1.6 Effects of Neutron Irradiation on Hardness Properties of Friction Stir Processed ODS Ferritic Steel

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OBJECTIVE

The effects of neutron irradiation were investigated on a friction stir processed ODS steel. To investigate the neutron irradiation behavior in the joint area, the hardness measurements as post irradiation experiment (PIE) were carried out on the cross section using a micro Vickers hardness tester.

SUMMARY

Oxide dispersion strengthened ferritic steels (ODS-FS) have been considered as one of the most promising structural materials for advanced nuclear systems such as fusion reactors and next generation fission reactors, because of its excellent elevated temperature strength, corrosion and radiation resistance. Especially, irradiation resistance is a critical issue for the high performance of ODS-FS. In this study, effects of the irradiation on hardness properties of friction stir processed (FSP) ODS-FS were investigated. FSP technique was employed on ODS-FS. A plate specimen was cut out from the cross section and irradiated to 1.2 dpa at 573K in the High Flux Isotope Reactor (HFIR). To investigate the effect of neutron irradiation on processed area, the hardness distributions were evaluated on the cross section. Hardness of FSP ODS-FS was various with each microstructure after irradiation to 1.2 dpa at 573K. The increase of Vickers hardness was significant in the stirred zone and heat affected zone. Base material exhibited the lowest hardening about 38HV. Since nano-oxide particles in stirred zone showed identical mean diameter and number density, it is considered that hardening differences between stirred zone and base material is due to differences in initial dislocation density.

PROGRESS AND SATATUS

Experimental

ODS-FS used in this study is Fe-15Cr-4Al-0.7Y_2O_3 ODS ferritic steel. Chemical compositions are shown in Table 1. The ODS-FS were fabricated by mechanical alloying and hot-extrusion process. An ODS-FS rod was machined to the dimension of 115 mm length × 20 mm width × 8 mm thickness, of which the longitudinal direction (L-direction) was parallel to the extruded direction, was friction stir processed in the air at room temperature. The material of the rotating tool used in this study is a polycrystalline cubic boron nitride (PCBN). The rotating tool is plunged into the plate and moved along bonding direction. The ODS-FS was friction stir processed at a tool traveling speed of 50mm/min and tool rotating speed of 800rpm. Consequently, the process was done parallel to the extruded direction. Detailed fabrication and processing condition are described in previous paper [1]. A plate specimen was cut out from the cross section and irradiated to 1.2 dpa at 573K in the High Flux Isotope Reactor (HFIR). To investigate the effect of neutron irradiation on processed area, the

hardness distributions were evaluated on the cross section using a micro Vickers hardness tester with 200gf for 10s at room temperature in a regular interval of 0.5 mm.

Fig. 1. Cross sectional optical micrograph of friction stir processed ODS-FS.

Table 1. Chemical compositions of ODS ferritic steel.

Fe	C	Si	Mn	P	Cr	W	Al	Ti	Y_2O_3
Bal.	0.018	0.02	0.02	<0.005	15.39	0.28	3.78	0.1	0.7

