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NiCoAlFeCrTi High Entropy Alloys Produced In Solid State.

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High-entropy (HE) alloys are recently developed alloys defined as solid solutions (SS) containing at least five principal elements in equiatomic or near equiatomic compositions. HE alloys usually possess simple FCC and/or BCC structures instead of complex structures. Mechanical alloying (MA), a dry high-energy ball milling process, has been one of the routes to synthesized HE alloys. Having the particular characteristic of form SS from elemental powders, by this technique is possible to obtain advanced materials in nanocrystalline scale, which can exhibit excellent properties like high hardness and elevated thermal stability. Since the development of HE alloys, AlCoCrCuFeNi alloy system has been widely studied in terms of microstructure and mechanical properties. Evidence of Cu segregation in as-cast alloys was observed [1]. Also, in HE alloys produced by MA, Cu remains no incorporated into the SS formed [2]. Research is being conducted to study microstructural and mechanical features of the mention alloy system using Ti, element with HCP structure, instead of Cu.

MA process was carried out in a high energy ball mill (SPEX-8000M) to synthesized equiatomic NiCoAlFeCr, NiCoAlFeTi and NiCoAlFeCrTi alloys systems from elemental powders. Hardened steel container and balls as grinding media were used. The ball-to-powder weight ratio was 5:1, under argon atmosphere to protect the powders from oxidation. The milling time was 10 h. The as-milled powders were consolidated by cold pressing at 1.5 GPa, sintered at 1200 ºC for 3 h inside sealed quartz ampoule in vacuum. The effects of additions of Cr and Ti on equiatomic NiCoAlFe systems are characterized by X-ray diffraction (XRD). The as-milled powders were characterized by scanning electron microscopy (SEM) in a JEOL JSM-5800LV and the sintered products were characterized in a JEOL JSM-7401F microscope supplied with an energy dispersive spectrometer (EDS). Besides, transmission electron microscopy (TEM) analyses on sintered products are being carried out.

According to EDS analyses, small variations in the chemical homogeneity in as-milled powders are present; however, the final composition in milled products is very close to the equiatomic ratio. Scanning electron micrograph depicting the typical lamellar microstructure obtained during mechanical alloying (Fig. 1). Figure 2 shows the representative microstructure in consolidated samples. Figure 2a shows two mainly phases, the darker one is an aluminum rich zone, while in zone *B* a low aluminum concentration is found. In Figure 2b two main phases are observed, the dark one is a Cr, Al rich phase. Bright phase identified as zone *B*, is a lower aluminum, medium Cr and Ni and high Co and Fe concentration zone. In figure 2c can be observed a high Ni, Co and Fe phase (zone *A*) and a Ti-Al-rich phase (zone *B*). Figure 2d shows that Ti and Cr together make more complex the microstructure observed. The Ti-rich phase are still present (zone *C*), in addition to two more phases, zone *A* with high Ni, Co and Al contents; and zone *B,* where it can be observed that Fe presents an apparent preference for Cr- rich regions. Additions of elements with cubic structure favor the formation of HE alloys with simple FCC y/o BCC structures. Ti promotes the formation of nanoparticles [3].

In synthesized HE alloys, the number of the phases formed and their structure depend on the alloying elements. The XRD spectra after sintering process give evidence about the formation of phases with simple FCC and BCC structures. Apparently, with the Ti additions, a HCP phase is formed (Fig. 3).

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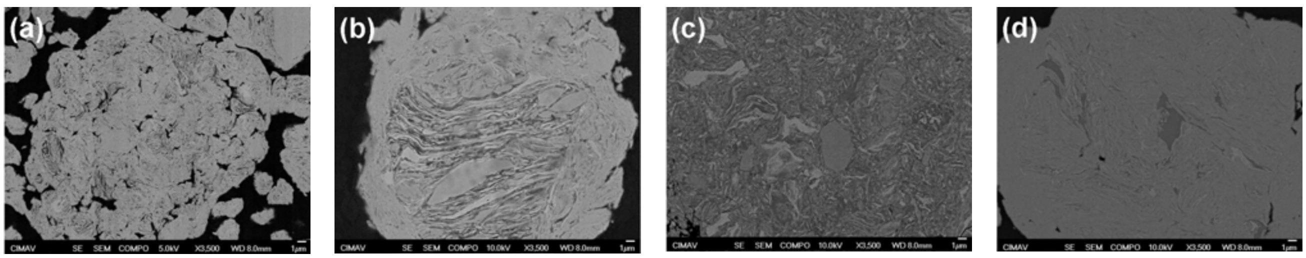

Fig. 1. Lamellar microstructure of mechanical alloyed powders, (a) NiCoAlFe, (b) NiCoAlFeCr, (c) NiCoAlFeTi and (d) NiCoAlFeCrTi systems.

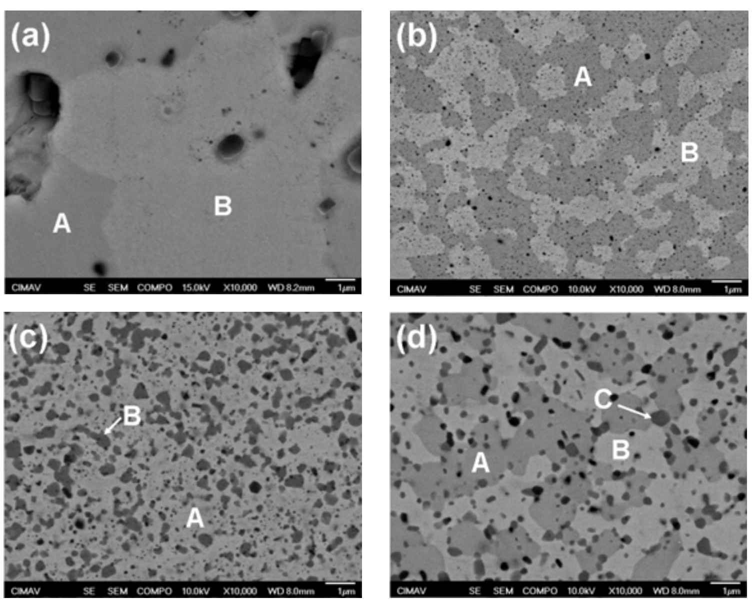

Fig. 2. SEM images of microstructure in sintered products. (a) NiCoAlFe, (b) NiCoAlFeCr, (c) NiCoAlFeTi and (d) NiCoAlFeCrTi systems.

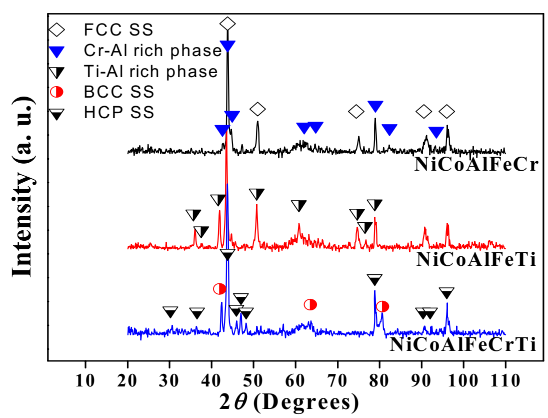

Fig. 3. XRD patterns of sintered products. (a) NiCoAlFe, (b) NiCoAlFeCr, (c) NiCoAlFeTi and (d) NiCoAlFeCrTi systems.

Table 1. Microhardness results.

System	Microhardness
NiCoAlFeCr	428 – 494 HV
NiCoAlFeTi.	533 – 616 HV
NiCoAlFeCrTi	730 – 783 HV