ODS Alloys for Nuclear Applications

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1. Introduction

ODS (oxide dispersion strengthening) alloy is one of the potential candidate alloys for the cladding or in-reactor components of Generation IV reactors and for the structural material even for fusion reactors. It is widely accepted as very resistant material to neutron irradiation as well as strong material at high temperature due to its finely distributed and stable oxide particles. Among Generation IV reactors SFR and SCWR are anticipated in general to run in the temperature range between 300 and 550°C, and the peak cladding temperature is supposed to reach at about 620°C during the normal operation[1]. Therefore Zr–base alloys, which have been widely known and adopted for the cladding material due to their excellent neutron economics, are no more adequate at these operating conditions. Fe-base ODS alloys in general has a good high temperature strength at the above high temperature as well as the neutron resistance.

In this study a range of commercial grade ODS alloys and their applications are reviewed, including an investigation of the stability of a commercial grade 20% Cr Fe-base ODS alloy(MA956). The alloy was evaluated in terms of the fracture toughness change along with the aging treatment. Also an attempt of the development of 9% Cr Fe-base ODS alloys is introduced.

2. Experiment

Annealed 20%Cr Fe-base ODS alloy (MA956) rod specimens were heat treated at 475°C for 25, 50, 75, 100, and 500 hr respectively. Hardness tests as well as Charpy impact tests were carried out on the heat treated samples at room temperature to investigate the change of the toughness. TEM (transmission electron microscope) observation and analyses on the microstructure was also carried out to investigate the microstructural evolution. A series of preliminary 9% Cr Fe-base ODS alloys were prepared by MA (mechanical alloying), HIP (hot isostatic pressing), and hot rolling processes. The chemical composition of the experimental alloys are shown with the commercial ODS alloy in Table 1.

The hot rolled specimens were normalized at 1150°C for 1 hr and tempered at 750°C for 1 hr. Tensile properties were evaluated at room temperature, 600, and 700°C. Microstructure of the experimental ODS alloy were also observed and analyzed using TEM.

Table 1. Chemical compositions of a commercial ODS alloy and five experimental ODS alloys

MA 956	Fe-20Cr-4.5Al-0.5Ti-0.5Y_2O_3
1	Fe-9Cr-0.2Y_2O_3
2	Fe-9Cr-0.2V-0.2Y_2O_3
3	Fe-9Cr-0.2V-0.2Ti-0.2Y_2O_3
4	Fe-9Cr-0.2V-0.2Ti-0.25CrN-0.2Y_2O_3
5	Fe-9Cr-0.2V-0.2Ti-0.50CrN-0.2Y_2O_3

3. Result and Discussion

3.1. Commercial ODS alloy (MA956)

Charpy impact test results with micro Vickers hardness test results are illustrated in Fig. 1. As the holding time at 475°C increases the hardness increased gradually. The impact absorption energy, however, demonstrates a drastic drop even at a very early stage of the heat treatment, e.g. after 25 hrs. And the fractographs of after the Charphy tests provide another evidence of the thermal embrittlement of the 20%Cr ODS alloy.

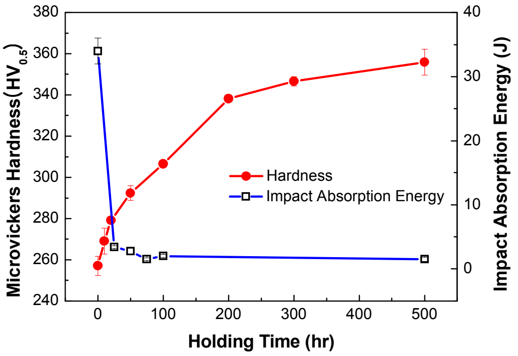

Figure 1. Changes of hardness and Charpy impact energy of 20%Ce ODS alloy (MA 956) along with the holding time at 475°C

The abrupt drop of the impact energy, i.e. the thermal embrittlement of the high Cr (over 12% Cr) ODS alloy is attributed to the formation of the Cr-rich α' phase which is a final product of the Spinodal decomposition in Fe-Cr system [2, 3].

3.2.Experimental ODS alloys

Five series of 9% Cr Fe-base ODS alloys were prepared by MA of the element powders of about 10 µm with 20 to 30 nm yttria (Y_2O_3) powders. MA conditions were monitored by investigating the particle size distribution of the MA powders with XRD (x-ray diffraction), and the optimal MA condition was selected to be 15:1 of the ball-to-powder ratio with 20 hours of MA time at 2,000 rpm of the planetary ball mill. The MA powders were HIPped at 1150°C under 15,000 psi for 20 hrs following the degassing process in the stainless can. The normalized and tempered alloy specimens were tensile tested and the test results at 600°C are illustrated in Fig. 2. The effect of Ti addition is distinctive as the alloys 3, 4, and 5 are significantly stronger that 1, or 2. Ti addition is known to partition into the yttria particles and refines the dispersoids and the inter-particles spacing[4].

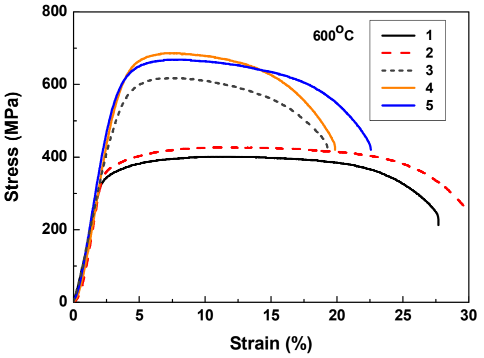

Figure 2. Stress-strain curves of the experimental 9%Cr Fe-base ODS alloys at 600°C

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