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EFFECT OF GRAPHITE ON MECHANICAL AND MACHINING PROPERTIES OF Al-BRONZE PREPARED BY P/M

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ABSTRACT

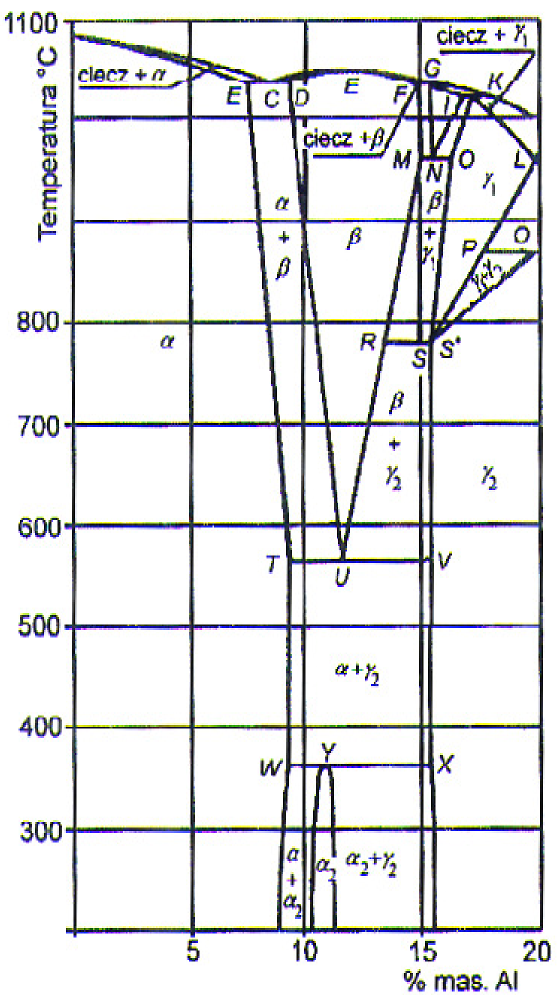
Aluminum bronzes are the highest strength standard copper based alloys. For their combination of high strength, excellent corrosion and wear resistance these alloys have a wide acceptance in engineering applications, so studying their improvement still important. In the present study, a base aluminum bronze alloy with a chemical composition of (Cu – 11%Al) is prepared basing on powder metallurgy technique with a determined suitable compacting pressure of 400MPa, sintering for 1 hour in 920°C in a vacuum furnace (10^{-4} tor), and then quenching from 950°C in cold water and tempered at 450^0C for 2hrs. Graphite particles of 0.05, 0.1, 0.3, 0.6, 1, and 3 weight percentages were added as reinforcing elements to the alloy. The influence of the graphite particles on physical, mechanical, and machining properties of the base alloy had been investigated. This included microstructure, hardness, compressive strength, and the roughness of the machined surface. To achieve the objective of the presented work, the tests included are: SEM analysis, XRF test, XRD analysis, microhardness test, compressive strength test, as well as the machining tests. The machining program is based on face turning with a constant depth of cut of 0.2 mm and using four cutting speeds of (80, 125, 250, and 400 rpm) for each of which four feed rates of (0.1, 0.18, 0.28, and 0.35 mm/rev) were used. The turning processes were carried out via a tool with a carbide tip type P10.

The study shows that an addition of 0.3wt% of graphite particles has the greatest effect on the properties of the studied aluminum bronze. The addition of 0.3wt% of graphite particles increases the hardness by (7.93%), the compressive strength by (11.62%). The results of the machining experiments show that such percentage of graphite particles reduces the surface roughness by (22.65% to 32.38%) when turning with the used machining conditions.

Keywords: Aluminum bronze, Compressive Strength, Graphite, Hardness, Powder Metallurgy, Surface Roughness.

1. INTRODUCTION

The properties of copper gave its alloys a wide acceptance in engineering applications. Coppers and certain brasses, bronzes and copper nickels are used extensively for automotive radiators, heat exchangers, home heating systems, solar collectors, and various other applications [1]. Copper-aluminum alloys form an important group of engineering materials which are renowned for their strength and corrosion resistance. The properties are closely dependent on microstructure. The equilibrium diagram, shown in Fig.1 [2], indicates that the solubility of Al in copper is 7.3% as maximum at 1036°C, but it grows to 9.4% at 565°C. Homogeneous alloys structure is created by "α" substituted solid solution of Al in Cu with body centered cubic lattice with similar properties as has the "α" solid solution in brasses [1]. "β" phase is a disordered solid solution of electron compound of Al&Cu with face centered cubic lattice. It is a hard and brittle phase precipitated from liquid metal at Al content of 9.5 to 12 % during the crystallization process.



