

## Al<sub>62</sub>Cu<sub>25</sub>Fe<sub>12</sub> and Quasicrystalline Phases and Their Influence on Oxidation

Lourdes Cristina Lucena Agostinho Jamshidi<sup>a\*</sup>, Reza Jamshidi Rodbari<sup>b</sup>, Luciano Nascimento<sup>a</sup>, Eduardo Padrón Hernández<sup>b</sup>

<sup>a</sup>Department of Chemical Engineering, Center of Technology and Geosciences, Federal University of Pernambuco, Av. Prof. Moraes Rego, 1235 - Cidade Universitária, Recife - PE - CEP: 50670-, Brazil.

<sup>b</sup>Department of Materials Science, Center of Exact Sciences and Nature, Federal University of Pernambuco, Av. Jornalista Aníbal Fernandes, 1235 - Cidade Universitária, CEP 50.740-560, Recife – PE, Brazil.

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**Abstract:** In this article, we will cover a study of the formation of icosahedral and decagonal phases two quasicrystals Al<sub>62</sub>Cu<sub>25</sub>Fe<sub>12</sub> and Al<sub>65</sub>Ni<sub>15</sub>Co<sub>20</sub> oxidation of influence in this alloy. For this purpose, research used the diffraction of X-ray, scanning electron microscopy/energy dispersive spectroscopy, differential scanning calorimetry and thermogravimetric analysis. The results displayed found aspects of morphological structural as well as the surface of the two compositions of quasicrystals, these were prepared and obtained in electric arc furnaces and induction and arc. Oxidation of Al<sub>62</sub>Cu<sub>25</sub>Fe<sub>12</sub> alloy, intermetallic phases presented with combinations of alloying elements and above 675 °C it was observed that the crystalline phase is stable. In icosahedral phase oxidation of aluminum forms a dense layer on the passivating outer most surface of the quasicrystal which causes depletion in both copper and iron. In Al<sub>65</sub>Ni<sub>15</sub>Co<sub>20</sub> nominal composition of oxygen interaction occurs on the surface of symmetry 10 times plane perpendicular vector. The formation of a thin film of aluminum oxide having well-ordered hexagonal structure and with the opposition area decagonal phase with the lateral size of approximately 35Å.

**Keywords:** aluminum oxide; phases icosahedral and decagonal; quasicrystals

### 1. INTRODUCTION

Since the discovery of an icosahedral quasicrystalline (IQC) phase in rapidly solidified Al–Mn alloys, however, arouse the curiosity of researchers in search of new knowledge on the subject, but discovery made since 1984, says the quasicrystals is solid with crystallographic prohibited long rotation symmetries reach and aperiodic in the atomic arrangement, with unusual physical properties [1]. The quasicrystalline materials have attracted considerable attention because of their excellent physical properties, chemical, mechanical and tribological properties, such as high hardness, enhanced elastic modulus, excellent surface properties, good resistance to oxidation and corrosion and low electrical and thermal conductivities [2].

The compositions of the quasicrystalline alloys are usually ternary or binary; some compositions have been research and success for certain uses. Among the

other compositions of quasicrystals, of course the most investigated to know; AlCuFe, AlMnPd, AlNiCo, AlPdMg, AlCuCo, AlCoFeCr. Due to their high stability, thermodynamic, non-toxicity and low production cost, quasicrystalline materials Al–Cu–Fe have great potential for practical applications in areas such as thermal barrier coatings resistant coatings for low friction wear, composite biomaterials, magnetic materials and catalysts with high selectivity and conversion, and as reinforcement layers / fillers for composite materials [3]. Quasicrystals are thermodynamically stable under conditions of high temperatures above 800°C under an inert gas atmosphere. But the system with AlCuFe elements shows the icosahedral phase, one of the most researched compositions by scholars on this subject. However, for the formation of quasicrystals there are other important phases in quasicrystalline alloy process. Typically, intermetallic, amorphous and crystalline phases are systems based on combinations

\*Corresponding author. E-mail: [crisrina.ufcg@gmail.com](mailto:crisrina.ufcg@gmail.com)

with other elements and Al, Co, Ni, Cr, Fe, Mg, Zr, Ti, Zn e Cu, are formed due to phase transitions existing between one phase and another on a solid state reaction. The quasicrystalline alloys exhibit rotational and structural symmetries with five, eight, ten and twelve have formations icosahedral, decagonal and dodecahedron in general deference of a unit cell structure [4].

