Paragraph Ran in the Queries

Paper Title: Effect of Nb and Ti additions on microstructure, hardness and wear properties of AlCoCrFeNi high-entropy alloy
Content :

Over the past two decades, high-performance metallic alloys, known as high entropy alloys (HEAs), have garnered significant attention due to their unique composition and properties. The concept of HEAs, first introduced by Cantor et al. [1] and Yeh et al. [2], involves alloys composed by multiple principal elements in equal or almost equal atomic percentages [3]. These alloys, by definition, must contain at least 5 main elements with concentrations typically ranging between 5 and 35 at%. HEAs, according to an alternative definition, are those that present a high configurational entropy, above 1.61 R (where R is the universal gas constant), which favours the stabilization of solid solutions rather than the formation of complex intermetallic phases [4], [5]. Consequently, HEAs offer a new perspective on high-performance alloys, with unique properties such as high wear resistance, high corrosion resistance, and high hardness, even at high temperatures [6], properties sometimes unachievable in conventional alloys [7].

Currently, HEAs design strategies encompass both equiatomic and non-equiatomic elemental ratios, allowing exploration of new compositions with diverse microstructures that may exhibit multiple phases [8]. Recently, the HEA design has explored nanocomposite structures, as demonstrated in the studies of Li et al. [9] and Li et al. [10]. These studies reported the development of (CuNiTiNbCr)N and (CuNiTiNbCr)C nanocomposite films, respectively, which exhibit high hardness, toughness, and excellent wear resistance. This is attributed to a CuNi-rich matrix, in addition to the high affinity between atoms of N and C with Ti, Nb, and Cr atoms, leading to the formation of reinforcing nanocrystalline phases (TiNbCr)N and (TiNbCr)C. Furthermore, excess C precipitates as a self-lubricating phase.

Nevertheless, among the most promising HEA systems, those based on transition metals stand out, with the AlCoCrFeNi system being particularly noteworthy due to its excellent synergy among constituent elements and the ability to control phase formation and properties through variations in molar ratios of its elements [11], [12]. The content of Al plays a crucial role in controlling the stability of the phases. At low Al contents (<0.4), the predominant structure is FCC. Between 0.5 and 0.9, a mixture of FCC and BCC phases is observed and increase the Al content to equimolar the structure is predominantly BCC [11], [13].

The addition of a sixth element to AlCoCrFeNi HEA has been explored in the search for optimizing the properties, highlighting the use of transition metals such as Cu, Mo, V, Ti and Nb. For instance, Dada et al. [14] studied the effects of Cu and Ti additions on the corrosion resistance of AlCoCrFeNi alloy obtained by laser additive manufacturing. The authors observed that both elements increased the corrosion resistance of the system, with the addition of Ti being more effective in reducing the corrosion rate, while the addition of Cu was effective in increasing the polarization resistance.

Similarly, Zhuang et al. [15] studied the effect of Mo content on mechanical properties of the AlCoCrFeNi system. It was observed that the addition of 0.5 at% Mo resulted in an increase in hardness, from 172 HV for the alloy without Mo, to 571 HV in the alloy with 0.5 at% Mo. Furthermore, the compressive strength increased from 368 MPa to 2360 MPa with addition of 0.5 at% of Mo. The increase in mechanical properties was mainly attributed to the formation of the σ phase, rich in Cr and Mo.

Dong et al. [16] investigated the effect of V addition on the microstructure and properties of AlCoCrFeNi HEA. They reported that V acts as a stabilizing element for the BCC crystalline structure, effectively enhancing microstructural homogeneity by reducing the segregation of Al, Ni and Fe. Furthermore, the addition of V led to an increase in the yield stress of the AlCoCrFeNi alloy, rising from 1378.9 MPa to 1726.5 MPa with the addition of 1 mol of V.

The addition of Nb, as reported by Ma and Zhang [17] also holds promise for enhancing mechanical resistance through the formation of a Nb-rich Laves phase, together with a BCC solid solution. This combination led to a notable increase in hardness from 520 HV for the AlCoCrFeNi to 747 HV upon the addition of 0.75 mol of Nb. In addition to contributing to the increase in mechanical strength, the addition of Nb in HEA systems has demonstrated a significant positive effect on ductility [18], [19].

Nonmetallic additions, such as Si, can further optimize the properties of this system. Guo et al. [20] reported a hardness of 1004 HV for the AlCoCrFeNiSi HEA heat treated at 1150°C for 2 hours. This increase in hardness, attributed to the higher volume fraction of B2 phase and Cr_3Si precipitates, improve the wear resistance [20].

Despite the positive effects on mechanical properties provided by solid solution strengthening through Nb and Ti additions in HEA systems, there is a fundamental need to further study the impact of hardening phases, especially Laves phases, on the tribological properties of these alloys. Since the wear behavior is strongly influenced by the microstructure, multiphase high-entropy alloys are expected to have the potential to provide superior wear resistance.

Given the growing interest in developing alloys with tailored properties and the significant role of Nb and Ti in advanced materials, in addition to both elements favoring the formation of hardening phases in HEA, this study aims to enhance understanding how these elements affect the tribological properties of arc-melted AlCoCrFeNi HEAs. The alloys design aimed to achieve a multiphase microstructure composed of a B2 solid solution phase alongside hardening phases such as Laves phase. The study particularly investigates how wear correlates with the microstructure to better understand wear mechanisms. This is of particular interest for several industrial applications, especially in sectors such as the oil and gas industry, where wear resistance is a critical factor for components used in the extraction and transportation of chemical products.