Punkt	Temp [°C]	% Al
A	1083	0
B	1036	7,4
C	1036	8,3
D	1036	9,0
E	1048	12,4
F	1036	14,95
G	1036	15,25
H	1036	16,0
I	1022	16,9
J	1022	17,1
K	1022	18,0
L	958	20,0
M	963	15,1
N	963	15,45
O	963	16,4
P	873	17,8
Q	873	20,0
R	780	13,6
SS'	780	15,6
T	565	9,4
U	565	11,8
V	565	15,6
W	363	9,1
Y	363	11,2
X	363	15,8

Fig.1: Cu-Al system equilibrium diagram [2]

During the slow cooling rate the β phase is transformed at eutectoid temperature 565°C to the lamellar eutectoid ($\alpha+\gamma_2$). The phase γ_2 is an inter-metallic compound of the formula Cu_9Al_4 and, in common with compounds of this type, is very hard and brittle, resulting in an overall brittleness of alloys [3]. After the recrystallization in solid state the slowly cooled alloys with Al content of 9.4 to 12 % are heterogeneous. Their structure is created with α solid solution crystals and eutectoid ($\alpha+\gamma_2$). From 10 to 12 % Al content alloys can be heat treated with a similarly process as in the case of steels. The martensitic transformation can be reached in the case when the eutectoid transformation is limited by fast cooling rate from the temperatures in the β or (α+β) areas. Retained β transforms into a hard acicular martensitic form by a process not requiring diffusion. The eutectoid ($\alpha+\gamma_2$) structure has certain undesirable features with respect to mechanical properties and corrosion resistance and is therefore avoided as far as possible for most commercial applications [1, 4].

Some copper alloys are made with a variety of combinations of properties such as strength, wear resistance, anti-galling and cold formability. These may be less easily machined. So in the development of copper - base alloys it is essential to study its machineability. In this study graphite percentage will be added to aluminum bronze alloy by using powder metallurgy (P/M) technique to improve some of its mechanical properties namely the hardness and the compressive strength and surface finish produced by its machining.

Research and development on metal matrix composites (MMCs) have increased considerably due to consistency in properties and performance in general compared to the un-reinforced matrix alloys and due to the availability of inexpensive reinforcements and cost effective processing routes which give rise to reproducible properties [5]. Particulate reinforced copper matrix composites are attractive in many applications, such as electronic materials, wear-resistance and heat-resistance materials, brush materials and torch nozzle materials and other applications [6]. This brings forward the need to study the behavior of these composites.

Graphite is stable over a wide range of temperatures, and is a highly refractory material with a high melting point (3650°C) [7]. Graphite, in the form of fibers or particulates, has long been recognized as a high-strength, low-density material, so its use as a reinforcing element has been increased considerably to produce MMCs with improved machining properties. Many attempts were published in this field.

In 2010 Kh. A. Ragab, et al. [8] studied the influence of SiC, SiO_2 and graphite on corrosive wear of bronze composites subjected to acid rain, sintered aluminum bronze composites was prepared and investigated for components subjected to motion in aqueous environments. Chandana Priyadarshini Samal in 2012 [9] present an investigation about the fabrication of Cu-graphite MMC by conventional and spark plasma sintering (SPS) techniques. The wear resistance of the composite increases with increase in graphite content due to the lubricating properties of graphite. In 2013 Shenq Yih Luo and Chung Hsien Lu [10] studied mechanical properties of aluminum bronze matrix alumina composites prepared by hot pressing. The results showed that the hardness of the sintered composites increases with the decrease of porosity. The composites without and with resin infiltration have about HRF 42-61 of about 34-40% of porosity and about HRF 62-83 of about 30-36% of porosity, respectively. In 2014 Haydar A. H. Al-Ethari, and Israa Adnan Njem [11] studied the effect of graphite on aluminum- SiC hybrid composite prepared by stir casting technique. The study showed that an improvement of (33%) in macrohardness and (23%) in compressive strength had been achieved by reinforcing with both SiC and graphite. The results of machining experiments showed that graphite reduces the effect of SiCp on the surface finish. In 2014 Haydar A.H. Al-Ethari and Hussain Hamza Aziz [12] studied the effects of SiC and graphite as reinforcing additives to Nikel Aluminum Bronze with chemical composition of (Cu-9%Al-5%Ni-4%Fe) prepared by powder metallurgy technique. The study showed that 2%SiC causes a maximum reduction of 23% in tool life, but an addition of 0.6% graphite with these 2% SiC causes an increase of (7%) in tool life.