The solid crystalline which are usually studied in research centers is;  $\text{Al}_{65}\text{Cu}_{22}\text{Fe}_{12}$ , and interestingly the quasicrystalline phase is the result of a peritectic reaction phase  $\beta\text{-AlFe}_3$  and the remaining liquid. But is  $\text{AlCuFe}$  formation is rich in aluminum and of course the coexistence of icosahedral quasicrystalline  $\psi$ -phase with other phases belonging. The mechanical conventional methods of obtaining quasicrystals are influenced by synthesis. Therefore, allows the preparation of widely varying composition and existence of phases, making it easy to technology. The quasicrystals have two structural namely; icosahedral ( $\text{AlCuFe}$ ) and decagonal ( $\text{AlNiCo}$ ,  $\text{AlCuCo}$ ) in this training phase related particulate grain and the preparation process. As well, the difference in concentrations of the two quasicrystalline materials to be balanced by interdiffusion in a transitional region, thereby forming to-one quaternary alloy  $\text{AlCo}$  (Cu, Ni) of the crystal in a narrow region. The alloy composition  $\text{AlCuFe}$  is icosahedral, which arose from other previous phase, these studies showed that the formation and stability of  $i\text{-AlCuFe}$  depended sensitively on composition and temperature. In addition, several subsolidus phases that can coexist with the  $i\text{-QC}$  were described in the  $\text{Al-Cu-Fe}$  system [5]. In this mechanism, the cubic phase  $\beta\text{-Al}$  (Fe, Cu), predominates is the main driving force in the formation of the icosahedral phase. Consequently, this solid solution ( $\beta$ -phase) regulates the composition of the alloys in the transformation to icosahedral  $i$ -phase [6].

The two compositions decagonal quasicrystalline alloys ( $\text{AlCuCo}$  and  $\text{AlNiCo}$ ) have its formation of a solid solution that derives from a common phase between both systems in that copper the compensation for the nickel. But, the decagonal phase is directly peritectic reaction with the liquid phase and the amount of aluminum present. Most of these quasicrystalline alloys are metastable which become irreversibly at regular crystals after heat treatment or amorphous shape with small crystals of irregular shape. It has shown that almost crystalline phase formed in  $\text{Al}_{62}\text{Cu}_{25}\text{Fe}_{12}$  conventionally solidified alloy is thermodynamically stable and do

not suffer abrupt transformation phases (There may be small regions and amorphous intermetallic traces) until the melting point to 1135K. However, the literature has shown that the quasicrystals icosahedron and decagonal phase is stable at high temperatures and transform the crystals and quasicrystalline phases low temperature [7].

Several phases in the  $\text{AlCuCo}$  system are isostructural to those in  $\text{AlCuFe}$ , when replacing Fe for Co, in this investigation, the structural relationship between the decagonal phase and the crystalline phases in the  $\text{AlCuCo}$  system is explored, there is one special class of crystals that are vacancy ordered phases which can be described as superstructures of cubic  $\text{CsCl}$ -phases [8]. There are also several  $\text{AlCo}$  phases that are stable while the corresponding  $\text{AlFe}$  phases are metastable. Another difference is that the quasicrystal in this system is decagonal instead of icosahedral. Periodicities of 4, 8, 12 and 16 Å was all discovered, but only the 4 Å periodicity have been confirmed as stable. Several articles have investigated the stability range of this phase with varying compositional ranges as a result, but all of them are centered on a composition of  $\text{Al}_{65}\text{Cu}_{17.5}\text{Co}_{17.5}$  [9]. This was the first stable decagonal phase found, and just like the  $i\text{-Al}_{62}\text{Cu}_{25}\text{Fe}_{12}$  phase for icosahedral phases, the  $d\text{-AlCuCo}$  could be grown to large single grains, allowing the possibility to investigate the quasicrystalline-related properties [10]. The objective of the present work is to investigate the formation and stability of  $i\text{-QC}$  phases the formation of icosahedral and decagonal phases, as well as oxidative behavior of each quasicrystals system  $\text{AlCuFe}$  and  $\text{AlCoNi}$ . For this purpose, we used the following techniques; X-ray diffraction, scanning electron microscopy and energy dispersive spectroscopy, calorimeter differential scanning and Thermogravimetric analysis.

## Theory

### Oxidation of the Phase Icosahedral and Decagonal

Oxygen generally exhibits different affinities with the intermetallic compound elements, leading to selective oxidation. Preferred oxidation of aluminum should lead to a change of concentration in the surface near area and should induce a phase transformation of the  $i$ -phase into the  $\beta$ -phase. In general, oxidation may proceed by two reactions: Absorbed oxygen diffuses into the quasicrystal and induces a phase transformation into an oxygen stabilized phase. Oxygen reacts at the surface forming metal oxides;

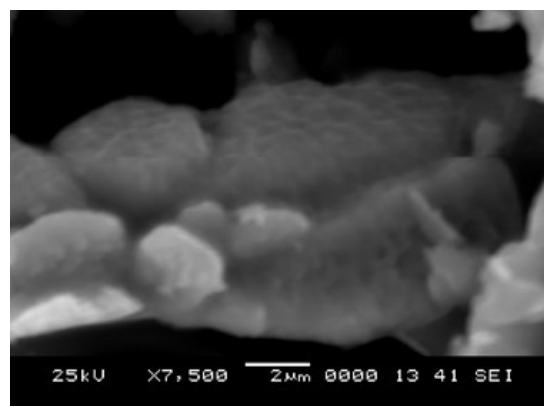
the interface zone underneath the oxide layer depletes in the preferentially oxidized element [11]. Thus, the concentration is shifted out of the stability range of the quasicrystalline phase and a phase transformation can occur for icosahedral phase and decagonal. After 30 min of oxidation the *i*-phase shows deep ditches etched at the grain boundaries and a buckled grain surface.

