24P048-P

Effect of Irradiation Damage on Fatigue Crack Growth Behavior in Steel Materials
鉄鋼材料の疲労き裂成長挙動に及ぼす照射損傷の影響

Katsuya Yamamoto, Yuki Sato, Shuhei Nogami and Akira Hasegawa
山本雄也，佐藤佑毅，野上修平，長谷川晃

Department of Quantum Science and Energy Engineering, Tohoku University
6-6-01-2, Aramaki-aza-Aoba, Aoba-ku, Sendai 980-8579, Japan
東北大学量子エネルギー工学専攻 〒980-8579 仙台市青葉区荒巻字青葉 6-6-01-2

The effect of irradiation damage on the micro-crack initiation behavior under low cycle fatigue in SUS316L austenitic stainless steel was investigated using proton irradiation and a low cycle fatigue test at room temperature in air. The micro-crack initiation (initiation of crack with 10–40 μm surface length) was observed at the slip band, twin boundary, grain boundary and triple junction in both the unirradiated and proton-irradiated specimens. Significant reduction of the micro-crack initiation life of each initiation site and increment of the number fraction of the micro-crack initiation at the slip band and twin boundary occurred due to the proton irradiation.

1. Introduction

It is important to improve the fatigue life assessment of structural materials to meet the demands of reliability and economy for fusion reactors because a fusion reactor material must support dynamic loads induced by thermal and electromagnetic stresses under neutron irradiation. The fatigue life is generally composed of micro-crack initiation, crack propagation and final fracture stages, therefore, fatigue life assessment of the fusion reactor material might be improved by evaluating the micro-crack initiation behavior under neutron irradiation.

The objective of this study is to investigate the effect of irradiation damage on the micro-crack initiation behavior under low cycle fatigue and its mechanism in austenitic stainless steel.

2. Experimental Procedure

Solution-annealed SUS316L austenitic stainless steel was used in this study. The average grain size was approximately 45 μm. Miniature plate specimen with a notch was used for the evaluation. The thickness, width of the minimum cross-section and radius of the notch were 1.52 mm, 1.25 mm and 10 mm, respectively.

2 MeV proton irradiation test was conducted using the 4.5 MV Dynamitron accelerator of Tohoku University. The proton beam was irradiated to the bottom of curve region of a specimen. The displacement damage of the uniformly irradiated region was 0.25 dpa, which ranged from the specimen surface to approximately 12 μm in depth from the surface. The irradiation temperature was approximately 230ºC.

Low cycle fatigue test was conducted at room temperature in air using an electromotive testing machine with a 2 kN load cell. The total strain range parallel to the loading direction was approximately 0.6% at the bottom of the fatigue specimen's curve region, which were controlled using a triangular wave (R = –1). The axial strain rate was approximately 0.01%/s.

Surface morphology at the bottom of the fatigue specimen's curve region was observed using a field emission scanning electron microscope (FE-SEM) and an atomic force microscope (AFM) by periodically stopping the fatigue test. The electron backscatter diffraction (EBSD) analysis for the same region was also conducted using an orientation-imaging microscope (OIM) equipped to the FE-SEM.

3. Results and Discussion

The micro-crack initiation was observed at the slip band, twin boundary, grain boundary and triple junction both in the unirradiated and proton-irradiated specimens, where the twin boundary was a Σ3 grain boundary with 60º misorientation angle between adjoining grains.

Fig. 1 shows the micro-crack initiation life at each initiation site of the unirradiated and proton-irradiated specimens. The micro-crack initiation life was defined as the number of cycles where a crack with 10–40 μm surface length was observed. The micro-crack initiation life (N_i) of the unirradiated specimen was approximately 4000–6000 cycles at all the initiation sites. Approximately 75–83% reduction of the micro-crack initiation life at the slip band and twin boundary (N_i = 1000) and approximately 50–67% reduction at the grain boundary and triple junction (N_i = 2000) occurred due to the proton irradiation. As shown in Fig. 2, the number fraction of each initiation site significantly changed due to the proton irradiation. Increment of the number fraction of the initiation at the slip band and twin boundary was caused by the irradiation.