This work aims at studying improvement of the mechanical and machining properties of (Cu – 11%Al) alloy prepared by P/M. This will be achieved through studying the effect of a wide range percentage of graphite particles as a reinforcement to the alloy. Many mechanical, physical, and machining tests are to be carried out to compare between the base alloy and the reinforced composite. The mechanical and physical tests include: hardness test, compression test, SEM test, and XRD test, while the machining test will include: measurement of the roughness for machined surfaces of the prepared samples.

2. SAMPLES PREPARATION AND TESTS

2.1. Samples Preparation

Table 1 demonstrates the powders used to prepare the samples for the present study, their particle size, and their sources.

Table 1: Powders used in preparation of samples

Powder	Particles Size (µm)	Source
Copper	**45**	**USA[skypring nanomaterials, Inc., Houston]**
Aluminum	**45**	**USA [skypring nanomaterials, Inc., Houston]**
Graphite	**75**	**China [Lianyungang Jinli Carbon Co., Ltd.]**

To study the effect of graphite on mechanical and machining properties of Cu-11% Al alloy, samples with (0, 0.05, 0.1, 0.3, 0.6, 1, and 3wt%) of graphite as a reinforcing element were prepared. A wet mixing was used with 2%wt of acetone. A mixing process for 6 hours was achieved by an electrical mixer. Uniaxial compacting via double action molds was carried out on electro hydraulic compacting machine type (Channel automatic cube and cylinder compression machines, CT340-CT440, UK). Two types of samples were prepared. Cylindrical samples with (17mm) in diameter and (12mm) in height used for hardness, microstructure, X-Ray, and machining tests, and samples for compression test, each has a diameter of (10mm) and a height of (12mm) according to ASTM B925–08 specifications [13].

The preferred compacting pressure was determined practically basing on presence of cracks on the surface of green compacts and by determining the pressure that gave the highest green density. A loading rate of (o.3 KN/sec) was used for all compacting processes with duration of (30 sec) for the achieved pressure. Lubricant was used for the inside walls of the molds.

The sintering process of the green compacts was achieved via vacuum high temperature tube furnace (model GSL 1600X, China) with a pressure of (10^{-4} tor). The sintering program is shown in Fig.2. The samples were left inside the furnace to cool down to room temperature. The heat treatment was carried out at a temperature of (950°C) for (30min) with a heating rate of (10°C/min) then quenching in cold water and tempered at 450^0C for 2hrs.

2.2. Physical Tests

2.2.1. X-ray Florescence (XRF)

This test was carried out by using X-Ray Fluorescence Spectrometer. It covered aluminum and copper powders to ensure their purities.

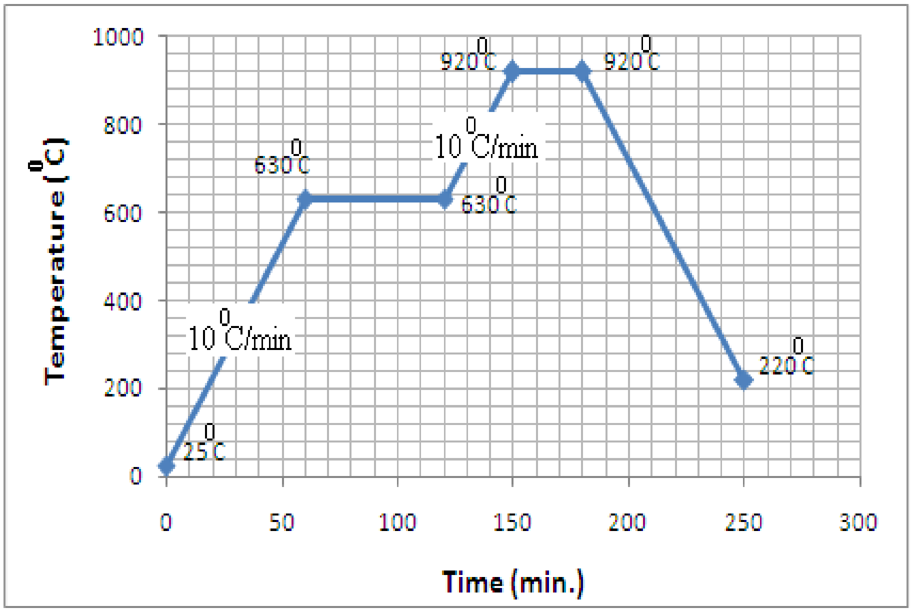


Fig. 2: The sintering program of the green samples

2.2.2. X-ray Diffraction (XRD): This test covered selected for the sintered and heat treated samples. The testing conditions are: Target: Cu, wave length of 1.54060 A^{o}, voltage and current are 40 KV and 20 µA respectively with a speed of 2deg/min.