However, oxygen reacts at the surface of quasicrystalline alloy metal oxides formed and the interface region beneath the oxide layer is preferably oxidized in the exhaust element. Research has shown that the composition AlCuFe oxidation starts with the growth of sequentially  $\gamma$ -Al<sub>2</sub>O<sub>3</sub> are formed  $\theta$ -Al<sub>2</sub>O<sub>3</sub> thereby have a strong nuclei of alumina  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> at the interface oxide/metal random manner through the copper layer growth; then processing occurs  $\theta$ -Al<sub>2</sub>O<sub>3</sub> for  $\alpha$ -Al<sub>2</sub>O<sub>3</sub>, these steps occur at elevated temperatures [12].

In the oxygen quasicrystalline alloy reacts in quasicrystal surface forming metal oxides. The interface region beneath the oxide layer is preferably oxidized in the exhaust element. Thus, the concentration is shifted out of the range of stability may occur phase quasicrystalline and a phase change [13]. In the system of quasicrystalline alloys AlNiCo has occurred in the formation of thin layers of oxides, by preference oxygen is bonded to aluminum, nickel continue while the metallic state. However, the atomic structure of the oxide layer of the binary NiAl alloy (110) is complex has certain similarities with the hexagonal phases of aluminum oxide. The composition of the aluminum oxide layer on the icosahedral phase AlCuFe noted by researchers that revealed a tendency of aluminum enrichment on the outer surface of the quasicrystals. But the behavior of intermetallic components quasicrystals in the presence of oxygen shows that the aluminum atoms move the mass to the surface. It is assumed to be due to driving force provided by the exothermicity oxide, with the other constituents of higher alloy as shown in Figure 1 [14].

Thus, the electron diffraction spots corresponding to aluminum to form film that is deposited on the surface Al<sub>65</sub>Ni<sub>15</sub>Co<sub>20</sub> decagonal, resulting in size growth of the field oxide layer between the interface quasicrystal/crystal. Early studies on the oxidation behavior of the pentagonal surface of the icosahedral (*i*-AlPdMn and *i*-AlCuFe) quasicrystal have shown that, similar to the oxidation behavior of elemental Al, the Al atoms predominantly

oxidize in a two-step process [15]. It has not been clear whether Mn or Pd is affected by the oxidation process. In principle, the thermodynamic data based upon the values of heats of formation (Al<sub>2</sub>O<sub>3</sub>- 1680 kJ/mol; Mn<sub>3</sub>O<sub>4</sub>-1390 kJ/mol; Pd- 85 kJ/mol) do at least allow it in the case of Mn [16]. However, Pd was suggested to be involved in the oxide formation as well. Despite of possible effects of Mn and Pd, the Al-rich quasicrystals show a similar oxidation behavior compared to Al single crystals and ordered Al alloys [17].



**Figure 1.** Dense layer of alumina formed the surface of the Al<sub>62</sub>Cu<sub>25</sub>Fe<sub>12</sub> alloy quasicrystalline.

Here we report the oxidation of the 10-fold-symmetry surface of a decagonal Al<sub>72.9</sub>Co<sub>16.7</sub>Ni<sub>10.4</sub> ( $\varphi$ -Al-Co-Ni) quasicrystal. Initial observation of the oxidation behavior of the decagonal surface of Al<sub>70</sub>Co<sub>15</sub>Ni<sub>15</sub> has revealed the dissociative adsorption of oxygen leading to a very thin layer of chemisorbed oxygen [18]. In the present study, the low-energy electron diffraction (LEED) and Auger electron spectroscopy (AES) results can be interpreted as formation of an aluminum-oxide layer with a thickness of about 5 Å consisting of five different domains in hexagonal structure which are placed in equal azimuthal orientation on the surface.

The aluminum oxidation was still observed even after prolonged exposure to more Langmuir existence of a 7200 Langmuir (L).

This oxidation of quasicrystalline *i*-AlCuFe which is thermodynamically stable between 750 and 850°C. Usually oxygen exhibits different affinities to the elements of an intermetallic compound leading to selective oxidation. Preferred oxidation of aluminum should lead to a change of concentration in the surface near area and should induce a phase transformation of the *i*-phase into the  $\beta$ -phase. In general oxidation may

proceed by two reactions: Absorbed oxygen diffuses into the quasicrystal and induces a phase transformation into an oxygen stabilized phase and oxygen reacts at the surface forming metal oxides; the interface zone underneath the oxide layer depletes in the preferentially oxidized element [19]. Thus the concentration is shifted out of the stability range of the quasicrystalline phase and a phase transformation can occur.

