Effect of Cold-Work on the Deformation and Fracture Properties of TP304 Stainless Steel

S. E. Kim[1], J. W. Kim[1*], and Y. J. Kim[2]

[1]Department of Nuclear Engineering, Chosun University, Gwangju, Republic of Korea
[2]Department of Mechanical Engineering, Korea University, Seoul, Republic of Korea

*Corresponding author: jwkim@chosun.ac.kr

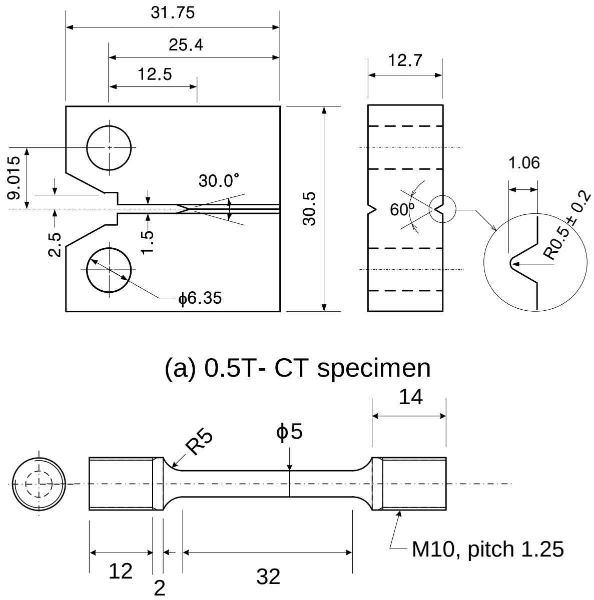
1. Introduction

Neutron irradiation is a main cause of aging degradation of the components installed around reactor core of nuclear power plants (NPPs), such as reactor pressure vessel and reactor internals. That is, their material properties can be changed by irradiation exposure, and also the dimensional changes due to void swelling can occur. Thus, it is necessary to clearly understand the effect of irradiation on the mechanical properties and to appropriately take into account the change of mechanical properties in the structural integrity evaluation for these components. In particular, the experimental data tested under various loading and stress conditions are required to conduct and verify the structural integrity evaluation of nuclear components under a large amplitude cyclic loading corresponding to excessive seismic event that is an important issue of NPPs. 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. 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].

Therefore, this study conducts the tensile and fracture toughness tests using cold-worked TP304 stainless steel (SS) and its weld metal. The effects of cold-work on the deformation and fracture properties are evaluated from the results, and the possibility of simulation of irradiation hardening by cold-working is investigated.

2. Experiment

In this study, tensile and J-R fracture toughness tests were performed using as-received SA240 TP304 SS and its cold-work materials with percent cold-work of 5%, 15%, and 22%. 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 side of SA240 TP304 SS plate. Table 1 lists the chemical compositions of SA240 TP304 SS and weld metal.



(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 (thickness: 12.7 mm; width: 25.4 mm), in accordance with the ASTM E1820-15 [4], was used for J–R fracture test. A round-bar-type specimen (diameter: 5.0 mm; gage length: 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 toughness tests were conducted at room temperature (RT) and 316°C at quasi-static displacement rate. In the J–R tests, crack extension was determined by the

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	-
Weld metal	0.020	0.40	1.90	0.024	0.010	19.64	10.79	0.03	-	-	0.10	5.8

normalization method defined in the ASTM E1820-15 standard [4].

3. Results and Discussion

The results of 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 regardless of test temperature. In particular, the increase in yield strength and decrease in uniform elongation were considerable. The cold-work effect on the tensile properties were more significant at 316°C than RT, so that for 22%CW cold-worked material, 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. Further investigation is need to explain the saturation of cold-working effect for weld metal.

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 316°C than RT. These behaviors are related to the increase in strength and the decrease in ductility of materials by cold-working. In case of weld metal, also, the effect of cold-working on fracture behaviors was almost the same as that of SA240 TP304 SS. Only, unlike SA240 TP304 SS, both maximum load and fracture resistance were dropped for 22%CW weld metal at 316°C.

The increase in yield strength, decrease in ductility, and prompt necking after elastic deformation are typical behaviors of tensile deformation observed from the irradiated austenitic stainless steels [6]. The decrease in fracture resistance is also a typical effect of irradiation observed from the austenitic stainless steels [7]. Thus, it is indicated that the change in the mechanical properties by cold-working is reasonably agreement with that by neutron irradiation, even though the cold-working cannot completely simulate the microstructures of irradiated materials.

4. Conclusions

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

Acknowledgment

This research was supported by National Research Foundation (NRF) funded by Ministry of Science and ICT (2018M2A8A4084016).

References

[1] S. Jitsukawa, K. Shiba, A. Hishinuma, and D.J. Alexander, Comparison of elastic-plastic fracture toughness of irradiated and cold-worked JPCA using miniaturized DCT specimens, *J. of Nucl. Mater.*, 233-237, (1996) 152–155.

[2] M. Kamaya, Elastic-plastic failure assessment of cold worked stainless steel pipes, *Int. J. Pres. Ves. Piping*, 31, (2015) 45–51.

[3] K.J. Choi, S.C. Yoo, T. Kim, and J.H. Kim, “Investigation of Warm Rolling and Dissolved Hydrogen on Crack Growth Rate of 316L Austenitic Stainless Steel in Promary Water Condition, *Proc. of KPVP*, KOPEC E&C, Gim Cheon, Korea, Nov. 19-20, (2015) 21-22.

[4] ASTM E1820-15, Standard test method for measurement of fracture toughness, ASTM International, West Conshohocken, PA, (2015).

[5] ASTM E8/E8M, Standard test method for tension testing of metallic materials, ASTM International, West Conshohocken, PA, (2009).

[6] M. Matijasevic, E. Lucon, and A. Almazouzi, Behavior of ferritic.martensitic steels after n-irradiation at 200 and 300℃, *J. of Nucl. Mater.*. 377, (2008) 101–108.

[7] EPRI, Materials Reliability Program: PWR Internals Age-Related Material Properties, Degradation Mechanisms, Models, and Basis Data-State of Knowledge (MRP-211), Electric Power Research Institute, Palo Alto, CA, 1015013 (2007).