



## Al-Cu-Fe quasi-crystalline thin film on 316 steel

### Abstract

Although 316 alloy has excellent properties, it is highly susceptible to corrosion and has low thermal stability and tribological characteristics, limiting its application. In this research, the magnetron sputtering method was employed to deposit the QC coating on the 316 S.S substrate. The scanning electron microscope (SEM) analysis and X-ray diffraction (XRD) methods were used to investigate the microstructure and morphology of mixed powders and Al-Cu-Fe QC coatings. Al-Cu-Fe thin layer deposited on the 316 steel surface without any cracks. The XRD patterns related to the annealed coating after heat treatment indicated the presence of  $\text{AlFe}_3$ ,  $\text{Al}_5\text{Fe}_5$ , and  $\text{Al}_{65}\text{Cu}_{20}\text{Fe}_{15}$  phases.

**Keywords:**  $\text{Al}_{65}\text{Cu}_{20}\text{Fe}_{15}$  phase; Quasicrystals; Thin film; 316 S.S alloy.

## Introduction

Quasicrystalline materials are appropriate for many practical applications due to their unique characteristics, including significant hardness, and notable resistance to corrosion. Previous studies have shown that the development of mixed quasi-crystalline (QC) coatings can enhance the titanium alloy's wear resistance (grade five). The performance of wear resistance for the Al-Cu-5Fe coating was 2.8 times that of the substrate. Although QCs have limited applications as structural materials due to their brittle nature, their distinctive characteristics raise the possibility of applications as functional materials in several fields such as a catalytic agent to produce hydrogen [1-4]. Plasma spray and High-Velocity Oxygen Fuel (HVOF) are widely used to make quasicrystalline coatings, but these methods are associated with problems such as porosity, unmelted particles, cracks, and oxides [5,6]. Magnetron sputtering is a widely used method for deposition wear and corrosion-resistant coatings. The quasi-crystalline phase formation depends on the substrate temperature [7,8]. The deposition of QCs on the substrates at room temperature leads to the evolution of the semicrystalline phase after subsequent heat treatment. However, the adjustment of stoichiometry in QCs is the main challenge [9-12].

Al-Cu-Fe-based quasicrystalline thin films show exceptional surface and mechanical properties. The direct growth of quasicrystals was reported in multilayer Al-Cu-Fe thin films after subsequent heat treatment [13]. Successful application of quasicrystalline and film coating obtained through three-electrode ion-plasma sputtering of assembled targets was reported [14]. The formation of the quasicrystalline phase was achieved by the Al-Cu system at temperatures relatively higher than 500 ( $T > 500^{\circ}\text{C}$ ) [15]. There was an increase in the amount and grain size of the i-phase throughout the process of annealing [16]. Phases that have a polyhedral atomic substructure in QCs, have greater nucleation rates within the system [17]. The creation of cracks within the targets throughout film deposition can lead to statistical deviations in the coating composition when the AlCuFeB coating is applied in this way [7]. The Al-Cu-Fe QCs reveal high corrosion resistance and good hydrogen storage for use in catalytic reactions. These alloys, at low temperatures, have similar thermal properties to zirconia oxides, which are considered excellent insulators [18].

In this study, the magnetron sputtering method was employed to deposit the QC coating on 316 S.S substrate. The microstructural aspects and electrochemical behavior of the substrate and the coated sample were studied and compared.

## 2. Experimental

Aluminum, iron, and copper powders with a purity of 99.9% were weighed using a scale with a precision of 0.0001 g in appropriate proportions. The powder mixture was milled using a planetary ball mill. A rotation speed of 150 rpm for 1.5 h was considered. After drying, the powders were compressed into discs having a 70 mm diameter and a 4 mm thickness in a

uniaxial hydraulic press. Before the coating deposition, the surfaces of the samples were sanded, degreased, and washed. Deposition of Al-Cu-Fe thin films on 316 S.S substrates was carried out within a magnetic sputtering chamber, which had a  $10^{-4}$  mbar base pressure. The deposition was accomplished at a pressure of  $2.5 \times 10^{-3}$  mbar under argon gas (purity 99.998%) and at room temperature. A sputtering deposition technique using an AlCuFe ternary target with a composition of  $\text{Al}_{62.5}\text{Cu}_{25}\text{Fe}_{12.5}$  was used to deposit the film. After the sputtering process, the samples were annealed with a continuous flow of argon at  $700^\circ\text{C}$  for 2 h [9,10].

### 3. Results and Discussion

Figure 1 shows the cross-section and the elemental distribution map taken from the cross-section of AlCuFe coating. The current thickness of the AlCuFe thin film was about 4000 nm. No cracks or breaks were observed in the target during 90 min of sputtering due to the appropriate preparation of the target by mixing method, eventually leading to the formation of an AlCuFe thin film. The cross-section image in Figure 1 is displayed in the backscattered electrons (BSE) mode, accordingly indicating the area related to the thin film is brighter than the substrate.