Some fundamental questions were raised about the mechanisms of the oxidation reaction on a quasicrystalline surface. In particular, one of the questions was whether there was an initial measurable chemisorption stage, as observed on classical crystalline aluminium-based alloys or on pure aluminium surfaces, or if the oxidation reaction occurred as soon as the surface was exposed to oxygen. Insofar as a chemisorption stage could be highlighted, another question was to know whether it depended on the surface temperature. In addition, at the end of the chemisorption stage, only aluminium is involved in the oxidation. This is in agreement with the thermodynamic data: the free enthalpy of formation of  $\text{Al}_2\text{O}_3$  (alumina), is equal to  $-1.080$  kJ/mol  $\text{O}_2$ , a value twice as high as that of the various iron oxides:  $\text{FeO}$  ( $-520$  kJ/mol  $\text{O}_2$ ),  $\text{Fe}_2\text{O}_3$  ( $-546$  kJ/mol  $\text{O}_2$ ) or  $\text{Fe}_3\text{O}_4$  ( $-558$  kJ/mol  $\text{O}_2$ ), and three times as high as that of  $\text{Cu}_2\text{O}$  ( $-335$  kJ/mol  $\text{O}_2$ ) [20]. The oxide coating formed, composed of  $\text{Al}_2\text{O}_3$  (alumina), is a passivation layer whose thickness is lower than two nanometers at room temperature, whatever the exposure to oxygen. The dense layer with passivating and inhibiting the oxidation of copper property, since it influences the adhesion properties/adsorption.

## 2. MATERIAL AND METHODS

**Synthesis:** The metallic powder aluminum, iron, copper, cobalt and nickel as its particle size, having 99.99% purity, from Sigma-Aldrich, were weighed in the appropriate proportions composition  $\text{Al}_{62}\text{Cu}_{25}\text{Fe}_{12}$  e  $\text{Al}_{65}\text{Ni}_{15}\text{Co}_{20}$ . They were mechanically homogenized and compacted in the form of disc with a diameter of 10 mm and 2 mm thick in a hydraulic uniaxial press. Initially, it made a pre-pressing under full load of 5 ton for 3 minutes. The precursor alloys were obtained by direct fusion of compressed constituents. The fusion was carried out in arc furnace under controlled atmosphere of argon. The arc furnace is fed by a static rectified BALMER generator whose power is 22 kVA. For the identification of the phases, it used a Shimadzu XRD 6000 diffractometer using

$\text{CuK}_\alpha$  radiation with a wavelength of  $1.5406\text{\AA}$ .

**Measurements:** The measurements were taken for a wide range of diffraction angles ( $2\theta$ ) range from  $20^\circ$  to  $120^\circ$  angular pitch  $0.05^\circ$  and a timing point at 2.4 s. The analysis by scanning electron microscopy/energy dispersive spectroscopy was performed with a Shimadzu SUPERSCAN SSX-550 with an acceleration voltage of 0.5 to 30kV with a 10V step, after the sample has been coated with a gold layer deposited under vacuum in order to improve contrast. The thermogravimetric analysis (TGA) and differential scanning calorimeter (DSC) were made on Perkin Elmer TG 6000 STATE equipment. Samples of quasicrystalline alloys were properly weighed and subjected to heating from ambient temperature approximately  $27^\circ\text{C}$  to  $750^\circ\text{C}$  the runs were carried out at heating rate of  $10^\circ\text{C min}^{-1}$  in a nitrogen atmosphere at a flow rate of  $50\text{ ml min}^{-1}$ .

