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Effect of Tungsten Mesh, Short Fibers and Particles Reinforcements on Toughness of Reduced Activation High Entropy Alloy for Fusion Plasma Facing Applications

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1. Introduction

Tungsten (W) is a potential candidate for forthcoming fusion plasma facing applications due to its high melting temperature, high mechanical strength, low sputtering erosion and adequate thermal conductivity [1,2]. However, tungsten accompanies some constraints including decrease in strength at temperatures above 1000ºC, high ductile to brittle transition temperature and irradiation induced embrittlement [3]. These limitations hinder the applications of W and persuade researchers to develop the innovative W-based materials [4] for future fusion plasma facing applications.

The researchers are developing novel W-based materials. However, the limitations of conventional alloys for instance poor workability [5], high energy in stimulating dislocation movement [6] and weak passivation [7] divert the research focus towards high entropy alloys (HEAs) [8]. The HEA offers high resistance to creep, fatigue and wear in addition to the high strength and hardness [6].

In order to analyze the effect of W-based reinforcement (fiber) in W-matrix, the composite samples have been developed via hot isostatic pressing (HIP) and chemical vapor deposition (CVD). Although the reduction in brittleness of W-matrix has been observed due to ductile fracture of W-fibers [9-12], but premature ending of deposition of W-matrix in CVD resulted in low density of composite [9] and secondary grain growth in HIP was observed [12]. These shortcomings of CVD and HIP ask for the development of composites by spark plasma sintering (SPS) for high temperature and nuclear applications.

The synthesis of WxTaTiVCr [13] based composites reinforced with mesh, short fibers and particles of W, by spark plasma sintering is being presented in this manuscript. The effect of reinforcements on toughness of HEA has been investigated.

2. Methods and Results

2.1 Experimental

Various types of composites were produced by adding ~10wt.% of horizontal layers of W mesh 3D mesh, short fibers and particles via SPS of powder mixture (of W, Ta, Ti, V and Cr) at 1500ºC. The sintering time was 10 minutes. Fig. 1 shows the configuration of HEA/W composite samples.

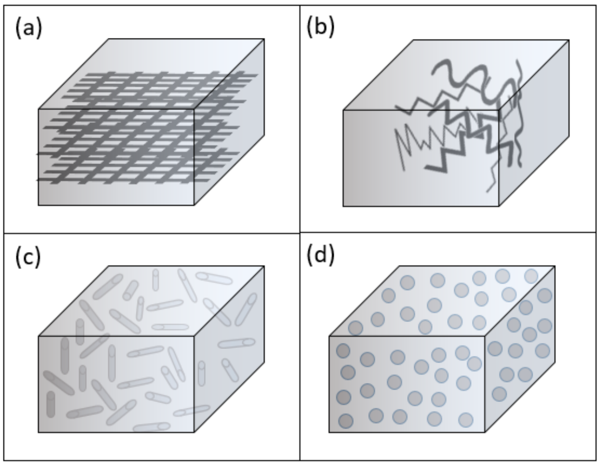

Fig. 1. (a) W_{Mesh} (b) $W_{3D\ mesh}$ and (c) $W_{Short\ Fibers}$ and (d) $W_{Particles}$ reinforced HEA (WTaTiCrV) composites.

In order to ensure the reduced activation properties in HEA/W composites, the addition of Mo, Cu and Nb was avoided [13]. X-ray diffraction (XRD) and scanning electron microscopic (SEM) analysis were carried out for microstructural characterization. Micro-Vickers hardness test was carried out for assessing mechanical behavior. Single edge notch beam (SENB) test was done to analyze the effect of reinforcement on toughness of composites.

2.2 Results

The W_{Mesh}, $W_{3D\ mesh}$, $W_{Short\ Fibers}$ and $W_{Particles}$ reinforced WTaTiVCr (HEA) based composites reveal BCC crystal structure as shown in Fig. 2. The BCC structure of W-based reinforcements and HEA matrix results in single BCC peaks.

