Improving the properties of Ni-Based Alloys by Co Addition

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Abstract: Grain refinement is caused by the addition of Co, which is why changing the amount of Co may be regarded to have an effect on both the microstructure and the behavior of corrosion. The behavior of the grain during corrosion is directly influenced by grain refining. After combining the powders of nickel, chromium, aluminum, and cobalt in the appropriate proportions, the alloys were then compacted to produce green pellets as the next step in the synthesis process. In the last step, the samples were created by using a technology called vacuum arc melting and casting. Both x-ray diffraction and optical microscopy were used in order to characterize the samples after they had been produced. The Vickers hardness tester was used to provide an assessment of the surface's toughness. It has been discovered that the characteristics of the alloy have been greatly improved.

Keyword: Ni Based Alloys, Corrosion properties, Vacuum arc melting

1. Introduction:

According to the results, the coating's corrosion resistance was improved over the substrate when compared to that of the substrate itself, while its hardness and wear resistance both improved as the amount of Ti and B4C contained inside it grew. Plasma cladding is the method of fabricating products that sees the most widespread use in industry due to its exceptional benefits. These benefits include excellent arc stability, high energy exchange efficiency (due to its relatively high energy density), low thermal distortion (due to its low cost of equipment), good matrix bonding (due to its thick coating), and low thermal distortion. Plasma cladding is the method of fabricating products that sees the most widespread use in industry due to its exceptional benefits. The choice of alloying components has been shown to have a significant impact on the microstructure of alloys as well as the resistance of alloys to corrosion [1]. Wen et al. [2] studied how the presence of different microstructures affected the corrosion resistance of Ni-Al intermetallic compounds that were synthesized by vacuum melting. According to the findings, a significant number of grain boundaries were found, and the presence of a multiphase structure led to the formation of a significant number of corrosive galvanic cells, which in turn led to severe corrosion. Both of these phenomena were caused by the presence of severe corrosion. Ye et al. [3] were able to create a crack-free CrMnFeCoNi high-entropy alloy coating by using an approach that involved laser surface alloying. This coating resulted in the formation of a single face-centered cubic (FCC) phase and had a level of corrosion resistance that was comparable to that of stainless steel 304. Ni has the potential to produce stable compounds as a solid solution element in a solid solution system if it is combined with numerous alloying elements and is a component of strengthening phases. [4–6] One of the reasons why chromium is so often used to improve a material's resistance to corrosion is because it has the potential to generate a dense oxide covering. However, very little study has been done on the effect that optimizing the materials used has on the composition and phase evolution of the plasma cladding at different stages of the process.

Ni is a transition metal with a molar mass of 58.69 g mol and a density of 8.90 g cm-3 when heated to 25 degrees Celsius. In the solid form, it exhibits a face-centered cubic (fcc) crystal structure, which is a kind of cubic. It melts at 1453 degrees Celsius and is resistant to corrosion and oxidation at temperatures ranging from mild to high. A value as low as 68.44 nm at 20 degrees Celsius indicates that the electrical resistivity of Ni is minimal when the temperature is kept low. When exposed to an oxidising environment, it is chemically inactive, and its corrosion resistance falls. Ni is a very adaptable metal that can easily combine with the majority of other metals to make alloys. Cobalt is located between the elements iron and nickel on the periodic table. Co has a molar mass of 58.93 g mol-1 and a density of 8.85 g cm-3, which are both comparable to Ni's molar mass and density. Cobalt is a ferromagnetic metal, similar to Ni in that it has a magnetic field. Co may exist in two distinct crystalline forms depending on the temperature; hexagonal closed packed at 417 °C and fourfold closed packed at 417 °C and 1493 °C, respectively (melting point) [(hcp; ε-Co) at $T < 417$ °C, and fcc; (α-Co)]. The combination of Co and Ni leads in a reduction in corrosion and wear rates [7]. Because of their superior qualities when compared to pure Ni or Co, nickel and cobalt-based alloys have been investigated as potential technical coatings. High strength, improved wear and corrosion resistance, appropriate electro catalytic activity, and specific magnetic properties are all characteristics of these materials [8]. According to [9], an important feature of the Ni-Co alloy system is that these two elements can form solid solutions (cobalt-cobalt-nickel, nickel-cobalt-nickel) over a wide range of concentrations, allowing alloys with any chemical composition to be produced in principle [9].

2. Materials and Methods:

2.1. Materials

For the present work Ni, Cr, Al, and Co powders with purity higher than 99.9 % were used as raw materials. As received powders of composition were synthesized by melting route in vacuum arc furnace.

