Transactions of the Korean Nuclear Society Spring Meeting
Gyeongju, Korea, October 25-26, 2012

Post-extrusion heat treatment effects on microstructure and mechanical properties of 9Cr nanostructured ferritic alloy

Ji-Hyun Yoon[a]*, Suk-Hoon Kang[a], Yongbok Lee[a], Thak S. Byun[b], David T. Hoelzer[b]
[a] *Korea Atomic Energy Research Institute, Deogjin-Dong 150-1, Yuseong, Daejeon, 305-353, Korea*
[b] *Oak Ridge National Laboratory, Oak Ridge, TN 37830, USA*
**Corresponding author: jhyoon4@kaeri.re.kr*

1. Introduction

Nanostructured ferritic alloys (NFAs) show enhanced high temperature strength by adding nano-scale oxide particles into ferritic-martensitic (FM) steel [1]. High Cr FM steels are under intense research as candidate materials for the components of next-generation nuclear systems [2-4]. The adequate mechanical and fractural properties are prerequisites for core materials that are subjected to a rigorous environment at a high temperature of up to 650°C and neutron irradiation of 200~400 dpa [5]. A few recent researches have reported that the fracture toughness of NFAs is very low at above 300°C [5, 6]. To overcome this drawback of NFAs, post extrusion heat treatments that can evolve the partial phase transformations in a 9Cr-NFA were applied in this study.

The objectives of this study are to improve the fracture toughness and ductility of NFA through a simple post-extrusion thermo-mechanical process, which can lead to changes in the microstructure of nanostructured 9Cr alloy into a dual phase structure.

2. Experimental

The pre-alloyed Fe-9Cr base metallic powder and 0.3 wt.% Y_2O_3 oxide particles were mixed and mechanically alloyed by ball milling. The mixed powder was sealed in 3 inch diameter mild steel cans, degassed, and extruded. The chemical composition of the as-extruded base material (9YWTV-PM1 in this study) is listed in Table 1.

Table 1. Chemical compositions of NFAs (wt.%).

Material	C	Cr	W	Ti	V	Fe
9YWTV-PM1	0.155	8.92	2.19	0.36	0.21	bal.

The tensile and fracture toughness tests were conducted for 9YWTV-PM1 up to 700°C using MTS 810 servo-hydraulic test machine in conjunction with high vacuum furnace. The microstructural examinations were carried out on 9YWTV-PM1 using field emission-transmission electron microscopy (FE-TEM), electron backscatter diffraction (EBSD) and X-ray diffraction (XRD). Differential scanning calorimetry (DSC) was used for monitoring phase transformation during heating and cooling samples. The DSC samples were heated and cooled at the rate of 5 K/min.

3. Results and Discussion

Onset temperature of $\alpha \rightarrow \gamma$ transformation in 9YWTV-PM1 was found to be 950°C as the results of in-situ high temperature XRD and DSC analyses as shown in Fig. 1.

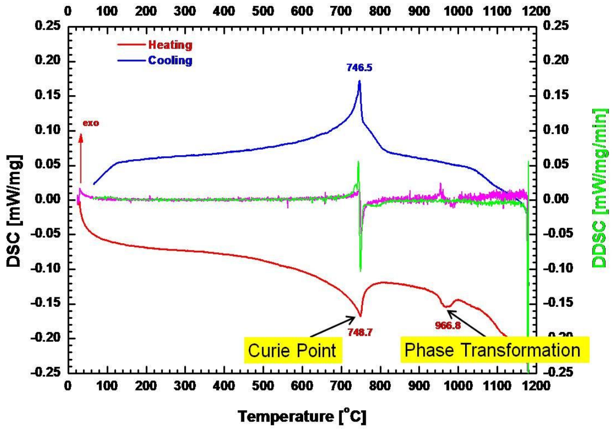

Fig. 1. DSC spectrum of as-extruded Fe-9Cr base NFA (9YWTV-PM1) heated and cooled at 5 K/min. The numbers above or below the features indicate the peak temperatures.

Phase fractions of γ as a function of temperature and time were calculated from XRD spectrums using peak area integration method as plotted in Fig. 2. Volume fractions of γ phase in samples those were exposed to various heat treatment temperatures were saturated after 50 min.