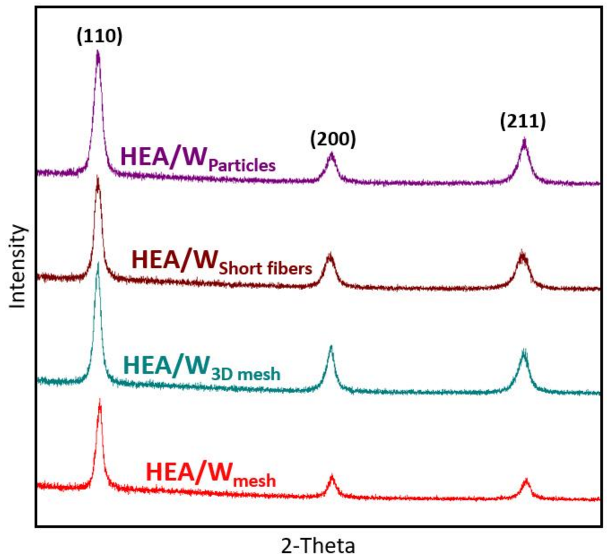

Fig. 2. XRD patterns of W_{Mesh}, $W_{3D\ mesh}$, $W_{Short\ Fibers}$ and $W_{Particles}$ reinforced HEA (WTaTiCrV) composites.

The SEM-EDS analysis of the composites revealed uniformly distribute constituents and Ti-rich minor phase. The microstructure, as shown in Fig. 3 also reveals no porosity and voids between the matrix and reinforcements.

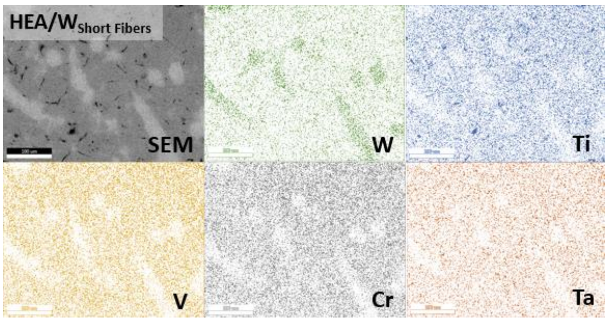

Fig. 3. SEM microstructure and elemental distribution in HEA/$W_{Short\ fibers}$ composite.

The HEA matrix was found to be dominating the hardness of HEA/W composites. With abrupt and minor variations, the hardness of the HEA/W composites remains ~750 HV.

The single edge notch beam test was carried out as per ASTM standard E 1820-01. Fig. 4. Shows the standard SENB test samples.

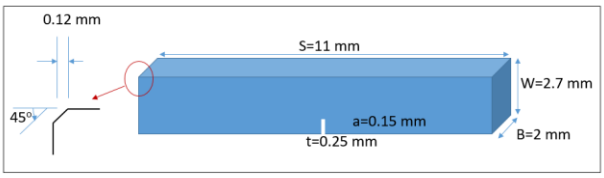

Fig. 4. Sketch of single edge notch beam test sample.

The SENB test was carried out in air environment, at room temperature and at strain rate of 0.05 mm/min.

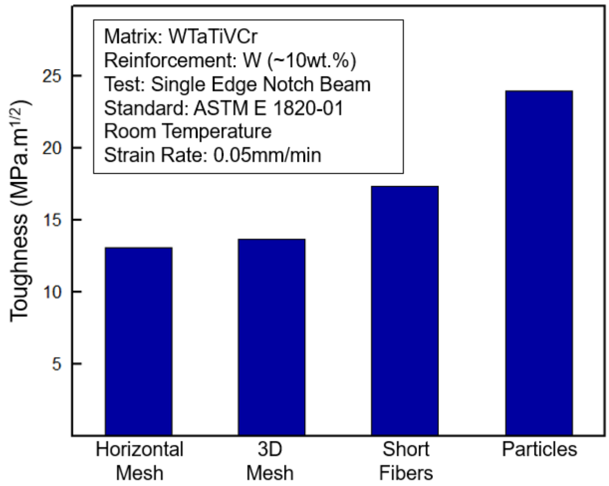

Fig. 5. Effect of various W-based reinforcements on the toughness of HEA/W composites.

With the addition of reinforcements, the modification in toughness was observed. The addition of $W_{Particles}$ is found most effective as it shows toughness of 24 MPa.m$^{1/2}$, which is almost 5 times higher than pure tungsten. The effectiveness of various reinforcement can be compared as W_{Mesh}<$W_{3D\ mesh}$<$W_{Short\ Fibers}$<$W_{Particles}$, see Fig. 5.

The successful development of HEA/W composite with improved toughness shows the potential of this material in future fusion application. To ensure applicability of these novel composites, the mechanical characterization at elevated temperatures and irradiation analysis is to be done.

3. Conclusions

The powder mixing followed by SPS developed HEA/W composites with improved hardness and toughness up to ~750 HV and 24 MPa.m$^{1/2}$ (WTaTiVCr/$W_{Particle}$), respectively. The reduced activation composition and improvement in mechanical properties forecast the potential fusion plasma facing application of this novel composites.

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