2.2.3. Scanning Electron Microscope (SEM) Test: This test covered selected sintered and quenched specimens to investigate the influence of each process on the microstructure of the prepared samples. It was carried out by using SEM device with (500X and 5kX). Appropriate grinding and polishing were carried out for the tested specimens by using paper grits as (180, 400, 800, 1000, 1200, and 2000) and polished by using diamond solution with 0.2mm, by using a grinding and polishing machine, then etching solution consist of (5g $FeCl_3$, 3mml of HCl and 92 mml of distilled water) at room temperature. Then, all samples were washed by distilled water and dried using electric drier.

2.3. Mechanical Tests

2.3.1. Hardness Test

Appropriate grinding and polishing were carried out before subjecting the specimens to the test. The test was conducted at micro Vickers hardness device type (Digital Micro Vickers Hardness Tester TH 717) using a load of 9.8N for 20sec with a square-base diamond pyramid. The hardness was recorded as an average of three readings for each specimen.

3.2.2. Compression Test

The test was conducted at universal testing machine type (Computer control electronic universal testing machine, model WDW-200 max load capacity 200KN) with a piston speed of 0.1 mm/min. The test covered base alloy specimen and specimens with 0.3% graphite after sintering and after heat treatment.

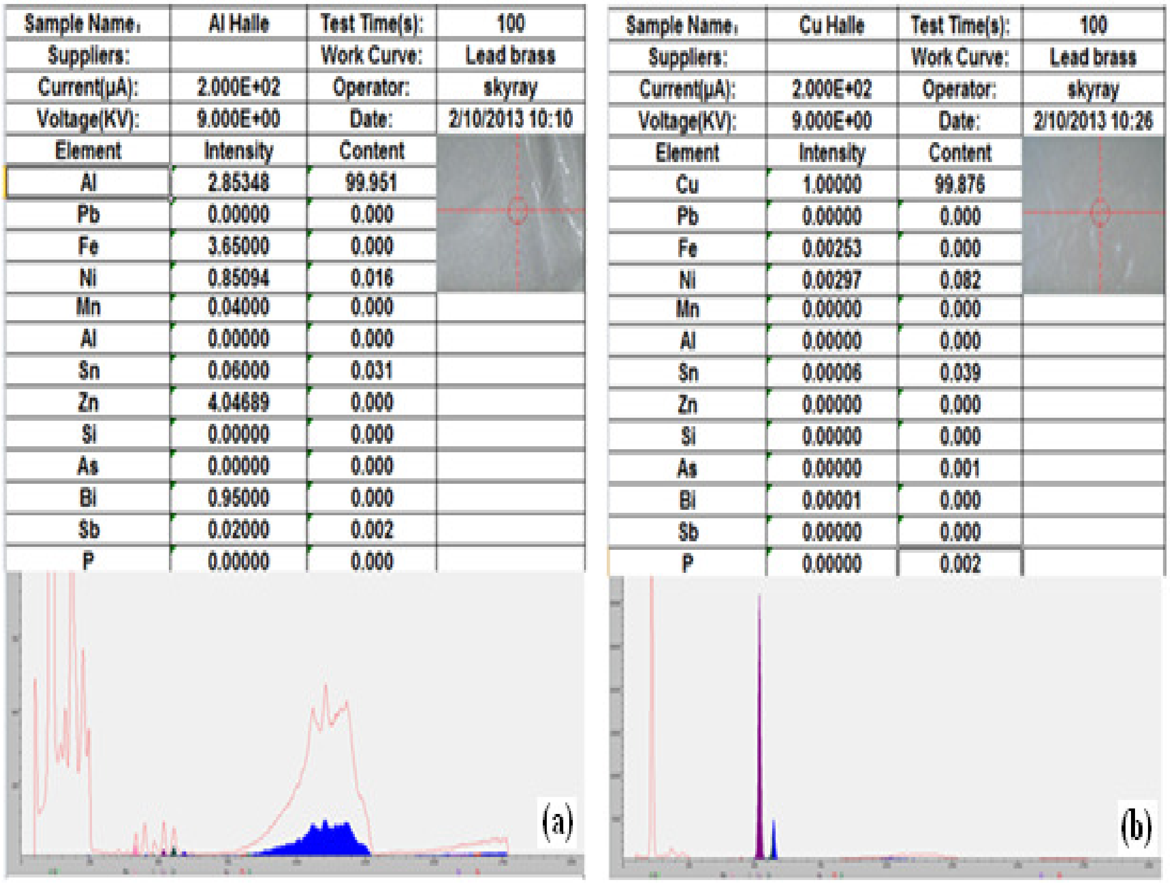
3.2.3. Machining Tests

The prepared samples with (17mm diameter × 12mm height) were machined by face turning at dry machining conditions. Four cutting speeds of (80, 125, 250, and 400 rpm) for each of which four feed rates of (0.1, 0.18, 0.28, and 0.35 mm/rev.) were used. A constant depth of cut of 0.2mm was used. The turning processes were carried out via a tool with a carbide tip type P10 with a chemical composition of (65% W, 9% Co,26% (TaC +TiC)), nose radius of 1.6mm and with tool angle of 55° [14]. For each face