International Journal of Current Science, Engineering & Technology ISSN : 2581-4311
Original Research Article | Open Access | AMCT 2017 Malaysia | *Special Issue*

Characterisation of $Al_{65}Cu_{20}Fe_{15}$ Quasicrystal Alloy Synthesised via In-situ Casting under Standard Room Ambient and Argon Enriched Atmosphere

Chee Wayne TAN[a], Joy Rizki PANGESTU DJUANSJAH[b*], Mohd Hasbullah IDRIS[c], and Wan Fahmin Faiz WAN ALI[d]

Faculty of Mechanical Engineering, Universiti Teknologi Malaysia (UTM), 81310 Skudai, Johor, Malaysia.

[a]tancheewayne@gmail.com, [b]joy@utm.my, [c]hasbullah@utm.my, [d]wan_fahmin@utm.my

ABSTRACT. Characterisation on a series of bulk $Al_{65}Cu_{20}Fe_{15}$ quasicrystal alloy synthesised via in-situ induction casting under argon (Ar) enriched atmosphere and standard room ambient is the focal point of this research. The significance of atmospheric inertness in the course of induction casting process as well as the impacts of subsequent heat treatment at 650 °C under 5 hours dwelling duration on the metallography of $Al_{65}Cu_{20}Fe_{15}$ quasicrystal alloy were investigated through VPSEM coupled with EDX as well as XRD. The $Al_{65}Cu_{20}Fe_{15}$ quasicrystal alloy specimens produced by induction casting under critically controlled inert environment and standard room ambient as well as subjected to posterior heat treatment process were inspected via vickers hardness test in accordance to ISO 6507-1:1997. Research findings inferred that inert atmospheric condition during induction casting is critical for the formation of icosahedral, i phase and served as oxidation retardant to the Al-Cu-Fe ternary system alloy, while the subsequent heat treatment at 650 °C promoted the grain growth of $Al_{65}Cu_{20}Fe_{15}$ icosahedral quasicrystalline compound.

Keywords: *Quasicrystal, Al-Cu-Fe, In-situ Casting, Argon, Heat treatment;*

Received: 15.10.2017, Revised: 15.12.2017, Accepted: 30.02.2018, and Online: 20.03.2018;

DOI: ***10.30967/ijcrset.1.S1.2018.280-286***

Selection and/or Peer-review under responsibility of Advanced Materials Characterization Techniques (AMCT 2017), Malaysia.

1. INTRODUCTION

Solid state matters were fundamentally classified into 3 major categories, namely crystalline group, non-crystalline group and quasicrystalline group. Crystalline structures are mainly characterised by the integral construction of either atoms, molecules or ions in a definite geometrical pattern [1,2]. The particles in crystalline systems are uniformly positioned to form long range order of 2 dimensional (2D) as well as 3 dimensional (3D) crystal network with infinite repetition of unit cells that may possess 2, 3, 4 as well as 6 fold axis of non-trivial rotational symmetry [1,2]. Non-crystalline solids on the other hand exhibit randomly configured network of particles throughout the amorphous system without long range repetition of unit cells and features only 1 fold axis of rotational symmetry [1,2].

Differing from crystalline solids which are systematically governed by long range repetitive array of atomic pattern, as well as amorphous solids with relatively random atomic regularity, quasicrystalline solids does not possess rotational axis and comprised of long range aperiodic yet ordered atomic configuration [3-5]. Quasicrystals may be sub-classified into 2 categories, namely the 2 dimensional (2D) polygonal or dihedral quasiperiodic group which composed of octagonal, decagonal as well as dodecagonal configuration with 1 periodic direction perpendicular to the quasiperiodic layers as well as 3 dimensional (3D) polyhedral quasiperiodic group which composed of icosahedral configuration with no periodic direction [3,4]. The lattice arrangement of crystalline matters were often described with generic models of regular tiling involving only one kind of unit cell with 2, 3, 4 and 6 fold rotational symmetry, meanwhile, quasicrystalline structures violated the conventional crystallographic restriction theorem by exhibiting Penrose tiling patterns involving two or more kind of unit cells, where the primary tiling units may possess 5, 8 10 and 12 fold rotational symmetry, while the secondary tiling units represented by voids or overlapping cells [4,5].

