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Effects of Thermo-Mechanical Treatment on Characteristics of 9Cr-Nanostructured Ferritic Alloy

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1. Introduction

Nanostructured ferritic alloys (NFAs), advanced oxide dispersion strengthened (ODS) alloys, show an enhanced high-temperature strength by adding nano-scale oxide particles into mainly ferritic-martensitic (FM) steel [1]. The high-Cr ODS alloys are under intense research worldwide as a candidate material for 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 extreme neutron irradiation of 200~400 dpa. However, the fracture behaviors describing the material resistance to crack initiation and growth in this temperature region have been rarely investigated, although the NFAs were designed to operate at high temperatures, typically above 550°C. A few recent researches have reported that the fracture toughness of high strength NFAs is very low at above 300°C [5, 6].

To overcome this drawback of NFAs, the post extrusion thermo-mechanical treatments (TMTs) that can transform the phase of the 9Cr base NFA into dual phase composite were applied in this study. It is well known that dual phase composite effect usually provides additional toughness and ductility [7].

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 compositions of the as-extruded base materials are listed in Table 1.

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

Material	Cr	W	Ti	V	C	Fe
9YWTV-PM1	8.92	2.19	0.36	0.207	0.155	Val.
9YWTV-PM2	8.93	2.19	0.37	0.206	0.080	Val.

The as-extruded coupons were hot-rolled in controlled conditions: at 900-1000°C for 20 or 50 % total thickness reduction.

The tensile and fracture toughness tests were conducted for NFAs up to 700°C using MTS 810 servo-hydraulic test machine in conjunction with high vacuum furnace. The microstructural examinations were carried out 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.

3. Results and Discussion

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. 1. The volume fraction of FCC in 9YWTV-PM1 gradually increases with time up to about 65%, while that in 9YWTV-PM2 appears to saturate at about 5%.

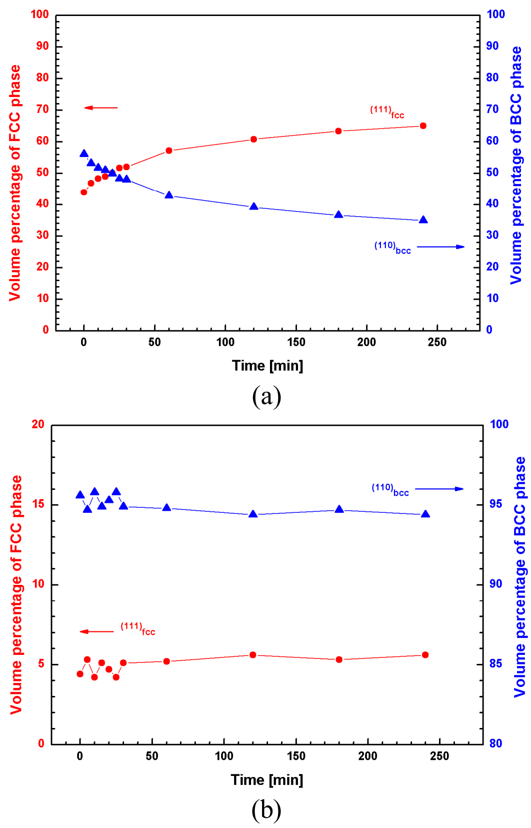
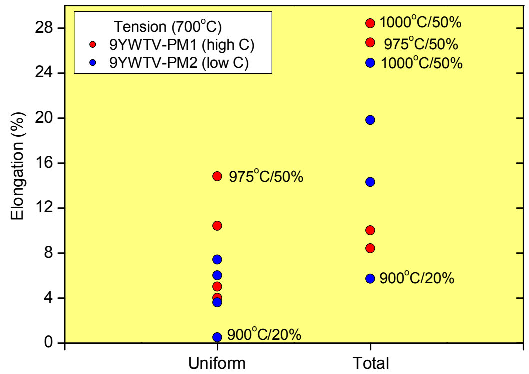
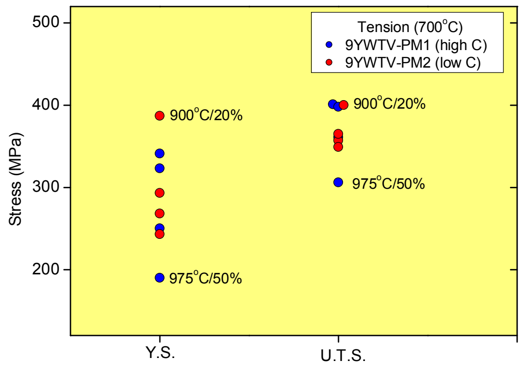


Fig. 1. Change of phase fractions in NFAs as a function of annealing time at 1000°C; (a) 9YWTV-PM1, (b) 9YWTV-PM2.

The effects of TMTs on the as-extruded NFAs are shown in Fig. 2. The ductility was increased, but the strength decreased after controlled rolling. The ductility increased as rolling reduction and temperature increased.



(a)



(b)

Fig. 2. Stress-strain curves for 9YWTV-PM1 obtained from tests at various temperatures.

Fracture toughness, K_{JQ}, were measured for the controlled hot rolled NFAs. All of the K_{JQ} values measured from 9YWTV-2 after the controlled hot rolling fall within the range of F/M steels as shown in Fig 3. The 9YWTV-PM2 controlled rolled at 900°C for 50% reduction resulted in the best fracture toughness among NFAs.

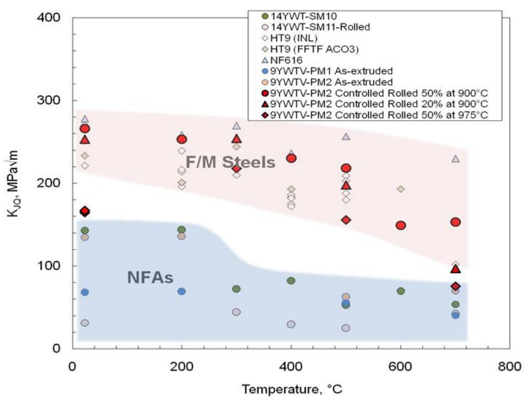


Fig. 3. Fracture toughness, K_{JQ}, of 9YWTV-PM1 measured at various temperatures.

4. Summary

The base (as-extruded) materials with very fine grains & nanoparticles have been successfully produced. Annealing & controlled rolling are used to strengthen the weak boundaries and vicinity area in NFAs. The fracture toughness of NFAs were improved significantly through the controlled rolling in the intercritical heat treatment temperature range. The refinement and optimization of processes and detailed characterization are underway

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