turning process the surface roughness was measured using surface roughness instrument type (TR200 hand-held roughness tester, model TA620Stan&Co). Surface roughness was recorded as an average of three readings. For each process a new tip was used. The surface roughness was recorded after one minute of each machining process.

4. RESULTS AND DISCUSSION

4.1. X-Ray Fluorescence (XRF)

Figure 3 shows the results of x-ray florescence test for aluminum and copper powders. The results indicate that the purity of aluminum was 99.951% while that for copper powder was 99.876%.



Sample Name:	Al Halle	Test Time(s):	100
Suppliers:		Work Curve:	Lead brass
Current(μA):	2.000E+02	Operator:	skyray
Voltage(KV):	9.000E+00	Date:	2/10/2013 10:10
Element	Intensity	Content	
Al	2.85348	99.951	
Pb	0.00000	0.000	
Fe	3.65000	0.000	
Ni	0.85094	0.016	
Mn	0.04000	0.000	
Al	0.00000	0.000	
Sn	0.06000	0.031	
Zn	4.04689	0.000	
Si	0.00000	0.000	
As	0.00000	0.000	
Bi	0.95000	0.000	
Sb	0.02000	0.002	
P	0.00000	0.000	

Sample Name:	Cu Halle	Test Time(s):	100
Suppliers:		Work Curve:	Lead brass
Current(μA):	2.000E+02	Operator:	skyray
Voltage(KV):	9.000E+00	Date:	2/10/2013 10:26
Element	Intensity	Content	
Cu	1.00000	99.876	
Pb	0.00000	0.000	
Fe	0.00253	0.000	
Ni	0.00297	0.082	
Mn	0.00000	0.000	
Al	0.00000	0.000	
Sn	0.00006	0.039	
Zn	0.00000	0.000	
Si	0.00000	0.000	
As	0.00000	0.001	
Bi	0.00001	0.000	
Sb	0.00000	0.000	
P	0.00000	0.002	

Fig. 3: X-ray florescence pattern for (a) copper powder; (b) aluminum powder

4.2. Compacting Pressure

Figure 4 illustrates the effect of compacting pressure on the green density of the base alloy samples. As it is obvious there is an increase in the green density with the compacting pressure till the density reaches a constant value. Up on these results a compacting pressure of 400MPa was used to prepare all of the samples.

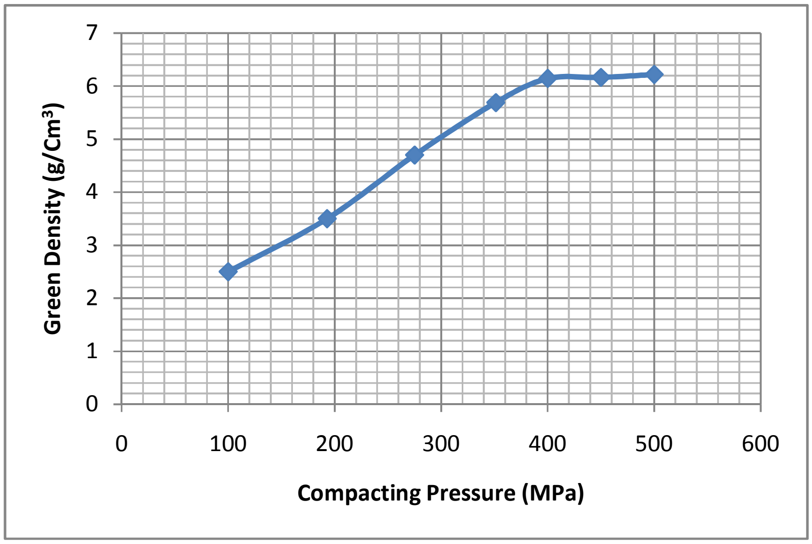


Fig. 4: Effect of compacting pressure on green density of the base alloy samples.

