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Characterization of (Cu-Fe-Ni-Co) High Entropy Alloy Fabricated by Powder Metallurgy

Hossam M. Yehia[1], Ahmed El-Tantawy[1], Ahmed M. Abdelkhalek[2], Omayma A. El-kady[3]
[1]Production Technology Department, Faculty of Technology and Education, Helwan University, Saray-El Qoupa, El Sawah Street, Cairo 11281, Egypt; hossamelkeber@techedu.helwan.edu.eg
[2]Quesna Technology Institute, Ministry of Higher Education, Benha, Egypt.
[3]Powder Technology Department, Central Metallurgical Research and Development Institute (CMRDI), Helwan 11421, Egypt; o.alkady68@gmail.com
*Corresponding author Email Address: hossamelkeber@techedu.helwan.edu.eg

Abstract— *High-entropy alloys (HEAs) represent an advanced class of metallic materials that differ from conventional alloys by consisting of four or more principal elements in nearly equal proportions. This unique composition leads to a significant increase in configurational entropy, resulting in exceptional mechanical and physical properties such as high hardness, excellent thermal stability, and superior corrosion resistance. HEAs typically exhibit either a body-centered cubic (BCC) structure, which provides high strength but low ductility, or a face-centered cubic (FCC) structure, which offers enhanced plasticity but lower strength. In this study, a Cu-Fe-Ni-Co high-entropy alloy (HEA) composite was fabricated using the powder metallurgy technique. The elemental powders were ball-milled for 30 hours to ensure uniform mixing, followed by cold pressing at 400 MPa. The green compact was then sintered at 1250°C for 60 minutes. The fabricated sample was evaluated for density, microstructure, hardness, and compressive strength. The results revealed a 96% relative density, with microstructural analysis indicating a single-phase structure. The sample exhibited a hardness of 200 HV.*

Keywords— *High-entropy alloy (HEAs); Density; Microstructure; Hardness; Compression strength; Powder metallurgy.*

I. Introduction

High-entropy alloys (HEAs) represent an innovative class of materials that differ from conventional alloys, which typically contain only one or two primary elements. HEAs, in contrast, generally consist of more than four principal elements. The term "high entropy" arises from the significantly increased configurational entropy observed under two conditions: first, when multiple elements are incorporated into the alloy, and second, when these elements are present in nearly equal proportions. These alloys are known for their exceptional properties, including high strength and hardness, excellent thermal stability, and superior corrosion resistance. However, one major drawback of HEAs is their high brittleness [1–9].

Structurally, the crystal lattices of most HEAs adopt either a body-centered cubic (BCC) or face-centered cubic (FCC) configuration. Alloys with a BCC structure tend to exhibit high strength but limited plasticity [10], whereas those with an FCC structure offer enhanced ductility but relatively lower strength [11,12]. The selection of elements in HEA design is crucial, particularly when considering the intended applications and cost-effectiveness of the alloy [13,14]. Extensive research has explored the effects of various elements on HEA properties, including aluminum (Al) [15], nickel (Ni) [16], copper (Cu) [17], titanium (Ti) [18], and tin (Sn) [19].

The fabrication of composites with a homogeneously dispersed reinforcement phase and a well-defined laminated structure can be achieved through various techniques. Commonly employed methods include flake powder metallurgy [20], vacuum filtration [21], freeze casting [22], electrophoresis [23], and preforming [24], among others. One effective and straightforward approach involves producing flake particles or constructing lamellar structures to ensure uniform dispersion of the laminated phases [25].

Typically, the resulting flake composite powders or raw materials undergo sintering through processes such as hot pressing (HP), hot isostatic pressing (HIP), or spark plasma sintering (SPS). In general, HEAs with an FCC structure exhibit good plasticity but relatively low strength [26, 27], whereas BCC-structured HEAs possess higher strength but suffer from reduced plasticity [28, 29] and increased brittleness [30, 31]. Due to their superior plasticity, FCC HEAs are more easily processed into flake powder particles, making them particularly suitable for flake powder metallurgy.

The aim of this study is to fabricate and characterize Cu-Fe-Ni-Co high entropy alloys using the powder metallurgy technique.

II. Experimental work

2.1 Materials and method

The fabrication of HEAs involved the use of high-purity base materials, including copper (Cu) with a particle size of 200–300 nm and a purity of 99.5%, iron (Fe) with a particle size of 10 µm and a purity of 99.98%, nickel (Ni) with a particle size of 2–3 µm and a purity of 99.9%, and cobalt (Co) with a particle size of 10 µm and a purity of 99.95%. All raw materials were obtained from the Central Metallurgical Research and Development Institute (CMRDI), Helwan, Egypt.

The elemental powders were mechanically milled for 30 hours to ensure uniform mixing and refinement. The milled powders were then compacted and sintered at 1250°C for 60 minutes with a controlled heating rate of 5°C/min to achieve the desired microstructural and mechanical properties.

2.2 Characterization

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Density measurements of the fabricated samples were performed using the Archimedes method. The hardness of the high-entropy alloys (HEAs) was measured using the HTV-1000 T Hardness Tester. Additionally, compressive strength tests were carried out to assess the mechanical performance of the samples under compressive loading conditions.

III. Results and Discussions

Figure 1 illustrates the microstructure of the fabricated high-entropy alloy (HEA) sample composed of Ni, Cu, Co, and Fe. The microstructure reveals a homogeneous solid solution with a uniform grain structure, attributed to the high-entropy effect, which plays a crucial role in stabilizing the single-phase matrix. The presence of multiple principal elements in nearly equal proportions promotes severe lattice distortion, reducing the tendency for phase separation and facilitating the formation of a stable solid solution. This unique microstructural stability enhances the alloy’s mechanical properties, such as improved hardness, strength, and wear resistance. The absence of significant secondary phases suggests that the alloying elements are well-distributed within the matrix, ensuring a balanced combination of properties beneficial for various engineering applications.

