Kirkuk University Journal /Scientific Studies (KUJSS)
Volume 11, Issue 1, March 2016 , p.p(42-53)
ISSN 1992 – 0849

Studying the Effect of Adding Up To 6wt%Cu on Some Mechanical and Physical Properties of Pure Aluminum

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Received date : 4 / 3 / 2015 **Accepted date : 22 / 10 / 2015**

ABSTRACT

Aluminum and its alloys solidify in columnar structure with large grain size which results in deterioration of their surface quality and strength. Aluminum alloys with a wide range of properties are used in engineering structures. Copper has been the most common alloying element almost since the beginning of the aluminum industry, and a variety of alloys in which copper is the major addition were developed. In this work, the influence of pure copper addition to commercially pure aluminum hardness, compression strength and thermal conductivity were studied. Six different Al-Cu alloys with 1,2,3,4,5 and 6%Cu content were prepared and experimentally tested. It was found that adding up to 6wt%Cu led to linear increasing in Brinell hardness, compression strength and slightly increasing in the thermal conductivity of aluminum-copper alloys.

Keywords: *Hardness, Thermal Conductivity, Aluminum Copper Alloys.*

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دراسة تأثير اضافة النحاس لغاية 6Wt% على بعض الخواص الميكانيكية والفيزياوية للألمنيوم النقي

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تاريخ استلام البحث: ٤ / ٣ / ٢٠١٥ تاريخ قبول البحث: ٢٢ / ١٠ / ٢٠١٥

الملخص

يتجمد الألمنيوم وسبائكه في بنية عمودية مع حبيبات كبيرة الحجم مما يودي الى خفض كل من الجودة السطحية والمقاومة. ويستخدم الالمنيوم وسبائكه ذات الخصائص العالية في الإنشاءات الهندسية .يعد النحاس احد اكثر العناصر استخداما كعنصر سبائكي يضاف الى الالمنيوم لتحسين خواصه. في هذا البحث، تم دراسة تأثير اضافة(١%-٦%)نحاس على الصلادة، مقاومة الانضغاط والموصلية الحرارية للألمنيوم. تبين أن إضافة النحاس يعمل على الزيادة الخطية في الصلادة البرينيلية ومقاومة الانضغاط ويزيد وبشكل خطي من قيم التوصيل الحراري.

الكلمات الدالة: الصلادة، الموصلية الحرارية، سبائك الالمنيوم–نحاس.

1. INTRODUCTION

Aluminum and aluminum alloys are gaining huge industrial significance because of their outstanding combination of mechanical, physical and tribiological properties over the pure aluminum. These properties include high specific strength, high wear seizure resistance, high stiffness, better high temperature strength, controlled thermal expansion coefficient and

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improved damping capacity [1]. Aluminum is the second widely used metal due to its describable chemical, physical and mechanical properties and it represents an important category of technical materials [2]. Due to its high strength – to – weight ratio, besides other desirable properties e.g. desirable appearance, non-toxic, non-sparking, non-magnetic, high corrosion resistance, electrical and thermal conductivities and ease of fabrication, aluminum and its alloy are used in a wide range of industrial applications for different aqueous solutions. These properties led also to the association of aluminum and its alloys with transportation particularly with aircraft and space vehicles construction and building, containers and packaging and electrical transmission lines [3]. Mechanical properties of Al-Cu alloys depend on copper content. Copper is added to aluminum alloys to increase their strength, hardness, fatigue strength, creep, resistance and machinability. The first and most widely used aluminum alloys were those containing 4 – 10 Wt% Cu [4]. Copper is being used, due to its relatively high solubility in aluminum [5]. Thus, (Al–Cu) solid solution matrix that is mechanically tougher than a pure (Al) matrix [6]. The grain size is obviously a function of several parameters, the most important of which are the nucleation rate and the growth rate. the nucleation rate depends on the amount of energy required for the creation of a new phase structure and melt under cooling below the liquids (which gives a direct thermodynamic stimulus for nucleation, decreasing the critical size of the solidification nucleus), and or by the presence of solidification sites for heterogeneous nucleation (that provide the suitable surface for nucleation, decreasing the amount of required energy)[7].

In this paper the influence of copper on hardness, compression strength and thermal conductivity were studied.

The following paragraphs provide a summary of studies on the effect of adding copper on the microstructures, mechanical properties and thermal conductivity of pure aluminum.

- Al-Rawajfeh and Al-Qawabah (2009): the influence of Cu addition to commercially pure aluminum on microstructure, microhardness, grain size ,impact energy, flow stress at 0.2 strain, mechanical behavior and corrosion resistance was studied. Three different Al-Cu containing alloys 3,6 and 9 Wt%Cu were prepared and experimentally tested both mechanically and chemically. The addition of Cu resulted in a linear reduction in the grain size, slight reduction in the impact energy, substantial increase in the flow stress at 0.2 strains, and improve in the mechanical characteristics[7].

- Rana and Rajesh (2012): the influences of some alloying elements such as (Si, Cu, Mg, Ni, Tin+Si, Ti and other elements) on the microstructures and mechanical properties of Aluminum alloys and aluminum alloy composites were studied, and they found copper effect the strength and hardness of aluminum casting alloys, both heat treated and not heat treated and at both ambient and elevated service temperature. It also improve the machinability of alloys by increasing matrix hardness. On the down side, copper generally it reduces the corrosion resistance of aluminum and in certain alloys and tempers, it increase stress corrosion susceptibility, ultimate tensile strength of the alloys increased with heat treatment [8].