4.3. Hardness Tests

Table 2 demonstrates the hardness of the specimens after the sintering and after the heat treatments processes. Graphite leads to increase hardness up to 178.5 for A3 sample, the hardness drops to a value of 63.13 for A6 sample, so a 0.3 wt% of added graphite had been considered as the best percentage to enhance the alloy. The recorded hardness was greater after solutionizing treatments in comparison to that for as sintered samples except the hardness for samples of high percentage of graphite (A4,A5 and A6 samples). The solutionized samples attained higher hardness as γ_2-phase in (α+γ_2) microstructure is the predominant phase. The martensite phase in the quenched and tempered samples causes the values of hardness be greater.

Table 2: Vickers hardness (HV) and compressive strength results of the prepared samples

Samples Code	Percentage of Graphite (%)	Hardness after sintering (Kg/mm^2)	Compressive Strength (MPa)	Hardness after heat treatment (Kg/mm^2)	Compressive Strength (MPa)
BA	0	105.866667	190.986	165.05	430
A1	0.05	80.786667		172.2	
A2	0.1	138.136667		162.5	
A3	0.3	160.1	157.563	178.15	480
A4	0.6	124.97667		73.465	
A5	1	108.52		75.53	
A6	3	103.3445		63,14	

Graphite work to prevent motion of dislocation and this makes the hardness increases for certain percentage. When the percentage of graphite increases over 0.3% the hardness decreases due to the of nature of graphite as it has a hexagonal closed pack structure, so with a presence of sufficient amount of graphite its layer may slide over each other leading to a drop in hardness as in A4, A5 and A6 samples, also due to the difference in the coefficient of thermal expansion between the bronze matrix and the graphite, a micro cracks may be created that will behave as a stress raiser.

4.4. Compressive Strength

Compressive Strength of the tested specimens is demonstrated in Table 2. Higher compressive strength were recorded due to the addition of graphite. Heat treatments caused the compressive strength to be increased for both reinforced and base alloy samples. This is due to the formation of hard and brittle martensite as indicated trough SEM and XRD tests. The compressive strength of sintered base alloy decreases from 190.986MPa to 157.563MPa after the addition of 0.3% graphite, but there is an increase of 11.6% after quenching and tempering. This belongs to that the graphite particles may not fit in their places by sintering only, but they reach their stable places only after heat treatment. These stable places enable the stress field around them to interact with those fields of dislocations in the microstructure.

4.5. XRD Tests

Figure 5 represents the charts of the X-ray diffraction results for sintered and for quenched and tempered BA samples. It shows a conversion to intermetallic compound of Al_4Cu_9. In this system there is α- phase with γ_2-phase. The sintering of alloy assists to get microstructure with α solid solution and intermetallic compound γ_2 which precipitates on the grain boundaries of α-phase. The formation of new intermetallic compound of Cu_9Al_{14} after quenching is obvious.