The first profound research on quasicrystal was pre-eminently contributed by Professor Dan Shechtman through the characterisation of rapidly solidified Al-Mn intermetallic compound synthesized via melt-spinning process [6]. The employment of melt-spinning technique allowed the molten Al-Mn composite to be rapidly quenched and solidified within milliseconds, hence resulted in the formation of metastable binary phase Al-Mn quasicrystal with icosahedral diffraction symmetry [6].

Quasicrystals in general exhibit extreme hardness, high electrical resistance, energy absorption, low coefficient of friction, thermal conductivity as well as density and accompanied by adversities such as brittleness and metastability [7,8]. Up to date, quasicrystal technology have been employed particularly on the aspect of non-stick surface coating for culinary kitchenware products via sputter deposition technique under Argon (Ar) enriched atmosphere as well as atomic dislocation impedance for steel reinforcement mechanisms [9]. The abundance of unique nanoclusters present in several quasicrystals had drawn massive interest and instigated immense scientific exploration on the materials, hence unleashed their potential to serve as catalysts for the synthesis of carbon nano-tubes (CNT) and facilitate the steam reformation process for the production of methanol [10-12].

The foremost scientific investigation emphasising on the formation of icosahedral, i quasicrystalline phase in Al-Cu-Fe ternary system was primarily conducted by Tsai et al. (1987) [13,14]. Tsai et al. (1987) revealed that the laboratory synthesised specimens of $Al_{65}Cu_{20}Fe_{15}$ compound which undergo rapid solidification as well as conventional cooling through natural convection are mainly dominated by icosahedral, i quasicrystalline phase and accompanied by the presence of relatively minute amount of several highly complex crystalline phases [13-15]. It had been discovered that Al-Cu-Fe ternary system remarkably outshined other quasicrystalline structures by exhibiting significantly high thermal stability of up to approximately 890 °C at relatively narrow composition domain, hence suggesting that the material may potentially be viable for numerous engineering applications and dispelled the notion on quasicrystals of being inherently metastable [14-16].

2. MATERIALS AND METHODS

2 distinctive $Al_{65}Cu_{20}Fe_{15}$ quasicrystal alloy ingots (represented by mole fraction) with the elemental composition of aluminium (Al), copper (Cu) and iron (Fe) purity level inspected via glow discharge spectrometry (GDS) as depicted in Table 1 were synthesized via in-situ casting as illustrated by the schematic diagram in Fig. 1. The significance of atmospheric inertness in the course of casting process on the properties of $Al_{65}Cu_{20}Fe_{15}$ quasicrystal alloy was studied by manipulating the input flow rate of argon (Ar) gas into the confined induction furnace during its operation at 0 ml/s and 20 ml/s in order to simulate standard room ambient and highly inert atmospheric condition respectively. The concentration of the inert gas within the confined induction furnace operated at 2000 Hz were ensured to be constant by maintaining the flow rate of Argon (Ar) gas throughout the entire casting process. The temperature profile of both $Al_{65}Cu_{20}Fe_{15}$ quasicrystal alloy samples were captured during the on-site casting process which comprised of melting, solidification and cooling in sequence by using a type R thermocouple connected to data logger.

Full annealing process were performed in order to microstructural homogeneity of the $Al_{65}Cu_{20}Fe_{15}$ quasicrystal specimens by relieving their internal stress, while promoting chemical equilibrium by increasing the interstitial diffusion rate of particles within the ternary alloy system [16]. The heat treatment process in this research involved critical elevation of the $Al_{65}Cu_{20}Fe_{15}$ quasicrystal alloy specimens temperature up to 650 °C in conjunction to locate the ideal temperature vicinity in promoting the grain growth of icosahedral, i quasicrystalline phase in Al-Cu-Fe ternary system as defined by Faudot et al. (1992) [7]. The $Al_{65}Cu_{20}Fe_{15}$ quasicrystal alloy specimens were subjected to heat dwelling at the particular ambient for up to 5 hours duration, followed by prolonged cooling to room temperature.

