§24. Fracture and Fatigue Crack Growth Behavior of Austenitic Stainless Steel in Cryogenic High Magnetic Field Environments

Shindo, Y., Narita, F., Takeda, T. (Dept. of Mater. Processing, Graduate School of Engineering, Tohoku Univ.),
Sanada, K. (Dept. of Mechanical Systems Engineering, Faculty of Engineering, Toyama Prefectural Univ.),
Nishimura, A., Tamura, H.

1. Purpose

Austenitic stainless steels have been used as structural alloys in high field superconducting magnets. In this application the alloys sustain high stresses in high magnetic fields at liquid helium temperature (4 K). It is known that plastic deformation at cryogenic 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 superconducting applications undergo martensitic transformation under service conditions, there may be unanticipated effects, such as changes in the tensile, fracture, and fatigue properties that can potentially degrade the performance of the device. Therefore, it is important to know both the fracture and fatigue crack growth behavior of austenitic stainless steels under anticipated operating conditions in order to assess the structural integrity of the components of superconducting magnets. The purpose of this work is to study the effects of cryogenic high magnetic field environments on the fracture[1)] and fatigue crack growth[2)] behavior of austenitic stainless steels.

2. Procedure

(1) The fracture behavior of the metastable austenitic stainless steels at cryogenic temperatures is studied. Elastic-plastic fracture toughness tests are performed on compact tension (CT) specimens at 4 K in magnetic fields of 0 and 6 T (T: Tesla), and the effect of magnetic field on the cryogenic fracture toughness is discussed. Quantitative phase analysis is also done by magnetic method, and the fracture surfaces are examined by scanning electron microscopy (SEM) to correlate with the fracture behavior.

(2) The fatigue crack growth in the metastable austenitic stainless steels in cryogenic high magnetic field environments is studied and the high magnetic field effect on the fatigue crack growth rate at 4 K is discussed in detail. Fatigue crack growth tests are performed with CT specimens at 4 K in magnetic fields of 0 and 6 T, and the crack growth rate data are expressed in terms of the J-integral range during fatigue loading. The J-integral range values are evaluated using an elastic-plastic finite element analysis. The measurement of martensite phase in the test specimens and the fractographic examination are also carried out.

3. Results

(1) (a) SUS 304 stainless steel precracked at room temperature shows an increase in the 4-K fracture toughness with the application of a 6 T magnetic field. In contrast, the magnetic field deceases the 4-K fracture toughness of SUS 304 stainless steel precracked at liquid nitrogen temperature (77 K). (b) Changes in the 4-K fracture toughness due to the presence of the magnetic field seem to be caused by the formation of the martensite phase around the crack.

(2) (a) The exposure to 4 K and the presence of a 6 T magnetic field increase the fatigue crack growth rate of SUS 304 stainless steel precracked at 77 K. Fig. 1 shows the plot of fatigue crack growth rate da/dN versus J-integral range ΔJ data for SUS 304 stainless steel (precracked at 77 K) at 4 K in magnetic fields of 0 and 6 T. (b) Based on the martensite measurement and the fracture surface observations, the martensitic transformation around the crack may be a reason for the dependence of the fatigue crack growth rate on the temperature and the magnetic field.

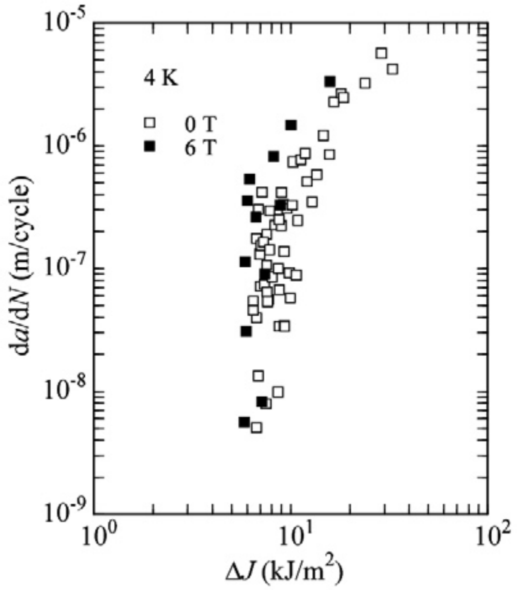

Fig. 1. Fatigue crack growth rates versus J-integral range at 4 K in 0 and 6 T.

1) Shindo, Y. et al.: Strength of Materials, **42** (2010) 221.
2) Shindo, Y. et al.: Metallurgical and Materials Transactions A **40** (2009) 1863.