Table 1. Properties of Co, Cr, Fe, Ni and Ti powder used to form high entropy alloy

Elements	Atomic weight (u)	Atomic radius (Å)	Structure
Co	58.933	1.251	HCP
Cr	51.996	1.249	BCC
Al	27	1.840	FCC
Ni	58.693	1.246	FCC

2.2. Synthesis of Alloys

The starting material were in the form of powder of Ni, Cr, Al, and Co elements with the purity higher than 99 at.%. The elements were weighed to obtain samples with compositions Ni-5Cr-5Al-xCo (x=0, 5, 10, 20, and 30) as described in Table 2.

Table 2 Composition of alloys

SAMPLE	Ni (wt. %)	Cr (at. %)	Al (wt. %)	Co (wt. %)
Ni-5Cr-5Al	90	5	5	0
Ni-5Cr-5Al-5Co	85	5	5	5
Ni-5Cr-5Al-10Co	80	5	5	10
Ni-5Cr-5Al-20Co	70	5	5	20
Ni-5Cr-5Al-30Co	60	5	5	30

Pellets of 15 mm diameter and 10 mm height were generated by uniaxial compaction of blended powder in 15 mm tungsten carbide die set. Metals in the form of powder or microscopic lumps are melted together to produce alloys in the Arc Melting process. When a nonconsumable tungsten electrode creates an electric arc, the gas is heated and plasma forms, releasing a tremendous amount of heat energy and melting the sample placed in a crucible within the copper hearth. The high temperature is accomplished by converting the energy of fast-moving electrons striking the sample to heat energy, which increases the temperature within the furnace to about 2000 degrees Celsius, forcing the sample to melt and melt the sample.

3. Results and Discussion

3.1. Thermal Analysis

The sample was characterised using DSC to determine the melting point and phase change that occurred during the heating process of the sample. Despite the fact that the DSC was used to determine the melting point of the Ni-5Cr-5Al alloy, the sample did not melt even when heated to 1550 degrees Celsius (the instrument's maximum temperature), indicating that the melting point of the alloy powder would be greater than 1550 degrees Celsius. The melting point of Ni-5Cr-5Al, as a result, could not be determined using DSC analysis. In addition, two exothermic peaks can be seen in the DSC. The first wide exothermic peak relates to the rise of crystallite size caused by lattice diffusion, while the second small exothermic peak corresponds to the nucleation and formation of a new phase

3.2 Density

The density of Ni-5Cr-5Al-xCo (x=0, 5, 10, 20, and 30) alloys was determined using Archimedes' principle, which is shown in Figure 1. The actual density of all the alloys is slightly less than that of the theoretical density due to some porosity which reduces the density. The density did not show any significant effect by changing the Co content because of almost same density of Ni and Co.

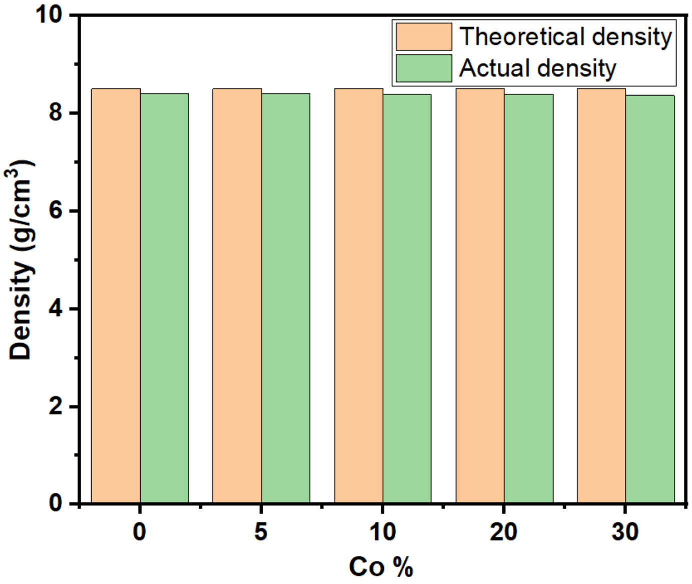

Figure 1 Density of Ni-5Cr-5Al-xCo (x=0, 5, 10, 20, and 30) alloys

3.3 Hardness

In this study, the Vickers hardness tester was used to determine the hardness of Ni-5Cr-5Al-xCo (x=0, 5, 10, 20, and 30) alloys (Figure 2). The hardness of the material rose as the quantity of Co was increased, owing to the fact that the addition of Co resulted in a reduction in the grain size. Because of the smaller particle size, there is more grain boundary area, which results in greater grain boundary density. Increased hardness is accomplished by increasing the Co content and decreasing the dislocation movement as a result of this restriction on dislocation movement.

