Development of Nano-oxide Dispersed Ferritic Alloys by Mechano-Chemical Synthesis and Advanced Consolidation Techniques

Abstract

Nano-oxide dispersed ferritic alloys are widely used as structural components in different applications as heat exchanger parts and super-heater tubes in thermal or nuclear power plants. It is observed that the strength of these ODS alloys (1100-1500MPa) could be significantly enhanced by uniform dispersion of higher amount of nanometric Y_2O_3 (ex-situ) or $Y_2Ti_2O_7$ / Y_2TiO_5 (in-situ) in high-Cr ferritic matrix in presence of other alloying elements like Al and Ti.

The present work aims at synthesis of 83.0Fe-13.5Cr-2.0Al-0.5Ti (alloy A), 79.0Fe-17.5Cr-2.0Al-0.5Ti (alloy B), 75.0Fe-21.5Cr-2.0Al-0.5Ti (alloy C) and 71.0Fe-25.5Cr-2.0Al-0.5Ti (alloy D) (all in wt %) each with 1.0 wt% nano-Y_2O_3 dispersed particles through mechanical alloying and subsequent consolidation by four novel techniques namely; high pressure sintering (HPS), hot isostatic pressing (HIP), pulse plasma sintering (PPS) and hydrostatic extrusion (HE) methods. Following this mechano-chemical synthesis and consolidation, extensive effort has been undertaken to characterize the as- milled and consolidated products by X-ray diffraction study, scanning and transmission electron microscopy, energy disperse spectroscopy, followed by evaluation of physical(density and porosity), mechanical (compressive strength, Young's modulus, hardness, fracture toughness and wear resistance) and chemical(oxidation resistance) properties.

The present ferritic alloys record extraordinary levels of compressive strength (2012-3325 MPa), Young's modulus (230-295 GPa), fracture toughness (4.6-21.8 MPa$\sqrt{m}$) and hardness (15.5-19.7 GPa), and measure up to 2-3 times greater strength with a lower density (~ 7.4 Mg/m^3) than that of other oxide dispersion strengthened ferritic alloys or steels (< 1200 MPa) or tungsten based alloys (< 2200 MPa). The novelty of these alloys lies in the unique microstructure comprising uniform dispersion of 10-20 nm Y_2O_3 (ex-situ) or $Y_2Ti_2O_7$ / Y_2TiO_5 (in-situ) particles in higher volume fraction in high-Cr ferritic matrix. The alloy D sintered by hot isostatic pressing at 1000 ^oC appears to offer the maximum improvement in desired properties as compared to the other three techniques. The rate of oxidation decreases with increase in Cr content with a maximum reduction in oxidation rate in alloy D (containing 25.5 wt. % Cr).

Thus, it was concluded that mechanical alloying followed by hot isostatic pressing (HIP) is the most promising route for synthesizing oxide dispersed in high-Cr ferritic matrix offering attractive mechanical properties.