It is well known that a localized deformation accompanied by coarse slip formation in the grain interior occurs in irradiated austenitic stainless steel due to obstruction of the dislocation motion by irradiation defects [1-6]. The localized deformation occurred due to not only neutron irradiation but also ion irradiation [1-3]. In the previous study [7], the larger surface morphology change under low cycle fatigue in the proton-irradiated SUS316L than the unirradiated one was considered to decrease the micro-crack initiation life at the slip band and twin boundary, probably due to the localized deformation by the irradiation. Therefore, reduction of the micro-crack initiation life and increment of the number fraction of the micro-crack initiation at the slip band and twin boundary due to the proton irradiation was considered to be induced by the localized deformation at a relatively early stage of the low cycle fatigue test.

4. Conclusion

The effect of irradiation damage on the micro-crack initiation behavior under low cycle fatigue and its mechanism in SUS316L austenitic stainless steel was investigated using proton irradiation and a low cycle fatigue test at room temperature in air. The results of this work are summarized as follows:

(1) The micro-crack initiation (initiation of crack with 10–40 μm surface length) was observed at the slip band, twin boundary, grain boundary and triple junction both in the unirradiated and proton-irradiated specimens.
(2) Significant reduction of the micro-crack initiation life of each initiation site and increment of the number fraction of the initiation at the slip band and twin boundary occurred due to the proton irradiation.

References

[1] T. Tanno, A. Hasegawa, S. Sasaki, S. Nogami, M. Satou: Proc. 14th Int. Conf. on Environmental Degradation of Materials in Nuclear Power Systems (2009) [CD-ROM].
[2] T. Miura, K. Fujii, K. Fukuya, A. Kawagishi, Y. Ito: INSS Journal **14** (2007) 167.
[3] T. Miura, K. Fujii, K. Fukuya: INSS Journal **15** (2008) 188.
[4] T. Onchi, K. Dohi, N. Soneda, M. Navas, M. L. Castano: J. Nucl. Mater. **340** (2005) 219.
[5] T. Onchi, K. Dohi, N. Soneda, J. R. Cowan, R. J. Scowen, M. L. Castano: J. Nucl. Mater. **320** (2003) 194.
[6] H. Nishioka, K. Fukuya, K. Fujii, Y. Kitsunai: INSS Journal **13** (2006) 147.
[7] S. Nogami, Y. Sato, A. Hasegawa: J. Nucl. Sci. Technol. **48-9** (2011) 1265.

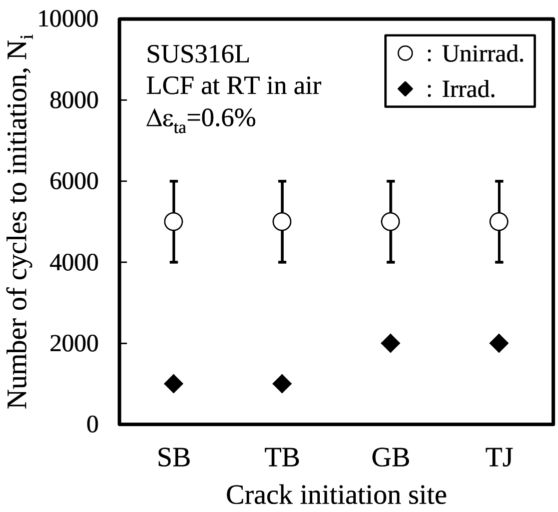

Fig.1. Micro-crack initiation life at each initiation site of the unirradiated and proton-irradiated specimens (SB: slip band, TB: twin boundary, GB: grain boundary, TJ: triple junction)

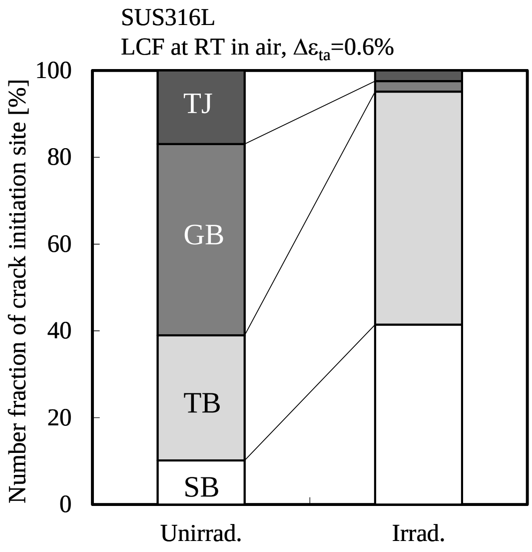

Fig.2. Number fraction of each initiation site of the unirradiated and proton-irradiated specimens (SB: slip band, TB: twin boundary, GB: grain boundary, TJ: triple junction)