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Phase Composition and Hardness of Series of Nanocrystalline CoCrFeMnMoNiTiW High-Entropy Alloys

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Metal matrix composites (MMC) with discontinuous reinforcements are mainly used for structural applications. The tensile strength, toughness and stiffness are the most important mechanical properties that are considered for these applications. Ceramic materials are the most used reinforcements for the preparation of MMC (Al_2O_3, SiC, TiC, ZrO_2, etc.). However, one of the problems that occur in the manufacture of MMC is the low adhesion to ceramic particles due to the lack of wettability. High-entropy alloys have been recently proposed as metal reinforcements in MMC with improved performance than ceramic reinforcing phases. Although the effectiveness of dispersoids depends on their size, spacing and homogeneous distribution, also the reinforcement effeft depends on the intrinsic properties of the particles, which produce elastic strain and hinder the motion of dislocation during plastic deformation [1]. The high-entropy alloys (HEA) were defined in the composition range in which the configuration entropy of the alloys would be sufficiently high to overcome the enthalpies of formation of intermetallic phases, giving as a desirable result the formation of solid solutions with face-centered cubic (FCC) and/or body-centered cubic (BCC) crystalline structures. Therefore, their physical, chemical and mechanical properties are very different from traditional or classical engineering alloys, since they are not based on a principal element. Through the technique of mechanical alloying, it has been possible to synthesize a large variety of HEA with a nanocrystalline structure. Therefore it is expected that HEA particles have a superior performance to another type of metal reinforcements used in the fabrication of MMC [2]. In this study, the phase composition and hardness of series of high-entropy alloys produced by mechanical alloying are reported. The aim is to collect data about the relationship between chemical composition, crystalline structure and hardness of HEA containing Co, Cr, Fe, Mn, Mo, Ni, Ti and W, which can be used for future research involving the design and synthesis of MMC with HEA particles.

Blended elemental powders in equatomic ratios were mixed for 30 min in a high-energy mill (SPEX-8000M). The mechanical alloying process was performed in a high-energy mill (EMAX), under an argon atmosphere to avoid excessive oxidation of the powders. The milling time was 5 hours. The ball to powder weight ratio was 10: 1. Stearic acid was used as a process control agent. The microstructural features were analyzed by scanning electron (SEM) and transmission electron microscopy (TEM). The phase composition was characterized by X-ray diffraction (XRD). Microhardness test were conducted in order to determine the influence of chemical composition on the hardness of the synthesized HEAs. The results are summarized in Table 1.

TEM images of the mechanically alloyed CoCrFeMoNi sample for 10 h are shown in Fig. 1. Selected area electron diffraction (SAED) pattern and high-resolution TEM micrograph reveal the nanocrystalline nature of the synthesized alloy. These results are representative for all alloys under study. The According to XRD results, most of the synthesized alloys possesses a mixture of FCC + BCC solid solution phases, except for the CoCrFeMnNi, CoCrFeMnNiTi and CoCrFeNiTi, which only exhibit the formation of FCC phases. Although it is expected that an alloy with BCC structure has greater hardness than a similar alloy with FCC structure, in this study it was demonstrated that an alloy, which has a FCC-type structure, reached the highest hardness. This value is approximately double that the average of the rest of the alloys.

References:

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Table 1. Hardness and phase composition of synthesized high-entropy alloys.

High-entropy alloy	Hardness (HV)	Structure
CoCrFeMnMoNi	610	FCC + BCC
CoCrFeMnMoNiTi	636	FCC + BCC
CoCrFeMnMoNiTiW	648	FCC + BCC
CoCrFeMnMoNiW	689	FCC + BCC
CoCrFeMnNi	695	FCC
CoCrFeMnNiTi	1271	FCC
CoCrFeMnNiW	770	FCC + BCC
CoCrFeMoNi	721	FCC + BCC
CoCrFeMoNiTi	654	FCC + BCC
CoCrFeMoNiW	743	FCC + BCC
CoCrFeNiTi	555	FCC
CoCrFeNiTiW	804	FCC + BCC
CoCrFeNiW	665	FCC + BCC
CoCrFeMnMoNi	610	FCC + BCC

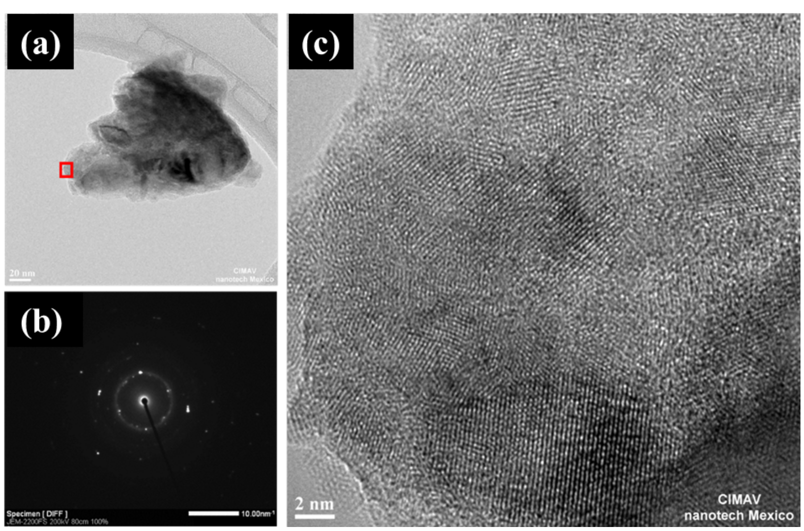

Figure 1. (a) TEM micrograph of a representative particle of mechanically alloyed CoCrFeMoNi, (b) corresponding SAED pattern and (c) HRTEM micrograph showing the nanocrystallinity of alloy.

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