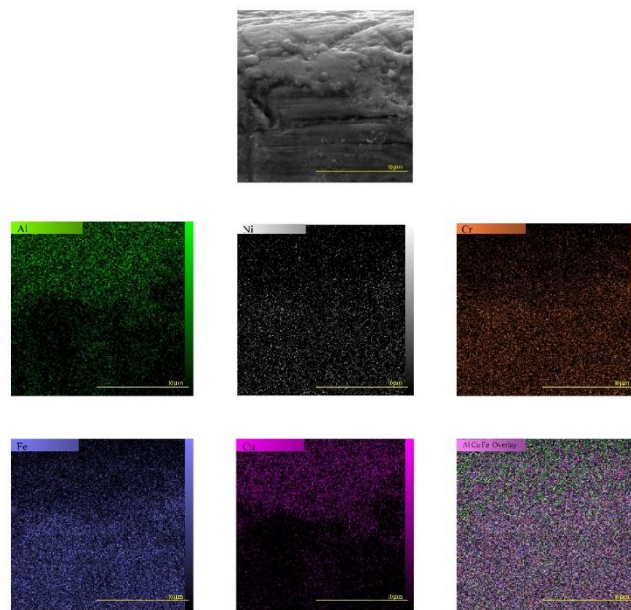


Figure 1: Cross-section and the elemental distribution map taken from the cross-section of AlCuFe coating.

Similar studies have reported a thickness of 85-260 nm for Al-Cu-Fe and Al-Co-Cu thin films accumulated on sodium chloride [19]. Also, Al-Cu-Fe and Al-Cu-Fe-Sc quasi-crystalline films with 200 to 260 nm thicknesses have been obtained by ion-plasma sputtering of three electrodes [20]. The distribution of titanium and vanadium elements and Al, Cu, and Fe emphasized forming AlCuFe coating on the 316 alloy as the substrate. Similarly, the very high catalytic performance of this alloy for methanol steam reforming was proven using the distribution map of aluminum, copper, iron, and oxygen elements of AlCuFe quasi-crystalline coating [21].

Figure 2 shows the morphology of thin film before and after heat treatment at 700°C for 2 h. The surface of the coating is completely continuous and without any visible cracks in two modes, as sputtered and after annealing. The five-facet morphology, which represents the presence of quasicrystal, has been visible in the annealed thin film morphology.

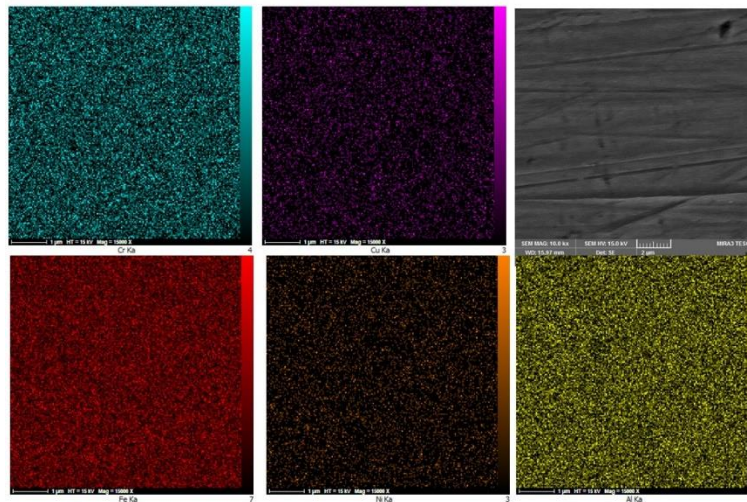


Figure 2. Morphology of AlCuFe coating applied on 316 S.S substrate before and after heat treatment at 700°C for 2 h.

Figure 3 reports the XRD results of as-sputtered AlCuFe coating applied on 316 S.S after annealing. The XRD patterns related to the annealed coating after heat treatment indicated the presence of  $\text{Al}_{65}\text{Cu}_{20}\text{Fe}_{15}$  and  $\text{AlFe}_3$ ,  $\text{Al}_5\text{Fe}_5$ , and  $\text{Al}_{65}\text{Cu}_{20}\text{Fe}_{15}$  phases. The quasi-crystalline phase of  $\text{Al}_{65}\text{Cu}_{20}\text{Fe}_{15}$  after annealing has been reported in similar studies [1].

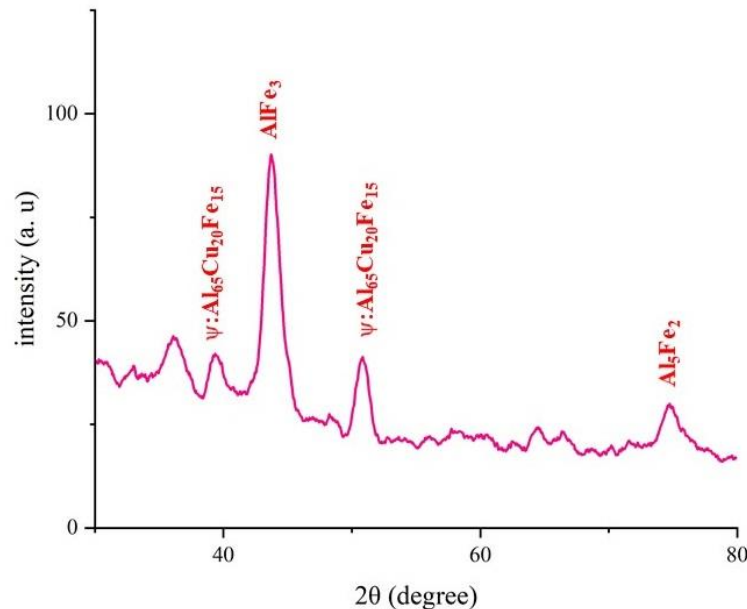


Figure 3. XRD results in AlCuFe coating applied on 316 S.S substrate after annealing

## 4. Conclusions

Al-Cu-Fe thin layer deposited on the 316 S.S alloy surface without any cracks. The XRD patterns related to the annealed coating after heat treatment indicated the presence of  $\text{AlFe}_3$ ,  $\text{Al}_5\text{Fe}_2$ , and  $\text{Al}_{65}\text{Cu}_{20}\text{Fe}_{15}$  phases.

## 5. References

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