Deformation and Fracture Behaviors of Cold-worked TP304 Stainless Steel Base and Weld Metals

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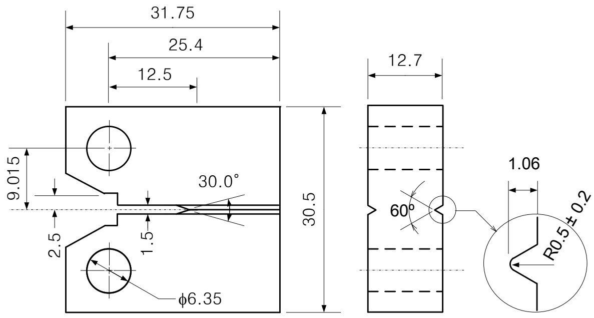
1. Introduction

Material properties of nuclear components installed around reactor core, such as reactor pressure vessel and reactor internals, can be changed by neutron irradiation. Thus, it is important to clearly understand the effect of irradiation on the mechanical properties and to appropriately take into account the change of mechanical properties in the evaluation of structural integrity for the nuclear components. However, the data are not sufficient and it is difficult to perform the test using irradiated materials due to limitations of test material, test facilities, and handling. In particular, there are no data tested under a large amplitude cyclic loading corresponding to excessive seismic event that is an important issue of nuclear power plants (NPPs). Thus, recently some studies proposed alternative test methods using materials that simulate the effect of neutron irradiation on the mechanical properties [1-3]. One of them is cold-work of materials, which is known to simulate the irradiation hardening of materials [1].

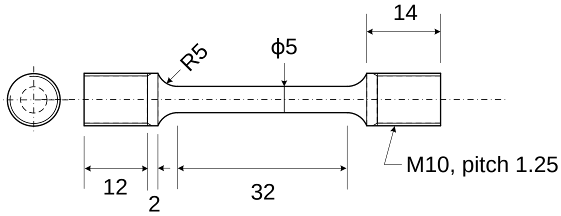
This study conducts the tensile and fracture tests using cold-worked TP304 stainless steel (SS) and weld metal. From the results, it is investigated whether the cold-work can simulate the change in the mechanical properties by neutron irradiation.

2. Experiment

Tensile and J-R fracture tests were performed using as-received SA240 TP304 SS and its cold-work materials with percent cold-work of 5%, 15%, and 22% (5%CW, 10%CW, and 22%CW). In addition, weld metal and its cold-worked materials were used for the experiment. As-received SA240 TP304 SS was provided as a plate with a thickness of 45mm. Weld metal was prepared by K-groove welding of both sides of SA240 TP304 SS plate. Table 1 lists the chemical compositions of SA240 TP304 SS base and weld metals.



(a) 0.5T- CT specimen



(b) Tensile specimen

Fig. 1 Specimens used for J-R fracture toughness and tensile tests

A compact tension (CT) specimen with thickness of 12.7 mm and width of 25.4 mm, in accordance with the ASTM E1820-15 [4], was used for J–R fracture test. A round-bar-type specimen with diameter of 5.0 mm and gage length of 25.0 mm, in accordance with the ASTM E8/E8M-09 [5], was used for the tensile test. Fig. 1 illustrates the specimens used for the experiment. In the weld metal, CT specimen was machined such that the crack is parallel with the weld line, and tensile specimen was machined so that the loading direction crossed the weld line.

Both tensile and J-R fracture tests were conducted at room temperature (RT) and 316ºC at quasi-static displacement rate. In the J–R fracture tests, crack extension was determined by the normalization method defined in the ASTM E1820-15 standard [4].

Table 1 Chemical compositions of as received SA240 TP304 SS and weld metal used for the experiment

Mater.	C	Si	Mn	P	S	Cr	Ni	Mo	N	Co	Cu	F/N No.
SA240 TP304	0.030	0.40	1.56	0.032	0.005	18.15	8.05	0.12	0.070	0.21	0.24	0.8
Weld metal	0.020	0.40	1.90	0.024	0.010	19.64	10.79	0.03	-	-	0.10	5.8

3. Results and Discussion

The tensile tests on SA240 TP304 SS showed that the yield and tensile strengths increase and the uniform and total elongations decrease as the percent cold-work increases for both temperatures. The cold-work effect on the tensile properties were more significant at 316ºC than RT. For 22%CW of SA240 TP304 SS at 316ºC, necking occurred immediately after elastic deformation and the uniform deformation was almost zero. The weld metal also showed a similar cold-working effect, except that the change in the strength and ductility was saturated at 15%CW or higher. The saturation of cold-work effect cannot be clearly explained yet.

In the J-R tests of SA240 TP304 SS, the maximum load of the load-displacement curve increased with increasing percent cold-work; i.e., the load-carrying capacity of specimen was increased by cold-work. However, the J-R curve of SA240 TP304 SS considerably decreased as the percent cold-work increased. That is, cold-work reduced the fracture resistance of SA240 TP304 SS. The reduction in fracture resistance was more significant at 316ºC than RT. These behaviors are related to the increase in strength and the decrease in ductility of materials by cold-work. In case of weld metal, also, the effect of cold-work on fracture behaviors was almost the same as that of base metal. Only, unlike SA240 TP304 SS, both maximum load and fracture resistance were dropped for 22%CW weld metal at 316ºC.

4. Conclusions

This study conducted tensile and J-R tests on cold-worked SA240 TP304 SS and its weld metal. From the results, it was concluded that the change in the deformation and fracture behaviors of SA240 TP304 SS and its weld metal by neutron irradiation can be reasonably simulated by cold-work, even though it cannot exactly simulate the microstructures of irradiated materials.

Acknowledgment

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