermediate stabilities progress from a slight decrease for annealed 304L to negligible change for 293 K-rolled 304L to increases in the 993 K-rolled 304L and in the 304 studied previously.[5] Such behavior suggests that the location where significant transformation first occurs with respect to the crack tip, as well as the amount of the transformation is important in determining the fracture toughness. A material that transforms easily produces a brittle zone ahead of the advancing crack, reducing its measured fracture toughness. The reduction in fracture toughness of martensite containing 304L is indicated by the low K_{IC} value for the specimens partially transformed by rolling at 77 K. A material that delays significant transformation until the higher strains present closer to the crack tip will avoid exposure of the brittle martensite regions to the tensile stress peak ahead of the crack, reducing locally brittle fracture and allowing the fracture toughness enhancing mechanisms identified in previous work[5] to dominate. The presence of a magnetic field during fracture will enhance this behavior. Completely stable specimens will not show an effect in the magnetic field.

CONCLUSIONS

The magnitude and the direction of change in 4.2 K fracture toughness with the application of an 8T magnetic field is a function of the stability of the alloy.

The least stable alloy shows a large reduction in 4.2 K fracture toughness with an applied magnetic field. The amount of fracture toughness reduction with an applied magnetic field decreases as the stability of the specimens increase. At intermediate stability, the direction of fracture toughness change reverses and improvements in fracture toughness are observed. For the fully stable condition, no significant changes in fracture toughness are observed.

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