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Perspective

High-Entropy Ceramic Precipitates Strengthening and Toughing Refractory High Entropy Composite Materials Prepared by Powder Metallurgy Method

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INTRODUCTION

The structural components of aerospace, nuclear reactors and land-based gas turbines are facing with harsh high-temperature service environments. Superalloys can be regarded as the satisfactorily commercial materials for high-temperature environments for few decades, but their high-temperature stability and mechanical properties cannot meet the increasing requirements. In 2010, Senkov's research group at the US air force laboratory successfully prepared two novel Refractory High Entropy Alloys (RHEAs): NbMoTaW and NbMoTaWV. After more than one decade, RHEAs have gradually becoming the most promising candidates for structural materials for ultra-high temperature above 1350°C and their hardness, wear resistance, corrosion resistance and high temperature performance exhibit more superior than those of conventional nickel-superalloys.

DESCRIPTION

However, RHEAs also have obvious weaknesses such as poor mechanical properties at room temperature and processability. In recent years, a large number of novel RHEAs such as HfNbTaTiZr, MoNbNiTaTi, TaHfMoNbTi have been gradually developed with the design goal of reducing density and increasing compressive strength and plastic elongation rate at room temperature and improving their overall mechanical properties at elevated temperatures. Currently, the microstructure of bulk RHEAs prepared by conventional vacuum arc melting method often exhibit coarse dendritic and they are prone to generate casting defects such as segregation, pores and shrinkage. However, altering the types and contents of main elements in RHEAs cannot achieve satisfactory effects in enhancing their overall mechanical properties. The contradiction between strength and ductility of RHEAs prepared by conventional melting metallurgy methods has reached their limit and thus the combined technology of nano-composition, mechanical alloying and laser additive manufacturing are likely to bring new breakthroughs in considerably improving the overall mechanical properties.

At present, high density of developed RHEAs is still a critical problem to hinder their potential application. Many studies have attempted to add light metal elements such as Ti, Al, etc. to reduce their densities, but the high temperature strength of these RHEAs is difficult to meet the requirements, indicating that it is hard to remove a large number of refractory metal elements. Thus, it is still necessary to refocus NbMoTaW and NbMoTaWV conventional alloys. On the one hand, we should further systematically reveal the microstructure and the mechanisms of poor workability at room temperature of two conventional RHEAs and provide theoretical basis for improving their overall mechanical properties. On the other hand, both partially replacing metallic elements in NbMoTaW and NbMoTaWV and interstitial solid solution non-metallic elements with small atomic radius (e.g. C, N, B, O, Si, etc.) could further regulate the microstructure of RHEAs, achieving unique high-entropy ceramic precipitates strengthening and toughening nano-scale RHEAs composite materials with considerable improvement of overall mechanical properties at both room temperature and high-temperature.

Generally, the powder composition of mechanically alloying method may have a wider adjustable range, finer microstructure, more uniform chemical composition and the formations of metastable and supersaturated phases. In our study, the mechanical alloying method was used to obtain RHEAs powders with ultra-fine grain size and homogeneous structure and composition. To solving the poor room temperature plasticity and processability of RHEAs, the non-metallic elements with small atomic radii such as C, N, O were doped by high-energy ball, resulting in severe lattice distortion in main crystal lattice of RHEAs and carbon atom supersaturation.

CONCLUSION

The formation of *in-situ* high-entropy ceramic precipitates may thus improve the toughness of RHEAs. Therefore, the nano-high entropy ceramics strengthening and toughening the NbMoTaWVC composite powders was successfully prepared and their overall mechanical properties at both room temperature and elevated temperatures are considerably enhanced. Currently,

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our research group employs electric field-assisted vacuum hot-pressing sintering and laser cladding methods to prepare bulk materials and coatings of refractory high-entropy alloys and high-entropy ceramics. The mechanically alloyed NbMoTaWVC RHEAs mainly consists of matrix phases with (bcc+bct) crystal structures together with (NbMoTaWV)C nano-high entropy ceramic precipitates, while the crystal structure of NbMoTaWV high entropy alloy exhibits single bcc, suggesting that the occurrence of martensitic transformation which is very similar to that of carbon steel when doping carbon atoms in NbMoTaWV RHEAs.