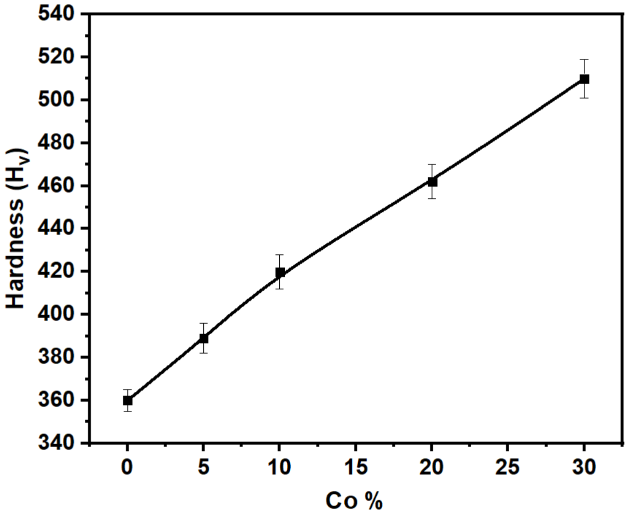

Figure 2 Hardness of Ni-5Cr-5Al-xCo (x=0, 5, 10, 20, and 30) alloys

3.4 Phase analysis and crystallite size

The XRD pattern of Ni-5Cr-5Al-xCo (x=0, 5, 10, 20, and 30) alloys is shown in Figure 3. The XRD of all the samples' peaks revealed a single FCC phase. With the addition and growth of Co content, the noticeable peak widened. The conspicuous peaks of the XRD peaks expand significantly after 30 percent Co addition. This widening denotes a decrease in grain size, which will be examined in the following section. By increasing the Co content, the XRD patterns reveal that the peak shifts to the left (toward the lower diffraction angle), indicating that the lattice expands during milling.

In all of the samples, the alloying elements Co, Cr, and Al formed a solid solution with the base material Ni, forming a single FCC phase with peaks (111), (200), (220), (311), and (312). (222).

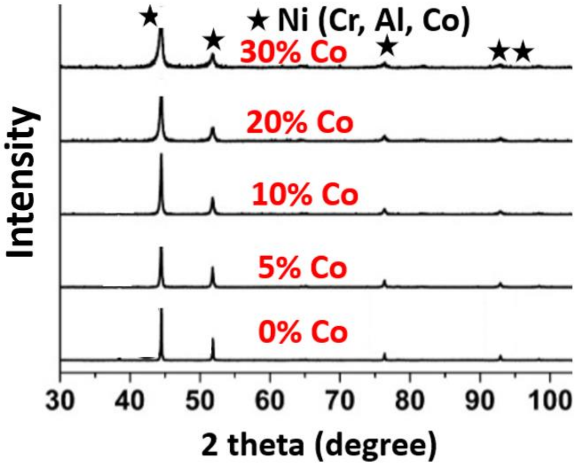

Figure 3. XRD patterns of Ni-5Cr-5Al-xCo (x=0, 5, 10, 20, and 30) alloys

3.5. Optical micrographs

Figure 4 depicts the optical microstructures of Ni-5Cr-5Al-xCo (x=0, 5, 10, 20, and 30) alloys. In all of the alloys, the precipitates may be found near the grain boundaries. These precipitates are undetectable in XRD because their concentration is minimal or their crystal structure is identical to that of the basic materials. Image was used to calculate the average grain size. Ni-10Cr-10Al-5Co had an average grain size of 34 m. The grain size was lowered to 25 m when Co was increased to 10%. With the addition of Co to 20 and 30 percent, the grain size was further decreased to 18 and 11 m, respectively. The decrease in grain size is in line with the XRD data, which show a broadening of the peak with the addition and rise of Co content, as discussed in the preceding section.