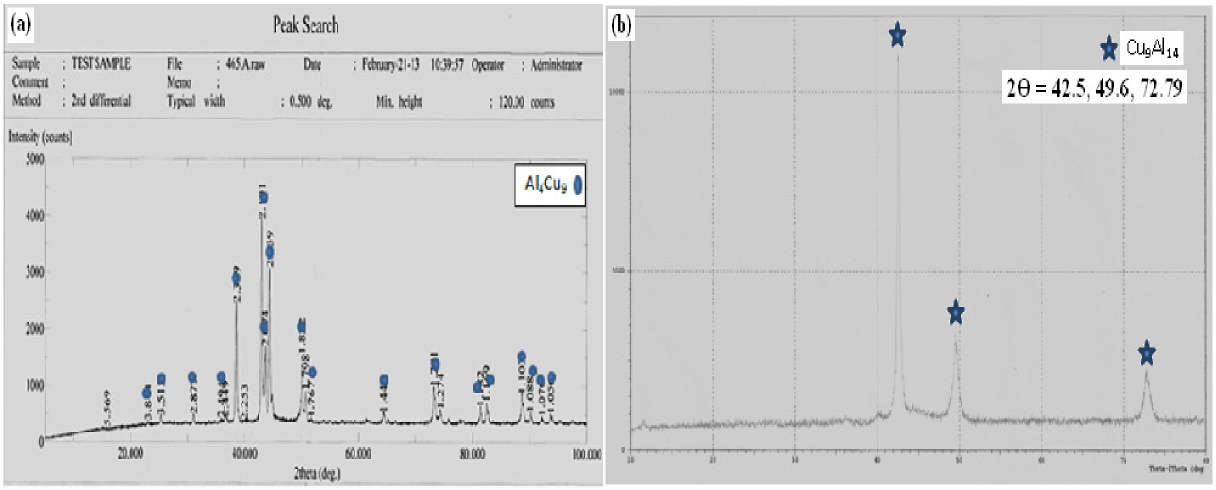
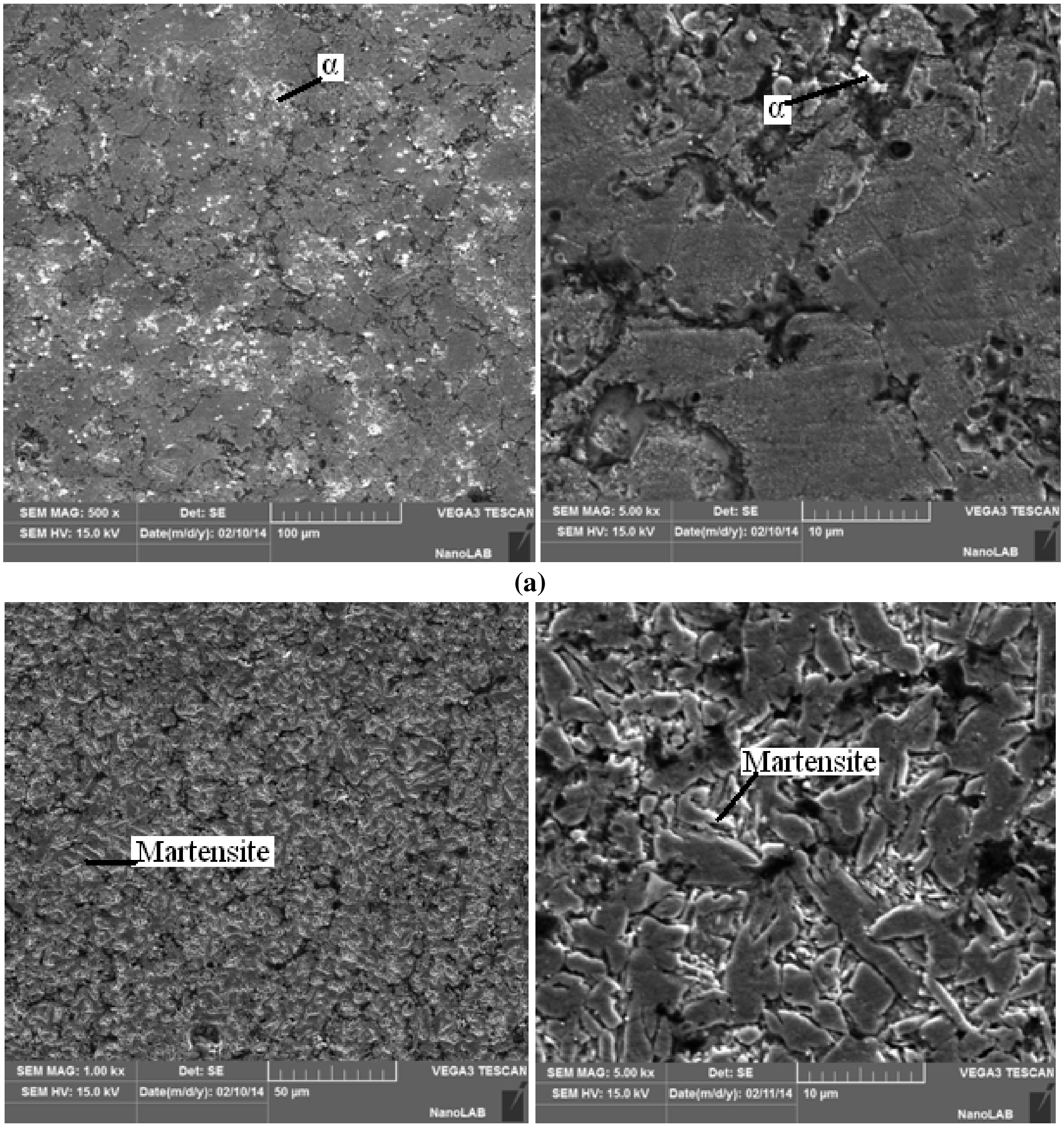


Fig. 5: XRD test result for: (a) sintered BA sample; (b) quenched BA sample

4.6. Scanning Electron Microscopy (SEM)

The SEM test is carried out for both sintered and quenched BA- samples. Fig. 6a refers to scanning electron microscope micrograph of (α + γ_2) phases of aluminum bronze alloy with its grain boundaries, while Fig. 6b refers to scanning electron microscope micrograph of martensite phase with its grain boundaries. The microstructure includes grains with martensite plates. Diffusion of elements in the matrix increases by localized elevation in temperature, this diffusion gives optimum distribution of particles which gives the mechanical properties such as hardness and compressive strength of the alloy.