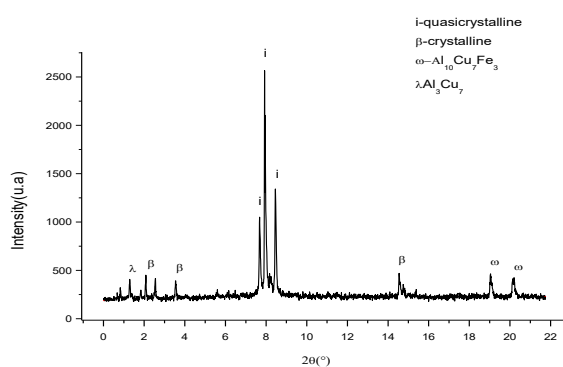
## 3. RESULTS AND DISCUSSION

### X-ray diffraction

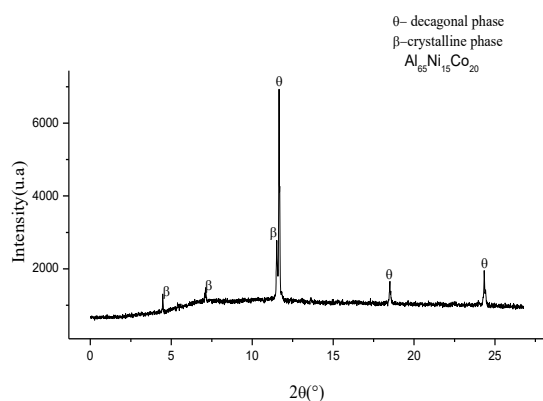
Both Figures 2 and 3 show the XRD patterns of the compositions of quasicrystals ( $\text{Al}_{62}\text{Cu}_{25}\text{Fe}_{12}$  and  $\text{Al}_{65}\text{Ni}_{15}\text{Co}_{20}$ ), as is shown below respectively. The diffractogram 1, presented in Figure 2 shows different layer phases present, is main peak in icosahedral phase and others to monoclinic phase  $\lambda\text{-Al}_{13}\text{Fe}_4$ , the other peaks is related to the cubic structure of the type of CsCl ( $\beta\text{-AlFe}(\text{Cu})$  or  $\tau\text{-AlCu}(\text{Fe})$ , and  $\theta\text{-Al}_2\text{Cu}$  tetragonal phases were detected. However, the crystalline phases are in equilibrium with each other; but between the crystalline phase's  $\omega$  and  $\beta$  icosahedral phase has a great similarity. The coordination of Fe atoms is very similar in both structures, the more this phase appears in three fields. Interestingly, the quasicrystalline i-phase always coexists with  $\beta$ -crystalline [21]. The equilibrium solidification for this transformation is the primary forming  $\lambda\text{-Al}_{13}\text{Fe}_4$  phase in the liquid phase giving rise to more of  $\beta$  phase by a peritectic reaction and finally the i-phase is formed by one second peritectic reaction of the type  $L + \beta + \lambda \rightarrow i\text{-phase}$  [22].

The diffraction X-ray from the sample  $\text{AlNiCo}$  show three decagonal phases. In this structure is a nearly periodic symmetry plane along the direction perpendicular to these planes. Subsequently  $\text{AlCo}$ ,  $\text{AlNi}$  and  $\text{NiAlCo}$ ; and the periodicities of approximately 0.4, 0.8, 1.2 and 1.6 nm in a specific direction, are meaning that there was a rapid solidification in this composition. Quasicrystals can

be quasiperiodic in one, two, or three dimensions. One-dimensional quasicrystals are quasiperiodic in one dimension (with various point group symmetries). Two-dimensional quasicrystals e.g., octagonal quasicrystals (point group symmetry  $8/mmm$ ) (e.g., CrNiSi and MnFeSi), decagonal quasicrystals ( $10/mmm$ ) (e.g., AlN-Co and AlCuCo) and dodecagonal quasicrystals ( $12/mmm$ ) (e.g., CrNi and VNi)—are quasiperiodic in two dimensions [23]. To identify  $\text{Al}_{65}\text{Ni}_{15}\text{Co}_{20}$  alloy formed plans for five reciprocal vectors corresponding to five adjacent planes  $2\pi/5$  with an angle of six vectors perpendicular to the other planes.



**Figure 2.** XRD pattern of quasicrystalline alloy  $\text{Al}_{62}\text{Cu}_{25}\text{Fe}_{12}$



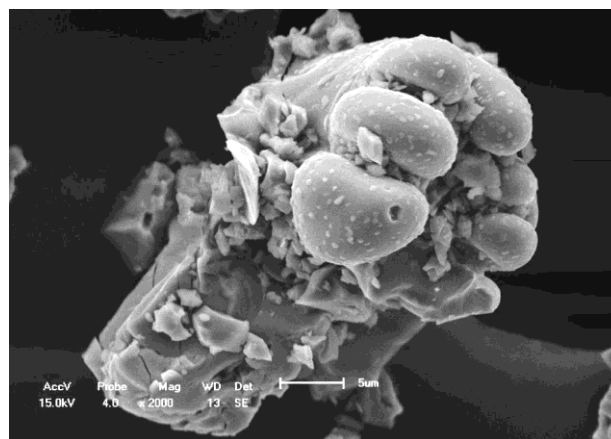
**Figure 3.** X-ray diffractogram (XRD) of the sample  $\text{Al}_{65}\text{Ni}_{15}\text{Co}_{20}$  melt  $900\text{ }^{\circ}\text{C}$ .

All diffraction peaks observed in the quasicrystal may be indexed in a single decagonal phase and no diffraction peaks corresponding to other phases. The value  $\Delta Q$  of the decagonal alloys are smaller than icosahedra's alloys, the difference is particularly remarkable in the main peak reflection,  $Q \approx 30\text{nm}^{-1}$  indicating that the characteristic magnitude

of the voltage to the phasons of quasicrystalline structure is considerably lower for decagonal phase even after rapid solidification [24].