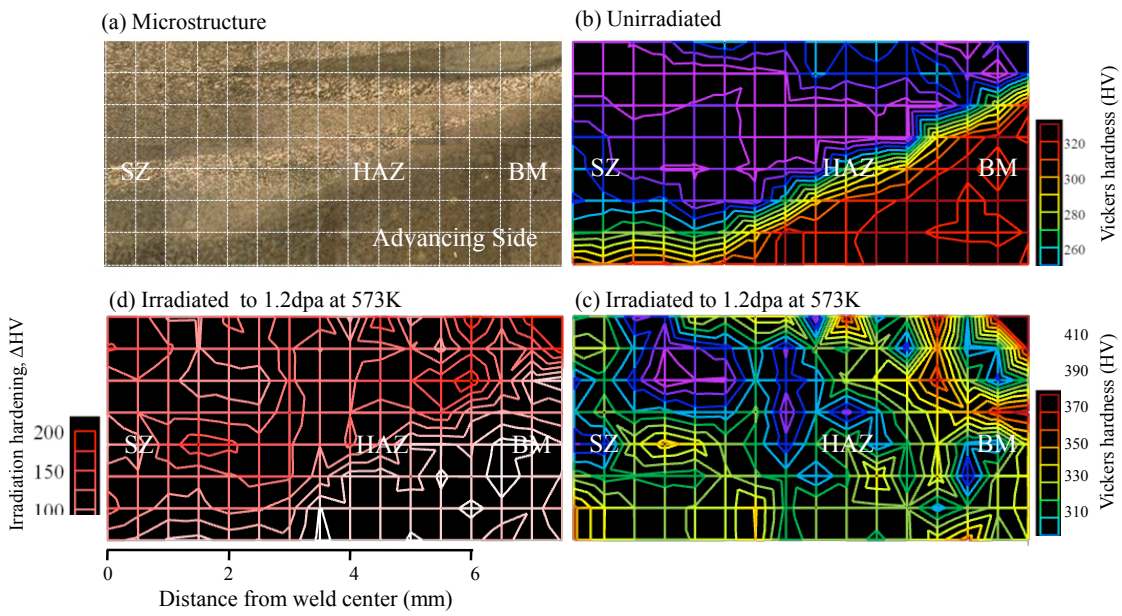

Fig. 2 Irradiation hardening of friction stir processed ODS ferritic steel

TEST RESULTS

Optical micrograph of friction stir processed ODS-FS on transverse cross section is shown in Fig. 1. Two distinct zones can be clearly identified as base material (BM) and stirred zone (SZ). The SZ exhibits a symmetric basin-shape with about 3mm depth at bottom and significantly spreading toward the upper surface. In Fig. 2, the hardness distribution on the transverse cross section is illustrated as a color level map. Each cross line indicates the measured point of hardness and its color shows the hardness level. The variable colored distribution area is well corresponding with the changes in the microstructure developed during friction stir process, that is, changing colored area matches with the geometries of rotating pin and shoulder. As seen in Fig. 2(b), boundary area between SZ and BM is limited to very narrow area that can be defined as a heat affected zone (HAZ). SZ around the weld center shows lower hardness of 210 ± 12 HV than that of 316 ± 6 HV of base material. The hardness distribution of tool advancing side after neutron irradiation in HFIR to 1.2 dpa at 573K is illustrated in Fig. 2(c, d). After irradiation, hardness distribution changed randomly from 310 to 420 HV, but degrees of irradiation hardening was clearly occurred in each microstructure. In Fig. 3, irradiation hardening of each microstructure SZ, HAZ and BM is illustrated. The irradiation hardening in BM is not so high about 38HV, compared with those in SZ showed about 120HV. This means that microstructural difference results different irradiation hardening at 572K. S. Noh et al. reported that nano-oxide particles in SZ were uniformly distributed and reserved with same mean particle size and number density with BM [1]. More detailed microstructural observation is essentially required, however, it can be assumed that this is because of dislocation density difference between BM and SZ developed during the friction stir process.

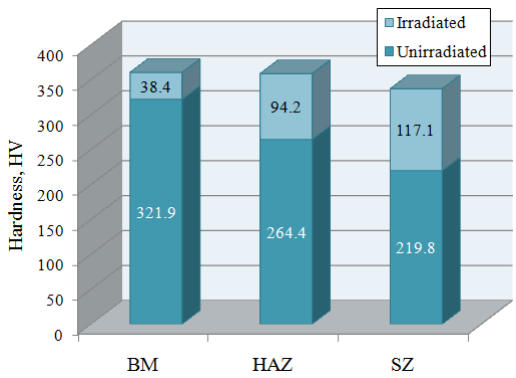

Fig. 3. Irradiation hardening of each microstructure.

Meanwhile, the dislocation density of metal is closely related to the thermal history during the processing. The maximum temperature of the work piece by frictional heat can be examined with some FSW parameters by Arbegast and Hartley [2]. They measured the average maximum temperature for a relationship between maximum welding temperature (T, °C) and FSW parameters (ω, v; tool rotation speed (rpm), traveling speed (mm/min)) and it can be expressed by, where the exponent *α* was

$$\frac{T}{T_m} = K\left(\frac{\omega^2}{v \times 10^4}\right)^{\alpha} \tag{2.1}$$

reported to be in the 0.06 in steels, the constant *K* is 0.65 in steels, and T_m is the melting point, 1513°C of this ODS-FS. Thus, the maximum temperature of the ODS-FS estimated during the process is estimated to be about 1305°C. Compared with tool traveling speed of Al alloy, 50mm/min on ODS-FS is very slow in this study, so the workpiece could be heated up to high temperature, 1305°C in several minutes. Consequently, it is considered that dislocation recovery occurred in the SZ and dislocation density was reduced during friction stir process. This could explain the result of irradiation hardening difference between SZ and BM after HFIR irradiation.

REFERENCES

[1] S. Noh, R. Kasada, A. Kimura, S. H. C. Park, S. Hirano, Microstructure and mechanical properties of friction stir processed ODS ferritic steels, Journal of Nuclear Materials, In Press (2011).

[2] W.J. Arbegast, P. J. Hartley, in: Proceedings of the Fifth International Conference on Trends inWelding Research 541 (1998).