(a)

(b)

Fig. 6: SEM image for BA sample: (a) sintered state (b) quenched state

4.7. Cutting Speed and Feed Rate Effects on Surface Roughness

Figure 7 and Fig. 8 show the effect of cutting speed and feed rate on surface roughness for both: BA and A3 samples. The results indicate that:

- The increase in cutting speed improves the machined surface quality. It is known that surface roughness has a decreasing trend with increasing cutting speed. The findings obtained also support the same trend.
- The analysis of the effect of feed rate on surface roughness shows that this parameter has a very significant influence, because its increase generates helicoids furrows the result tool shape and helicoids movement tool work piece. These furrows are deeper and broader as the feed rate increases. Surface roughness values increase by increasing feed rate.

- In A3 sample the recorded values of surface roughness are lesser than that recorded for the base alloy sample. This is due to the presence of graphite which has lubricating effect that reduces the amount of friction between the tool and work piece. This also reduces the machining temperature.

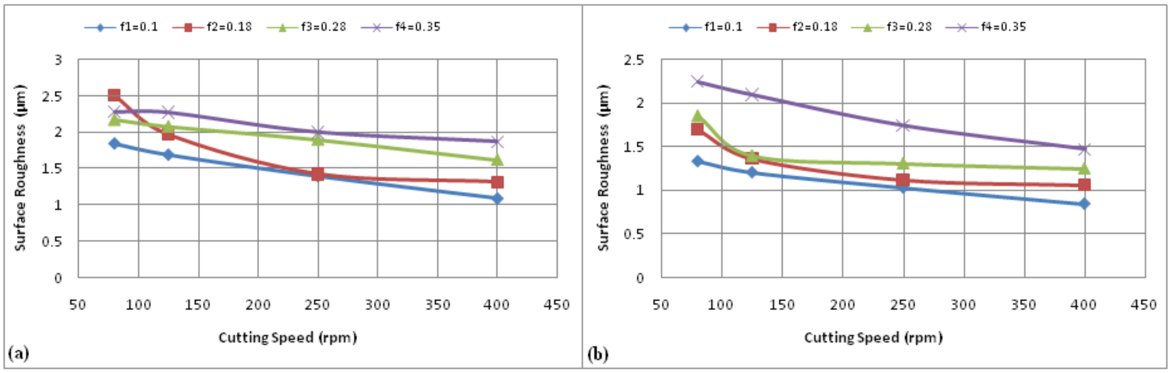


Fig. 7: Effect of cutting speed on surface roughness at a depth of cut of 0.2mm: (a) for BA sample; (b) for A3 sample

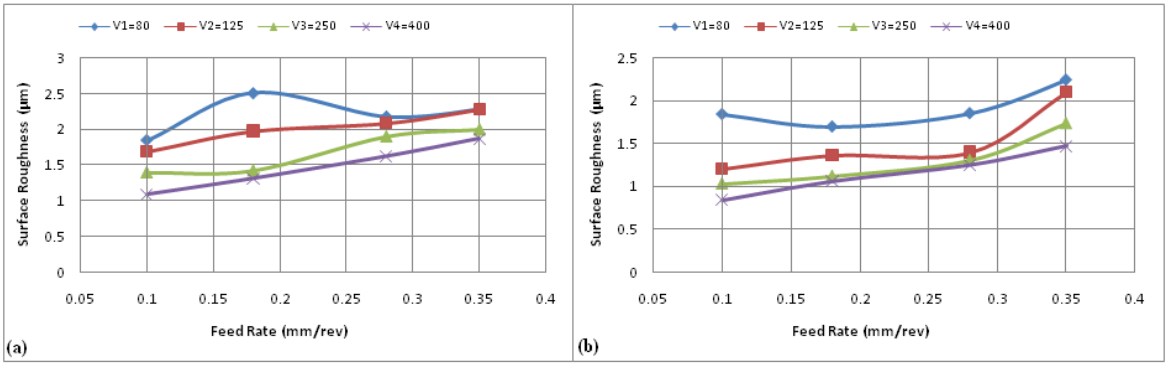


Fig. 8: Effect of feed rate on surface roughness at a depth of cut of o.2mm: (a) for BA sample; (b) for A3 sample

4.8. Conclusions

According to the results of the present work, the following can be concluded:

1- Addition of 0.3wt% of graphite particles to Cu-11%Al alloy improved its mechanical properties as micro hardness was increased by 7.93%, and compressive strength by 11.62%.
2- Adding of 0.6, 1, or 3wt% graphite causes a drop in mechanical properties of the studied alloy.
3- Adding of 0.3wt% graphite improves machineability of the studied alloy, so as the roughness of machined surface with the used machining conditions is reduced by (22.65% to 32.38%).

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