doi:10.1017/S1431927622010832
Microsc. Microanal. 28 (Suppl 1), 2022

Synthesis of a Cr-Mn-Fe-Co-Ni-CNTs High Entropy Alloy

I. Macias-González[1], O.I.R. Torres-Hernández[2] L.A. Cáceres-Díaz[3], C.D. Gómez-Esparza[4,5], F. Pérez-Bustamante[6] and R. Pérez-Bustamante[7,*]

1. Universidad Autónoma de San Luis Potosí, Facultad de Ingeniería, San Luis Potosí, SLP., México
2. Instituto Tecnológico Superior de San Luis Potosí, San Luis Potosí, SLP, México
3. CONACYT-Centro de Tecnología Avanzada, San Luis Potosí, SLP, México.
4. Universidad Autónoma de Chihuahua, Facultad de Ingeniería, Chihuahua, Chih., México
5. Subsecretaría de Inteligencia y Análisis Policial, Secretaría de Seguridad Pública del Estado, Chihuahua, Chih, México.
6. Universidad Autónoma de Coahuila, Saltillo, Coah, México
7. CONACYT-Corporación Mexicana de Investigación en Materiales, San Luis Potosí, SLP, México.

Corresponding author: raul.perez@ciateq.mx

A new alloys group appeared in the year 2004 synthesized by two research groups [1,2]. Yeh et al. defined those as high entropy alloys (HEAs), while Cantor et al. named as multi-component alloys, and has since great attention has been paid to HEAs in the materials research field. The HEAs are solid solutions alloys that contain more than five principal elements in equiatomic or near of equiatomic (at.%). This alloys group breaks with the conventional approach of the metallic alloys that are primarily based on a majority element, with additions of other elements in smaller quantities to promote increased structural and mechanical performance. If mechanical alloying is used for the manufacture of high entropy alloys, these can result in microcrystalline, sub-microcrystalline or even nanocrystalline alloys, with which their mechanical properties can be increased.

Among the wide variety of HEA reported, the most thoroughly studied is the quinary equiatomic FCC HEA Cantor alloy (CrMnFeCoNi). Its mechanical performance shows a strong dependence of the processing conditions and has been studied through several experimental procedures [3-5]. Mechanical alloying is a powder processing technique that allows the production of chemically and structurally homogeneous materials, starting from mixtures of elemental powders (Fig. 1). Two of its main advantages are that materials can be synthesized at the nano-scale, and the solubility is extended. If mechanical alloying is used for the manufacture of high-entropy alloys, these can result in nanocrystalline alloys, with which their mechanical properties can be increased

Equiatomic high entropy alloys were obtain from elemental powders (Figs. 2 a-f) with purity higher than 99.5% in weight (metal basis), Co (particle size of 25 µm), Cr (particle size of 35 µm), Fe (particle size of 75 µm), Ni (particle size of 20 µm) and Mn (particle size of 35 µm). Multi-walled carbon nanotubes (CNTs) were added in an equiatomic concentration in order to produce a CrMnFeCoNi(CNTs) HEA alloy. As reference a quinary equiatomic CrMnFeCoNi was synthesized and studied as reference. The powders were initially weighed and mixed (PM), and subsequently mechanically alloyed (MA) for 10 h. The milling was performed in a high-energy ball mill (SPEX 8000 M) under an argon atmosphere using hardened steel vial and grinding media. The ball-to-powder weight ratio was 5:1. Methanol was added as a process control agent to inhibit the particle agglomeration. The morphology of the elemental powders and the CNTs was examined through scanning electron microscopy. The mechanical behavior of the alloys was reported by Vickers microhardness tests.

Figure 2g, shows the hardness results of the CrMnFeCoNi and the CrMnFeCoNiCNTs HEA alloys. Is has been reported that the processing conditions could lead to abnormal hardening as in the case of cold rolling conditions [4], high-pressure torsion [5] and others [3]. In the case of the HEA alloy containing CNTs (Fig. 2g), whose dispersion is through MA, a noticeable and improved hardness behavior is observed. Even though nanotubes were added in a equiatomic concentration, their nanometric nature and the fragmentation behavior carried out along 10 h of milling derives in their multiple fragmentation, providing an increased interaction with the remaining elements of the Cantor alloy.