Table 1 GDS analysis of raw materials

Element	Purity Level [%]
Aluminium (Al)	98.9
Copper (Cu)	99.9
Iron (Fe)	98.2

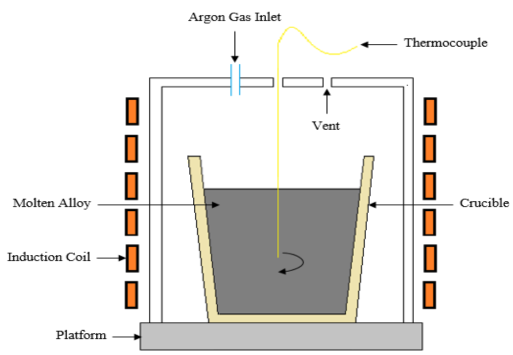
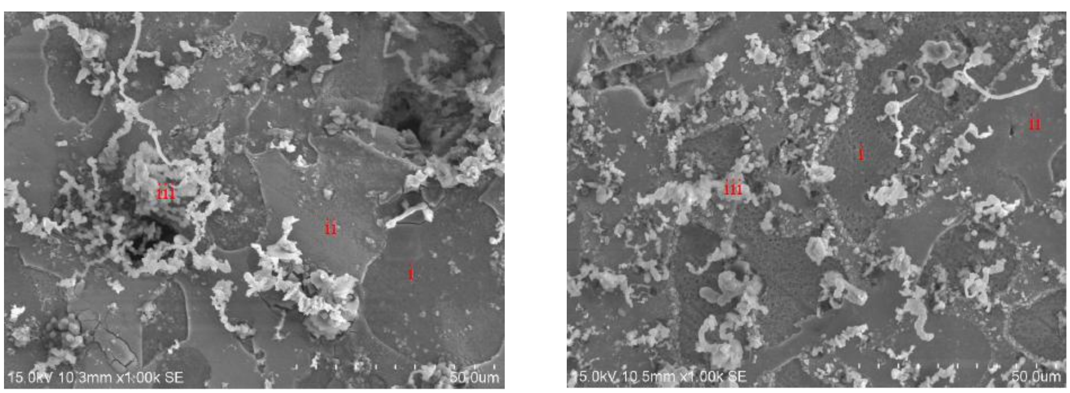
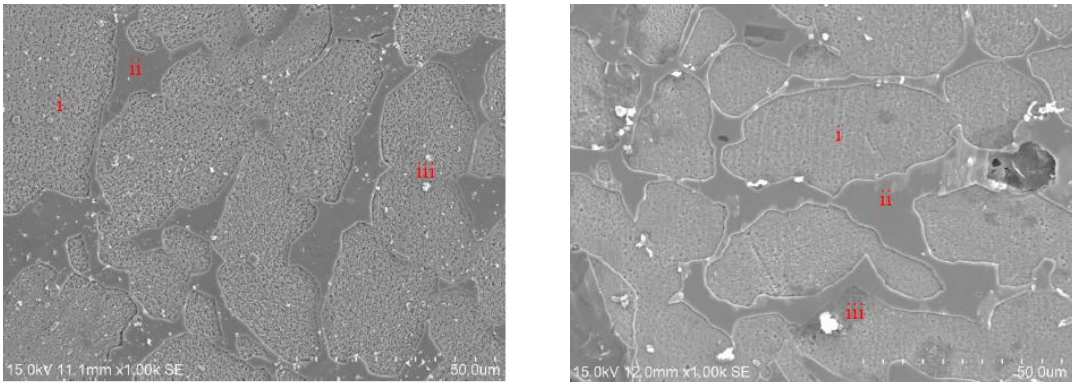


Fig. 1 Schematic diagram of in-situ casting setup



(a) (b)

Fig. 2 ×1000 magnified morphology of $Al_{65}Cu_{20}Fe_{15}$ synthesised in standard room ambient (a) without subjected to heat treatment (b) subjected to heat treatment at 650 °C



(a) (b)

Fig. 3 ×1000 magnified morphology of $Al_{65}Cu_{20}Fe_{15}$ synthesised in argon enriched atmosphere

(a) without subjected to heat treatment (b) subjected to heat treatment at 650 °CVariable pressure scanning electron microscopy (VPSEM) coupled with energy dispersive x-ray spectrometry (EDX) as well as x-ray diffraction (XRD) were performed to characterise the metallography of $Al_{65}Cu_{20}Fe_{15}$ quasicrystal alloy synthesised under both standard room ambient and inert atmospheric condition. Vickers hardness inspection were performed on all categories of specimens in accordance to ISO 6507-1:1997 by using Shimadzu DUH-211 micro hardness tester, while the post-indentation morphology of specimens were analysed via optical microscope [17,18].