Table 1 presents the relative density, hardness, and compressive strength of the fabricated Ni-Cu-Co-Fe high-entropy alloy (HEA) sample. The sample achieved a 96% relative density, indicating 4% porosity, which suggests a high degree of diffusion and bonding between the elemental particles during the sintering process. The low porosity contributes to the enhanced mechanical performance of the alloy, as voids and defects are minimized, leading to better load distribution within the material. The high level of diffusion between the elemental particles ensures the formation of a homogeneous solid solution, which is essential for optimizing the alloy’s properties.

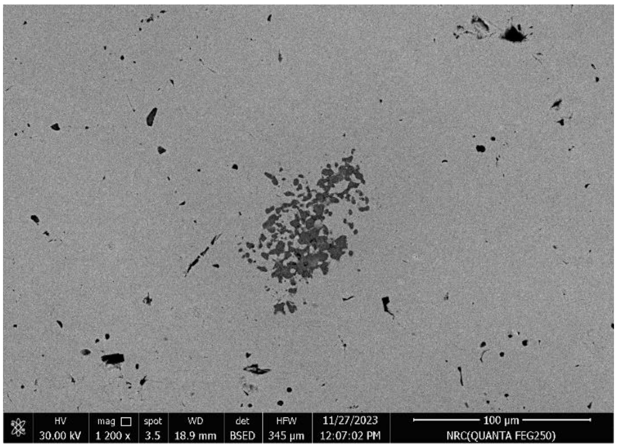

Fig. 1 Microstructure of the fabricated HEAs sample

TABLE 1. Summary of HEAs Relative density, hardness, and compressive strength properties.

Sample	Relative density	Vickers Hardness	YCS	UCS
	%	HV	MPa	MPa
HEA	96	200	806	874

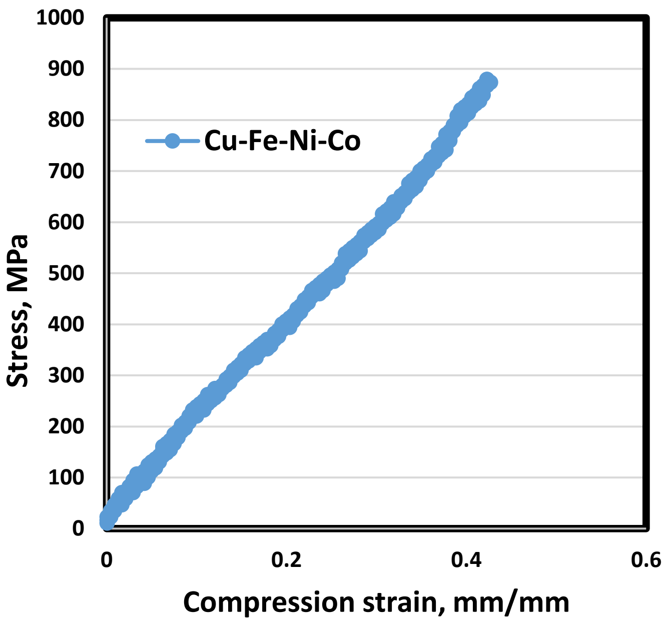

Fig. 2. Stress-strain curves of the fabricated HEAs sample

The fabricated HEA exhibited a hardness of 200 HV, reflecting its ability to resist deformation under applied loads. Additionally, the sample demonstrated high strength, with a yield strength of 806 MPa and a compressive strength of 874 MPa. These values indicate that the alloy possesses a strong resistance to plastic deformation and can withstand significant compressive stresses before failure. The high strength of the alloy can be attributed to the solid solution strengthening effect, lattice distortion, and the refined microstructure resulting from the powder metallurgy process.

Figure 2 illustrates the compressive deformation behavior of the sample, showing a yield strength of approximately 806 MPa and a compressive strength close to 874 MPa. The fracture characteristics indicate that the sample exhibits limited plastic deformation, suggesting a brittle failure mode. This behavior is commonly observed in HEAs with a dominant BCC structure, where high strength is often accompanied by reduced ductility. The absence of significant elongation before failure suggests that the alloy might require further optimization, such as the addition of ductile phases or post-processing treatments like heat treatment, to improve its toughness and plasticity for more demanding applications.

Overall, the results highlight the excellent mechanical performance of the fabricated HEA, making it a promising candidate for applications requiring high strength, wear resistance, and stability under compressive loads. However, further studies on microstructural modifications and compositional tuning may help enhance the alloy’s ductility and fracture toughness, expanding its potential for broader engineering applications.

IV. Conclusions

- The Ni-Cu-Co-Fe HEA was successfully fabricated using the powder metallurgy technique, exhibiting a homogeneous solid solution due to the high-entropy effect.

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- The sample achieved a 96% relative density with 4% porosity, indicating strong diffusion and bonding between elemental particles during sintering.
- The alloy demonstrated a hardness of 200 HV, a yield strength of 806 MPa, and a compressive strength of 874 MPa, highlighting its excellent mechanical performance.
- Limited elongation before fracture was observed, suggesting the need for further optimization, such as heat treatment or the addition of ductile phases, to enhance toughness and plasticity.

Conflict of interest: no conflict of interest with any organization or someone.

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