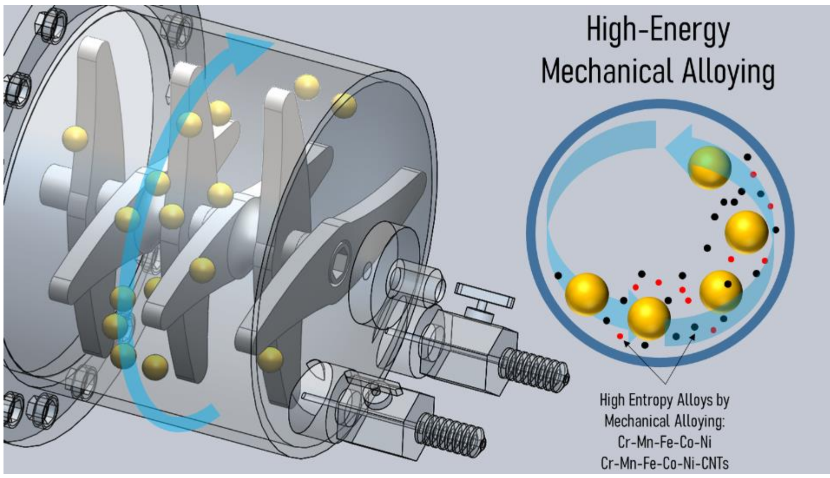

Figure 1. Schematic representation of the high-energy milling process used in the synthesis of HEAs

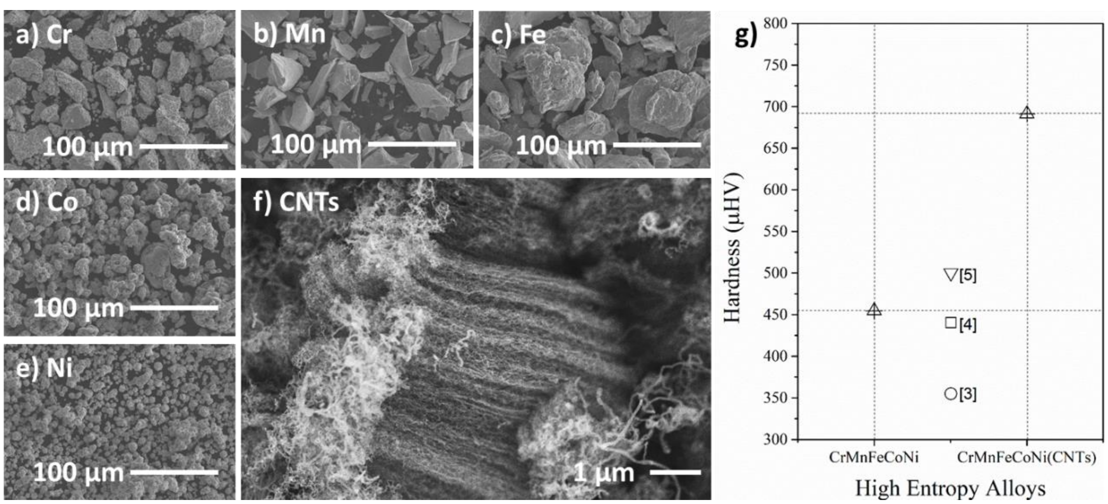

Figure 2. (a-f) Elements used in the HEA synthesis, (g) Hardness results of HEA alloys

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https://doi.org/10.1017/S1431927622010832 Published online by Cambridge University Press

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[6] R. Pérez-Bustamante acknowledge the research funding received from the Consejo Potosino de Ciencia y Tecnologia (project: FME/2021/SO-02/11)