### Scanning Electron Microscopy and EDS

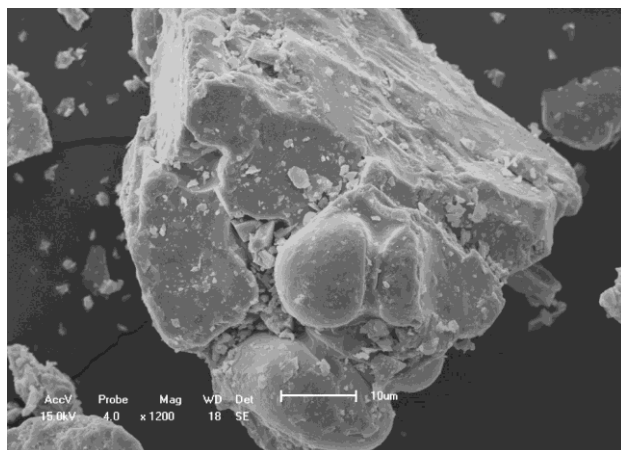
In this electron microscopy analysis scan has as objective to verify surface morphology of the two quasicrystalline alloys, we can observe them spectra showing energy dispersive spectroscopy later. EDS peaks correspond to the different elements present in the samples that were obtained by the arc furnace. This surface of Figure 4 of  $\text{Al}_{62}\text{Cu}_{25}\text{Fe}_{12}$  noted faceted, with disagreements format "cauliflower". It is seen that the nucleation of  $\beta$  phase can occur in which sites, platelet grow from this interface to the core of small crystals nodules form on the icosahedral phase. But, it is appropriate to say that the refinement in grain boundaries and /or grain surface with protrusions. In this initial phase oxidation observes a surface topography mode, to form a thin oxide layer with a thickness in micrometers ( $\mu\text{m}$ .) After a period of two hours lumps are observed irregularly distributed on the grain surface.



**Figure 4.** Morphology of showing nodules islands of quasicrystalline alloy  $\text{Al}_{62}\text{Cu}_{25}\text{Fe}_{12}$ .

We verified this second SEM image, corresponding to Figure 5 of the quasicrystal  $\text{Al}_{65}\text{Ni}_{15}\text{Co}_{20}$  oxidative behavior surface 10 times the symmetry of quasicrystalline alloy. For this  $\delta$ -AlNiCo composition is seen that the oxidation occurs in consequence, the dissociative adsorption of oxygen, which leads to a very thin layer of chemically oxygen. Similarly, the previous image AlCuFe alloy, the formation of nodules islands, which form a layer of aluminum oxide with a thickness of  $5\text{Å}$  consisting of

five different areas of hexagonal structure that are placed in the same azimuthal orientation on the surface [25].



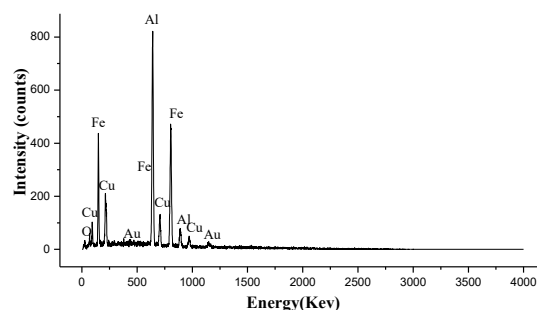
**Figure 5.** Structure of nodular decagonal phase of the quasicrystal  $\text{Al}_{65}\text{Ni}_{15}\text{Co}_{20}$ .

From spectroscopy analysis of excited electrons by X-ray (LEED) observed a tendency of aluminum enrichment in the outermost surface of quasicrystalline alloys. More is initially chemisorption of oxygen; secondly forming an oxide thin film [26]. The growth of this film exhibits reach saturation in about 50 L. This is clearly saturation kinetics nature since once few monolayers of oxide are formed,  $\text{O}_2$  chemisorption rate and ionic transport through the oxide film is extremely low in ambient temperature. Composition analysis with an EDS as shown in Figure 6 shows that the regions are composed mainly of Cu, Fe, O and a small amount of Al that can complex with Cu,  $\text{Al}_2\text{O}_3$ ,  $\text{AlFe}_3$ ,  $\text{Al}_3\text{Cu}$ ,  $\text{Cu}_2\text{O}$  and  $\text{Fe}_3\text{O}_4$  or  $\text{CuFeO}_2$  since the phases present in the transformation is due to the strong presence of Fe conduction electrons and Cu which are protected by the thin layer of aluminum oxide which enables the peritectic reaction between the phases of  $\gamma\text{-Al}_{13}\text{Fe}_4$  liquid and to form the highly dense phase  $\omega\text{-Al}_7\text{Cu}_2\text{Fe}_1$ . The nodules represent  $\beta$  phase droplets formed mainly by surface tension of liquid (saturated caused by solid state reaction) in a bubble or hollow retraction (cavity) solidified in its original liquid form.

