Post-extrusion heat treatment effects on characteristics of 9Cr nanostructured ferritic alloy

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1. Introduction

The nanostructured ferritic alloys (NFAs), an advanced oxide dispersion strengthened (ODS) alloys show enhanced high temperature strength by adding nano-scale oxide particles into mainly ferritic-martensitic (FM) steels [1]. The high Cr ODS alloys are under intense research worldwide as a candidate material for components of next generation nuclear systems like fuel cladding, duct, turbine blade, etc. [2-4].

An adequate fracture toughness is prerequisite property for core materials that are subjected to a rigorous environment of high temperature up to 650°C and extreme neutron irradiation of 200~400 dpa. However, characterizations for NFAs have been limited to tensile strength and creep strength. Especially, fracture behaviors describing the material resistance to crack initiation and growth in this temperature region were investigated rarely, although the NFAs were designed to operate at high temperatures, typically above 550°C [5]. A few recent researches reported that the fracture toughness of high strength NFAs is very low above 300 °C [5, 6].

To overcome this drawback of NFAs, the specially designed post extrusion heat treatment process was applied to the Fe-9Cr base NFA in this study.

The objective of this study is to improve fracture toughness of the NFA with high strength through the heat treatment after extrusion, which changes microstructure in nanostructured Fe-9Cr base alloy into 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. The microstructural examinations were carried out on 9YWTV-PM1 by using field emission-transmission electron microscopy (FE-TEM), electron backscatter diffraction (EBSD) and X-ray diffraction (XRD).

The post-extrusion heat treatments were applied for the as-extruded base material to improve fracture resistance by evolution of microstructure. The intermediate characterizations are being repeated to find optimum heat treatment condition and microstructure.

3. Results and Discussion

The average grain size of the as-extruded NFA was 160 nm. The size distribution was uniform as shown in Fig. 1. It was found that most grains were oriented to the <110> direction. The grain shape aspect ratio was ~ 4.

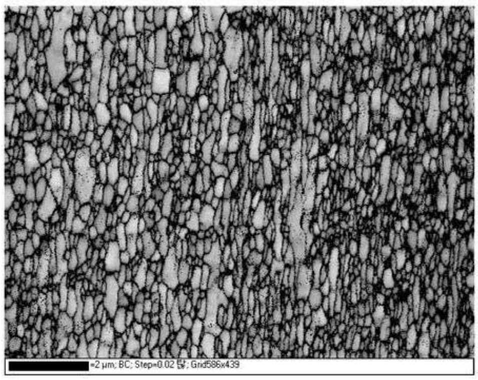

Fig. 1. FE-SEM micrograph showing the microstructure of the as-extruded Fe-9Cr base NFA (9YWTV-PM1).

The nano scale (~2 nm) clusters which were evenly distributed in grains were observed as shown in Fig. 2.

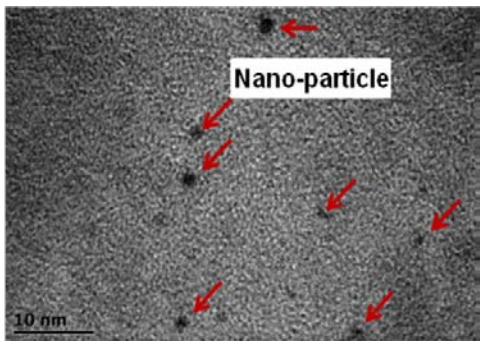

Fig. 2. FE-TEM micrograph showing the nano clusters formed in the as-extruded FE-9Cr base NFA.

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 problem of this material is elongation. The elongation of the alloy was much lower than those of commercial ferritic-martensitic steels at all test temperatures. The uniform elongations are more or less than~ 1% over the test temperature range.

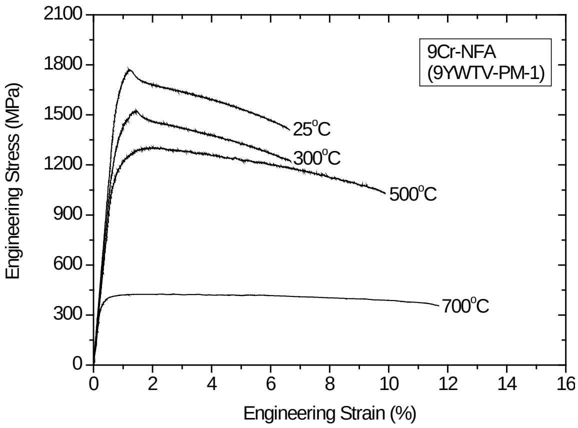

Fig. 3. Stress-strain curves for 9YWTV-PM1 obtained from tests at various temperatures.

The as-extruded alloy showed the low fracture toughness less than 70 MPa√m at all temperature up to 700°C. The fracture toughness decreased with increasing temperature as shown in Fig. 4.

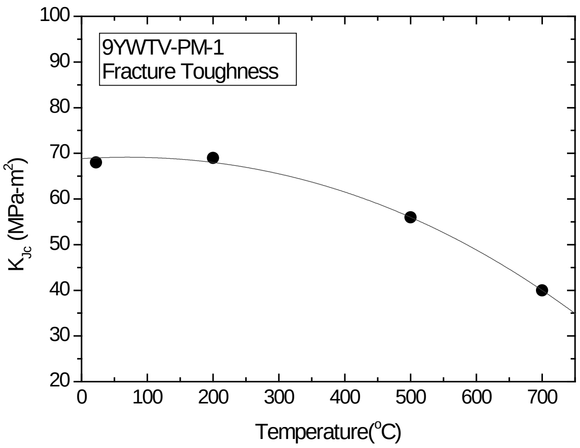

Fig. 4. Fracture toughness of 9YWTV-PM1 obtained from tests at various temperatures.

It was observed that γ phase appeared at the grain boundary region in the specimen which was cut from 9YWTV-PM1 block and annealed at 1050°C. 1050°C falls in the intercritical heat-treatment temperature range calculated by using computational thermodynamics. The fraction of γ phase increased with increasing annealing time as shown in Fig. 5. The γ phase is presumed to be the austenite retained after the annealing followed by air cooling. It is expected that a rapid quenching after annealing can transform austenitic phase into martensitic.

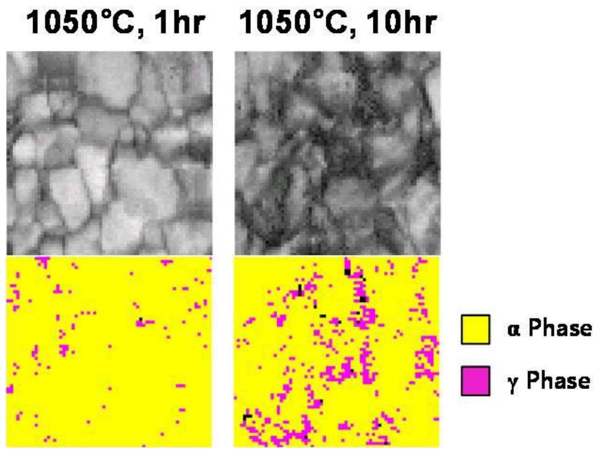

Fig. 5. EBSD maps for annealed 9YWTV-PM1.

The microstructural examinations for 9YWTV-PM1 NFA which was subjected to various heat treatments and intermediate evaluations of fracture toughness are underway.

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