3. RESULTS AND DISCUSSION

The ×1000 magnified morphology of $Al_{65}Cu_{20}Fe_{15}$ quasicrystal alloy synthesised under standard room ambient and argon enriched atmosphere were shown in Fig. 2 and Fig. 3, while the corresponding EDX analysis and XRD pattern were depicted in Fig. 5 and Fig. 6. It is deduced that the $Al_{65}Cu_{20}Fe_{15}$ quasicrystal alloy synthesised via on-site casting in the absence of inert atmospheric condition were highly dominated by "region iii", identified as the bright clusters of oxidized compound as depicted by the morphology in Fig. 4.

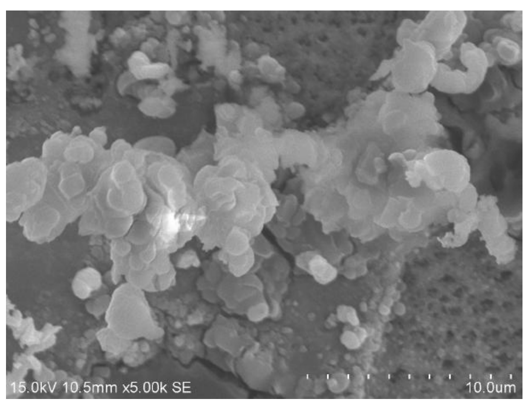


Fig. 4 ×5000 magnified microstructure of oxide clusters on $Al_{65}Cu_{20}Fe_{15}$

The Vickers hardness value for each categories of $Al_{65}Cu_{20}Fe_{15}$ quasicrystal alloy specimens collected through the semi-destructive experiment were computed and analysed via box and whiskers plot as depicted in Fig. 7. The formation of higher intensity of oxide compound in the $Al_{65}Cu_{20}Fe_{15}$ quasicrystal synthesised under standard room ambient resulted increment in terms of hardness magnitude of the alloy. Meanwhile, heat treatment process conducted at elevated temperature which promoted minute oxidation and the formation of icosahedral phase further impart hardness to the quasicrystal alloy. The exhibition of uneven edges around the vicinity of mechanical imprint, accompanied by the propagation of cracks observed thorugh the post-indentation topography captured at ×100 magnification scale as shown in Fig. 8 conjectured that the compound to be brittle.