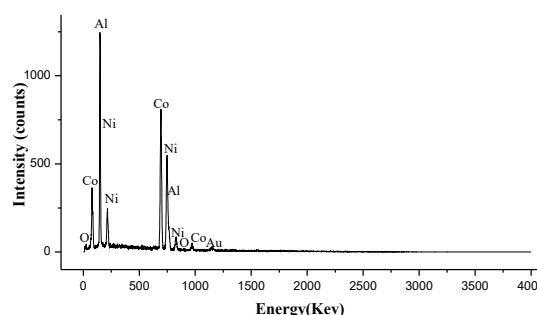
Therefore, EDS can be seen in the spectrum of Figure 6 and 7, a more intense peak showing the greatest concentration of aluminum, this is due to higher amount of cobalt in nickel ratio in the decagonal phase. It must be said, the ternary composition  $\text{AlNiCo}$  in decagonal phase occurs by substitution of Co and Ni, comes a vacancy formation

in quasicrystalline alloy structure; this produces a disorder of the type of solid solution. The diffuse scattering is often observed in the XRD patterns in the decagonal phase. However, it should be noted that the portion contains higher amount of aluminum is from a continuous band solidly solution- of isostructural  $\text{AlCo}$  and  $\text{AlNi}$ . This decagonal phase is formed along  $\text{Al}_{73}\text{Co}_{27}/\text{Al}_{69}\text{Ni}_{31}$ . Soon, you can check in the EDS spectrum is the second highest peak of the cobalt atom (Co). In decagonal phase quasicrystal presents stable structural variations; we noted the part with cobalt wealth is due to another structure similar to that of  $\text{AlCoPd}$  in  $\omega$ -phase. In other compositions, there are also other phases like decagonal orthorhombic [27].

They were obtained by hybridization at a temperature of  $800\text{-}900^\circ\text{C}$ , while at higher temperatures, depending on the composition, and decagonal phase that was formed.



**Figure 6.** Analysis of EDS quasicrystalline alloy  $\text{Al}_{62}\text{Cu}_{25}\text{Fe}_{12}$ .

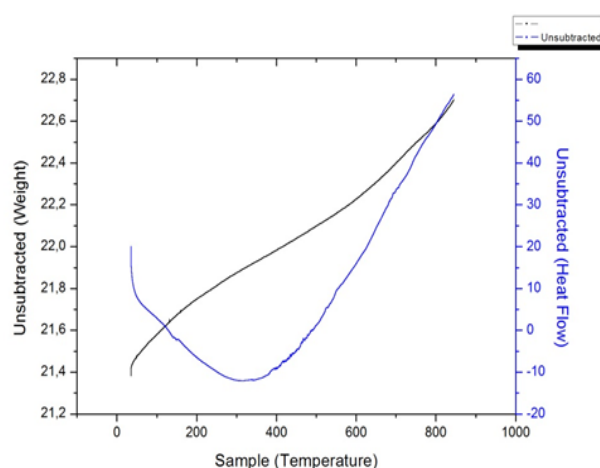


**Figure 7.** EDS representation of quasicrystalline alloy  $\text{Al}_{65}\text{Ni}_{15}\text{Co}_{20}$ .

### Thermal Analysis DSC and TG

Figure 8 shows the DSC curve behavior as can

be seen, it is well accentuated curvature at the temperature of 300°C to characterize an endothermic peak. Showing us that it is the aluminum melting point and pure copper in the formation of quasicrystalline alloy. This endothermic peak corresponds to melting of pure Al powder, Cu, following the dissolution of the liquid iron (Fe), after mechanical casting process. Therefore, at this phase in the quasicrystalline alloy AlCuFe is being processed by the arc furnace mergers, Al and Cu elements are coming into contact with one another in low-temperature is displayed on the graph.

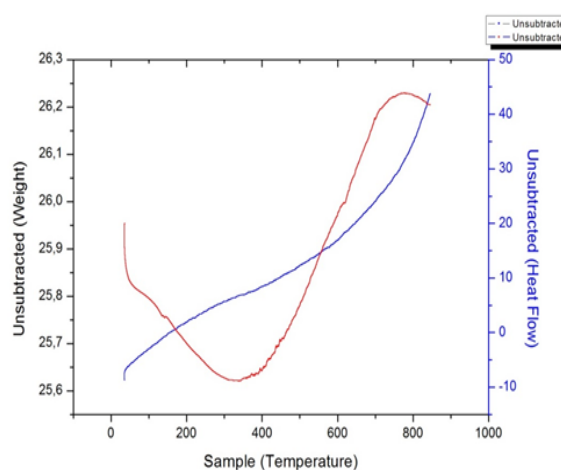


**Figure 8.** Representation of DSC and TG curves in the quasicrystal alloy  $\text{Al}_{62}\text{Cu}_{25}\text{Fe}_{12}$ .