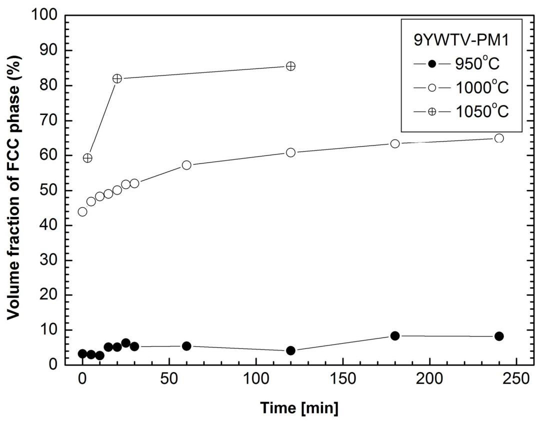

Fig. 2. Phase fraction of FCC (γ) in Fe-9Cr base NFA (9YWTV-PM1) samples exposed at various heat treatment temperatures as a function of time.

The ultimate tensile strength of the base material at room temperature is 1.77 GPa. The alloy retained relatively high strength up to 700°C, though there was a sudden drop in strength above 500°C as shown in Fig. 3.

The uniform elongations are more or less than~ 1% over the test temperature range.

The effects of partial phase transformation heat treatment on as-extruded 9YWTV-PM1 were significant over a testing temperature range. Strength of 9YWTV-PM1 increased after heat treatment except data obtained from testing at 700°C as shown in Fig 3.

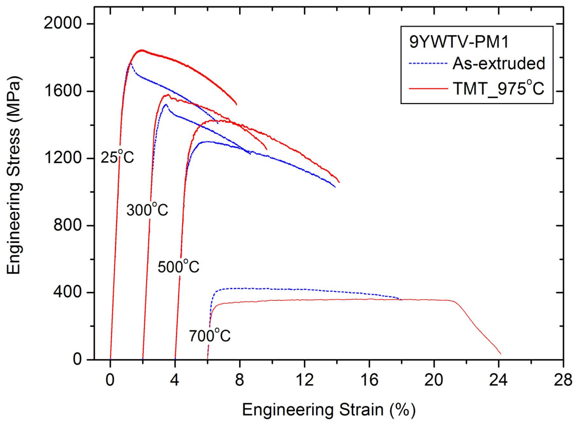

Fig. 3. Stress-strain curves for 9YWTV-PM1 obtained from tests at various temperatures.

Uniform elongation increased after the heat treatment also. The data obtained from tension tests for as-extruded and heat treated alloys are listed in Table 2.

Table 2. Tension testing results for 9YWTV-PM1 obtained at at various temperatures.

Temp.	Y.S. (MPa)	U.T.S. (MPa)	U.E. (%)
R. T.	1705/1675	1766/1842	1.2/1.9
300°C	1386/1492	1521/1581	3.4/3.6
500°C	1182/1259	1301/1428	6.0/6.2
700°C	396/302	424/359	9.7/16.1

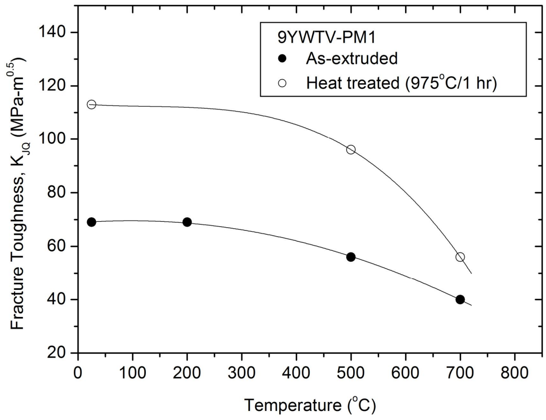

Fig. 4. Fracture toughness, K_{JQ}, of 9YWTV-PM1 measured at various temperatures.

Fracture toughness, K_{JQ}, were measured as-extruded and heat treated 9YWTV-PM1 through 3-point bending testing. K_{JQ} were calculated from J_Q values measured at each testing condition.

Fracture toughness of the 9YWTV-PM1 has increased by more than 40 % at every testing temperature after heat treatment as shown in Fig. 4.

In conclusion, it is found that the mechanical property and fracture toughness of 9Cr-NFA has been improved through the heat treatment that leads partial phase transformation in nano grains.

REFERENCES

[1] D.T. Hoelzer, J. Bentley, M.A. Sokolov, M.K. Miller, G.R. Odette, M.J. Alinger, J. Nucl. Mater., Vol. 36, pp. 166, 2007.

[2] R. LINDAU et al., Fus. Eng. Des., Vol. 75, pp. 989, 2005.

[3] R. L. Klueh et al., J. Nucl. Mater., Vol. 341, pp. 103, 2005.

[4] D. A. McClintock et al., J. Nucl. Mater., Vol. 392, pp. 353, 2009.

[5] R. Chaudi et al., J. Nucl. Mater., Vol. 403, pp. 15, 2010.

[6] T.S. Byun, J.H. Kim, J.H. Yoon, D.T. Hoelzer, J. Nucl. Mater., Vol. 407, pp. 78, 2010.