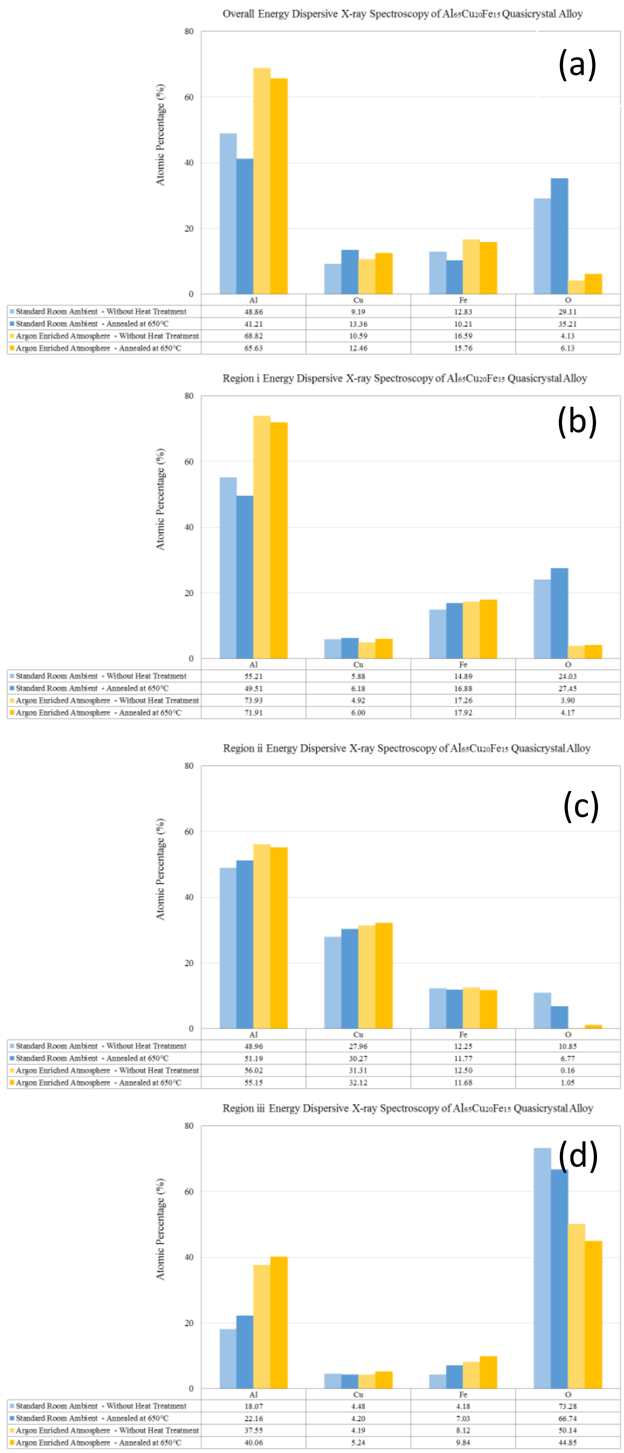


Fig. 5 EDX analysis (a) overall region (b) region i (c) region ii (d) region iii

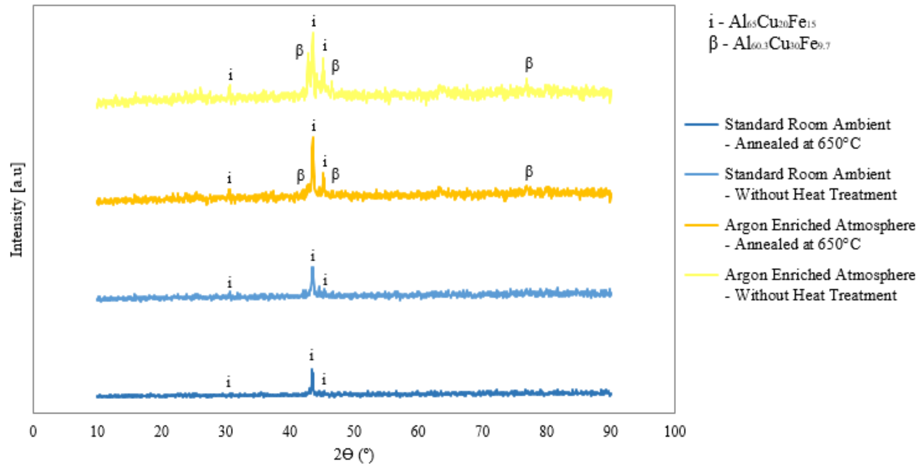
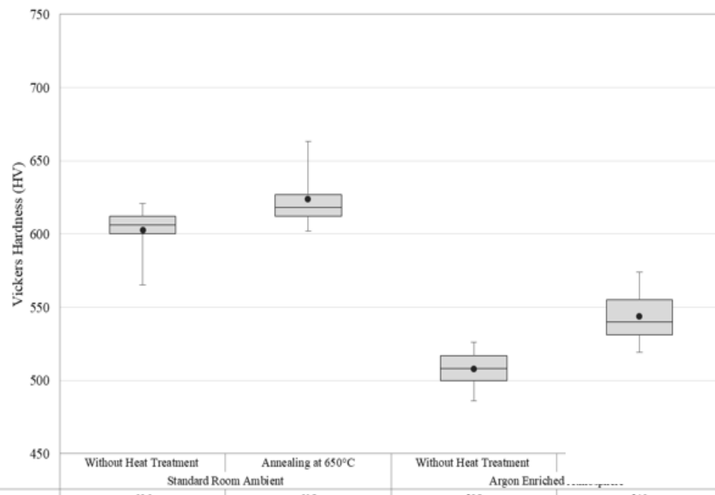


Fig. 6 X-ray diffraction pattern



Median, M (HV)	606	618	508	540
Mean, μ (HV)	602.6	623.8	507.7	543.8
Standard Deviation, SD (HV)	14.93	18.31	12.13	16.48