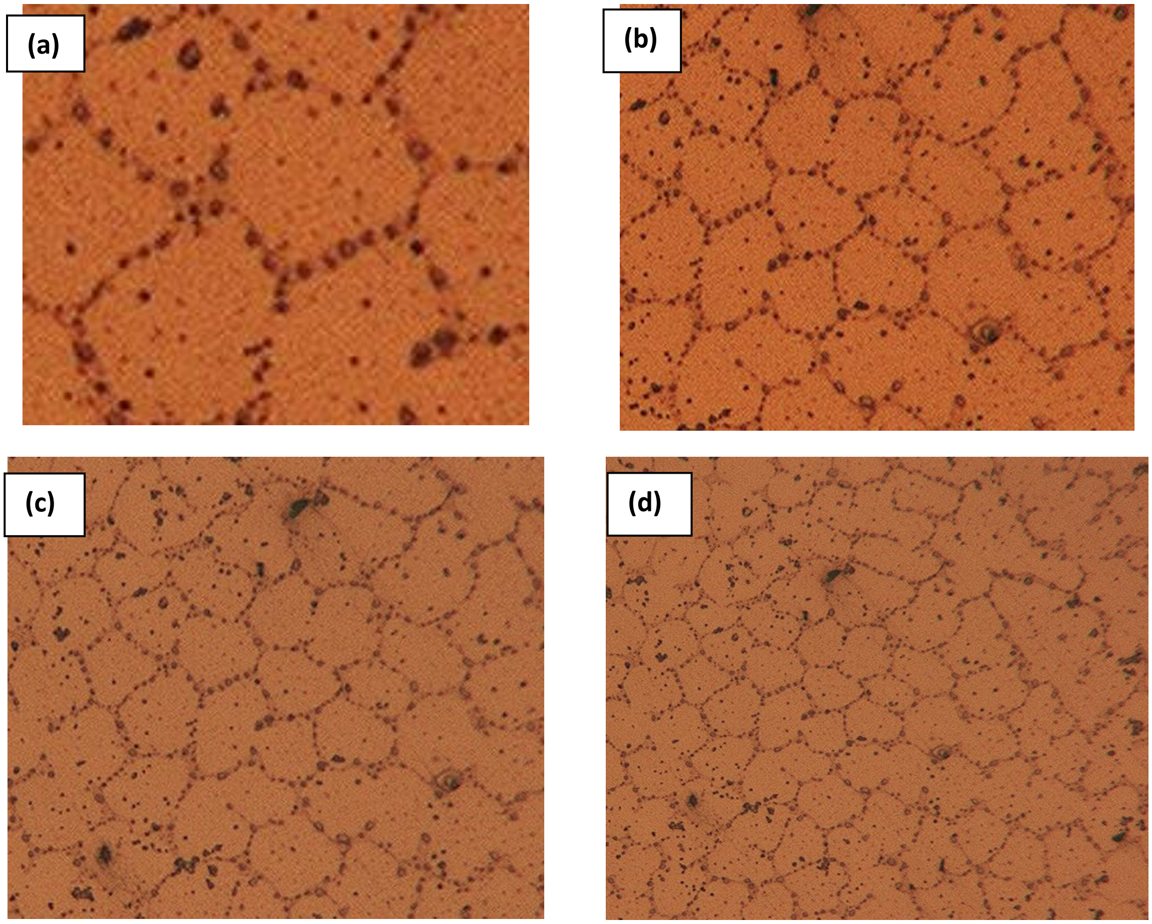

Figure 4 Optical micrograph of microcrystalline a) Ni-5Cr-5Al-5Co, b) Ni-5Cr-5Al-10Co, c) Ni-5Cr-5Al-20Co, and d) Ni-5Cr-5Al-30Co alloys

4. Conclusion:

The present research work was undertaken with the aim of developing the bulk Ni-5Cr-5Al-xCo (x=0, 5, 10, 20, 30) alloys by vacuum- arc melting furnace and study the effect of Co on the electrochemical corrosion behavior of Ni-based alloys. Ni-5Cr-5Al-xCo (x=0, 5, 10, 20, 30) alloys were successfully synthesized using a vacuum arc melting furnace. The grain size of Ni-5Cr-5Al-xCo (x=0, 5, 10, 20, 30) alloys were determined from micrographs using ImageJ software. The grain size continuously decreased with the increase of Co content. Co, Cr, Al formed solid solution with Ni which was confirmed by XRD results. The melting point of Ni-5Cr-5Al-xCo (x=5, 10, 20, 30) alloys could not be determined by DSC and might be above 1550 °C. The density was determined using Archemedes principle and the actual density was found slightly lesser than the actual density due to presence of some porosity.The hardness of Co-containing alloys was more than Co-free alloys and continuously increased with the increase of Co content.

Conflict of Interest : Authors declare no conflict of Interest.

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