So is revealing reaction is a eutectic melting, as is seen in the literature in binary phase diagram Al/Cu eutectic temperature. Underlining this stage of the mechanical process there is a predominance of aluminum the other copper and iron elements. However, we have an exothermic peak temperature of 800°C informing the occurrence of a series of solid crystalline phase transformation during heating for quasicrystalline phase. As is the homogenization of the alloy composition is gradually completed obtain the  $\omega\text{-Al}_7\text{Cu}_2\text{Fe}$  intermetallic to the main phase icosahedral.

As can be observed in the TG curve quasicrystalline alloy AlCuFe occurred small mass loss at temperatures as follows; the first mass loss was at 40°C for a percentage of 21.4 %; yet another loss occurred at 100°C for 21.6 %; the third significant loss occurred at 410°C 21.9%; with increasing temperature of 700°C obtain a mass reduction of 22.6%. However, at lower temperatures thermal decomposition decreases with decreasing particle size,

becoming a solid mass loss held between 45°C to 820°C. It can be said that the decomposition temperature provides an enrichment of the element composing the quasicrystal and also a depletion of the alloying element in different regions of the grain. Thus, the DSC curve for the training quasicrystal  $\text{Al}_{65}\text{Ni}_{15}\text{Co}_{20}$  revealed similar factors with AlCuFe, but we note that the endothermic peak occurred at a transition temperature from 320°C to 400°C. In the literature it is considered that the phase boundaries are displaced from the use of mechanical synthesis process. Moreover, it is likely will change the decagonal face occurs in structural relaxation. Naturally, cooling and heating peaks composition AlNiCo alloys is reversible martensitic transformation. Other possible  $\beta$ -crystalline phases is coexists with the solid solution phase is of  $\gamma$ -face-centered-cubic. However, the formation of crystalline domains AlNiCo thermal diffusion is the predominant effect, enabled only by Al atom being caused by plastic deformation in the decagonal phase [28]. In referring to the TG curve of Figure 9 of the quasicrystal  $\text{Al}_{65}\text{Ni}_{15}\text{Co}_{20}$  exhibited more significant mass loss of points in terms percentage/temperature AlCuFe. Initially, the first mass loss event has occurred at 35°C for 25.65% percentage. Then, the second weight loss occurred at a temperature of 395°C in 25.8%. The third and fourth points passed in certain temperatures 510°C with 25.9% and 700°C to 26.0%.The fifth point occurred at a temperature of 805°C to a mass loss of 26.2%. These weight losses shown in the TG curve has an influence on the oxidation of almost linear quasicrystal and the atmosphere of the environment.



**Figure 9.** Representation of DSC and TG curves energy flow and mass of the quasicrystal  $\text{Al}_{65}\text{Ni}_{15}\text{Co}_{20}$ .

#### 4. CONCLUSION

The main conclusions of the research are as follows:

- The quasicrystalline phase becomes stable above 675°C and the crystalline phase a solid solution which controls the formation of quasicrystalline phase;
- In this decagonal alloying Al<sub>65</sub>Ni<sub>15</sub>Co<sub>20</sub> is the saturated type with vector perpendicular plane and rich of cobalt atom;
- The effect of the high temperature causes variations in boundary defects of the quasicrystal AlNiCo grains, these displacements are related to the temperature range default phasons;
- The λ-Al<sub>13</sub>Fe<sub>4</sub> phase in the liquid phase giving rise to β-crystalline by peritectic reaction and form the i-phase which is comprised of a second type peritectic reaction  $L + \beta + \lambda \rightarrow i$ -phase;
- The volume of distribution of the cobalt atom (Co) in quasicrystalline alloy AlNiCo got a reverse anisotropic diffusion behavior for self-diffusion along the periodic and aperiodic direction surface;
- The existence of γ-Al<sub>2</sub>O<sub>3</sub> provides the spinel formation on copper and iron oxidized forming CuO and FeO;
- Oxidation of aluminum by changing concentration in the near-surface area induces phase transformation. Such transformations are abrupt since intermetallic phases are observed;
- The decagonal quasicrystals oxidation effect of AlNiCo proceeds in oxygen consumption divided into two crucial stages; the first chemisorption has a rapid exposure to Langmuir 10 to 20; the following by a slower absorption presumably the formation of oxide thin film;
- Oxidation has been found to be accompanied by a phase transformation of the i-phase into the

phase λ-Al<sub>2</sub>Cu and such a reaction can be understood by assuming Cu segregation which in turn might be responsible for the nodular growth of the oxide.

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