Fig. 7 Vickers hardness box and whiskers plot

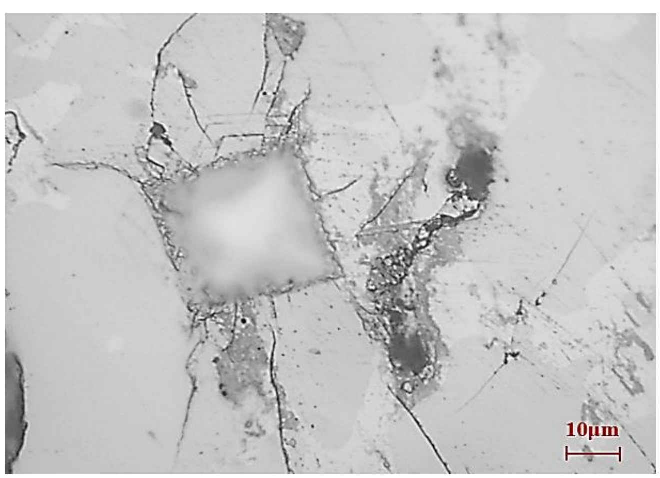


Fig. 8 × 100 magnified post- indentation topography of $Al_{65}Cu_{20}Fe_{15}$

4. SUMMARY

It is inferred that the application of argon gas had effectively displaced the gaseous elements in surrounding atmosphere, hence substantially retarded oxidation on the Al-Cu-Fe ternary system alloy in the course of in-situ casting, while increased the apparent diffraction intensity of icosahedral, i phase $Al_{65}Cu_{20}Fe_{15}$ compound. Cost effective semi-inert gas such as nitrogen may be employed in heat treatment process with dwelling temperature of no higher than 700 °C whenever appopriate to prevent oxidation and contamination to the aluminium rich Al-Cu-Fe quasircystal specimens.

ACKNOWLEDGEMENT

The supports provided by the Ministry of Higher Education, Malaysia and Faculty of Mechanical Engineering, Universiti Teknologi Malaysia (UTM) under cost center Q.J130000.26224.11J666 are greatly appreciated.

REFERENCES

[1] W. Massa, Crystal structure determination, 2nd Edition, Berlin, Springer, (2004).
[2] M. Ladd, Symmetry of crystals and molecules, Oxford, Oxford University Press, (2014).
[3] J.B. Suck, M. Schreiber P. Häussler, Quasicrystals: An introduction to structure, physical properties and applications, Berlin, Springer, (2002).
[4] M.V. Jaric, Introduction to mathematics of quasicrystals, Texas, Academic Press, (1989).
[5] M. Schmiedeberg, H. Stark, Comparing light induced colloidal quasicrystals with different rotational symmetries, J. Phys. Condens. Mat., 24 (2012) 1-3.
[6] W. Steurer, Why are quasicrystals quasiperiodic, Chem. Soc. Rev., 41 (2012) 6719-6729.
[7] C. Suryanarayana A. Inoue, Bulk Metallic Glasses, Florida, CRC Press, (2011).
[8] M. Kalman, The quasicrystal laureate, Massachusetts Institute of Technology (MIT) Technology Review, Cambridge, (2011).
[9] L. Fehrenbacher, Sputtering technique forms versatile quasicrystalline coatings, Materials Research Society (MRS) Bulletin, Maryland, (2011).
[10] K. Kajiwara, S. Suzuki, Matsui Y, H. Sato K. Hata, Characterization of quasicrystalline Al-Cu-Fe nanoclusters as catalysts for the synthesis of carbon nanotubes, Liverpool, 6th International Conference on Aperiodic Crystals, (2010).[11] A.P. Tsai, T. Tanabe K. Satoshi, A novel catalyst fabricated from Al-Cu-Fe quasicrystal for steam reforming of methanol, Catalysis Today, 111 (2006) 153-157.
[12] B.P. Ngoc, C. Geantet, M. Aouine, G. Bergeret, S. Raffy S. Marlin, Quasicrystal derived catalyst for steam reforming of methanol, Int. J. Hydrogen Energ., 33 (2008) 1000-1007.
[13] A.P. Tsai, Metallurgy of quasicrystals, in physical properties of quasicrystals, New York, Springer, (1999) 5-45.
[14] A.P. Tsai, I. Akihisa M. Tsuyoshi, A stable quasicrystal in Al-Cu-Fe system, Jpn. J. Appl. Phys., 26 (1987) 1505-1507.
[15] H. Mehrer, R. Galler , W. Frank , R. Bluher A. Strohm , Weinheim, Diffusion in quasicrystals, in quasicrystals: structure and physical properties, Wiley, (2003).
[16] M. Gogebakan, B. Avar O. Uzun, Quasicrystalline phase formation in the conventionally solidified Al-Cu-Fe system, Materials Science Poland, 27 (2009) 919-926.
[17] H. Chandler, Hardness testing, Ohio, ASM International, (1999).
[18] ISO 6507-1:1997, Metallic materials-vickers hardness test, International Organization for Standardization (ISO), Geneva, (1997).