- Zuher and Thamir(2013): an experimental work had been conducted to illustrated the effect of adding copper (Cu) with different percentages to the pure aluminum (Al) and noise variables (error) on the quality of thermal conductivity (k). Alloys had been prepared by changing percentages of copper in pure aluminum and the percentages were (5, 10, 15, 20&25%). The effect of an average deviation and variability on the thermal properties after an addition of copper through use of normal probability plot. The results shows increasing copper content lead to increase thermal conductivity by (15.47%) and the property of thermal conductivity had goodness off it test and percentages the effect of adding copper to pure aluminum (Al) and error were (97%, 3%) respectively [9].

2. EXPERIMENTAL WORK

2.1. Casting Materials:

Different samples of Al-Cu Alloys were used in this work. The base material used throughout this work was the commercial pure aluminum of 99.9Wt% Al, pure copper with 99.9 % purity was used as an alloying element. Six alloys with different weight percentage copper were prepared, i.e. (1, 2, 3, 4, 5 and 6Wt% Cu).

2.2. Equipment and Experimental:

The following machines and equipment's were used:

a) Sensitive balance device three digits.

b) Carbolite electrical furnace, chamber furnace (CWF) type 11/13, UK .

c) Thermo couple K-type.

d) Digital camera.

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e) Digital Ernest Brinell hardness tester model (Twin R/SR 2000).

f) Thermal conductivity device type Manchester M71RH, UK cuss ions technology.

g) Optical microstructure, Altay type microscope.

3. MANUFACTURING ALLOYS BY CASTING

3.1. The Specimen Were Prepared Through Gravity Casting Process:

a) Weighing the alloying elements by using sensitive balance with accuracy (0.001g).

b) The melting procedure was firstly performed by melting aluminum, using graphite crucible which was preheated in an electrical furnace, then the addition of copper element was carried out at (750 ^{o} C).

c) During the addition of copper to the molten aluminum manual stirring for (10 seconds) with graphite rod with diameter (2.5 cm) was applied carefully to avoid producing too much dross.

d) The mold drilled with (2mm) diameter in the upper and lower position of the mold to fit the first thermocouple sensor to be in contact with molten alloy and the second one was positioned in the lower part of the mold body and the steel casting mold dimension is shown in Fig. (1) .

e) Pouring the molten alloys in to steel mold as shown in Fig. (2) , then leaving the casting to cool to the room temperature and digital camera was used to record the temperature readings, because of difficulty of recording the temperature drop in the start of casting alloys.

f) Six casting of aluminum – copper were manufactured with different addition. The preliminary chemical composition is given in Table (1).

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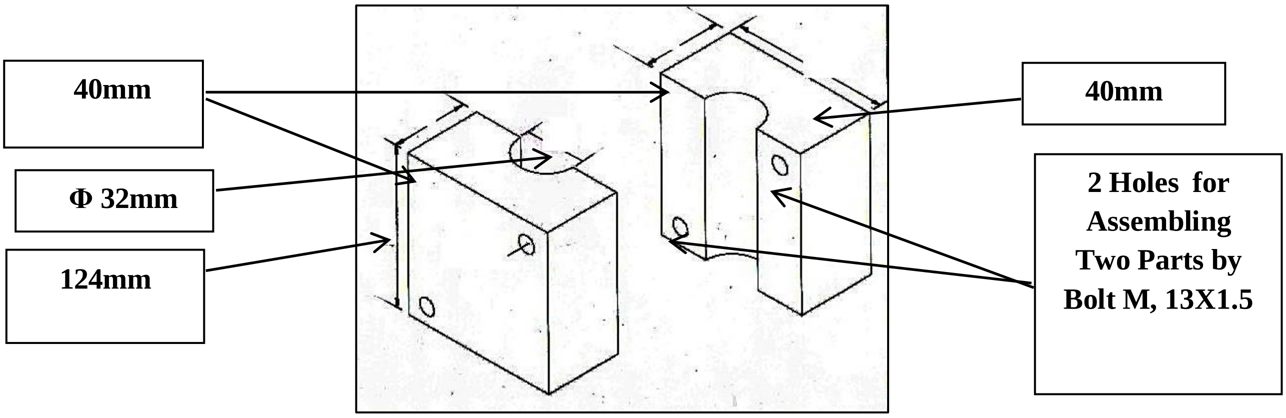

Fig. (1): The Carbon Steel Mold Dimensions

Fig. (2): Shows the Components of the Casting System

Table (1): Chemical compositions of samples .

Specimen code	%Al(g)	%Cu(g)
1	99	1
2	98	2
3	97	3
4	96	4
5	95	5
6	94	6

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3.2. The Preparation of Specimens:

The following steps were used to prepare specimens for tests:

a) Wet grinding was performed by using SiC emery paper in grade [400, 800, 1000].

b) Polishing by using alumina particles (Al_2O_3) with size 0.3µm, then specimens were cleaned by water and degreased with ethanol and dried for (hardness, thermal conductivity and compression specimens)[10].

4. RESULTS AND DISCUSSION

4.1. Cooling Rates For Aluminum Copper Alloys:

Fig. (3) shows part of (Al-Cu) equilibrium phase diagram. It is observed that the maximum solubility of Cu in Al is (5.65%) at (548 ºC) and is reduced to (0.1%) at room temperature. So normal casting processes as in the present study should led to the formation of ($CuAl_2$). Moreover, Fig. (3) reveals that the solidification temperature of (Al-Cu) alloys is a function of Cu content. It was observed from the results, that the time - temperature curve, illustrated in Fig. (4), that the liquid (Al-Cu) when its poured from (750ºC) in to the mold (carbon steel) suffers from a sudden temperature drop from 750ºC to 200 ºC. The solidification starts after (200 ºC) drop at time less than (1minutes) from the pouring (Al-Cu) liquid, and this was proved by the researcher [11].

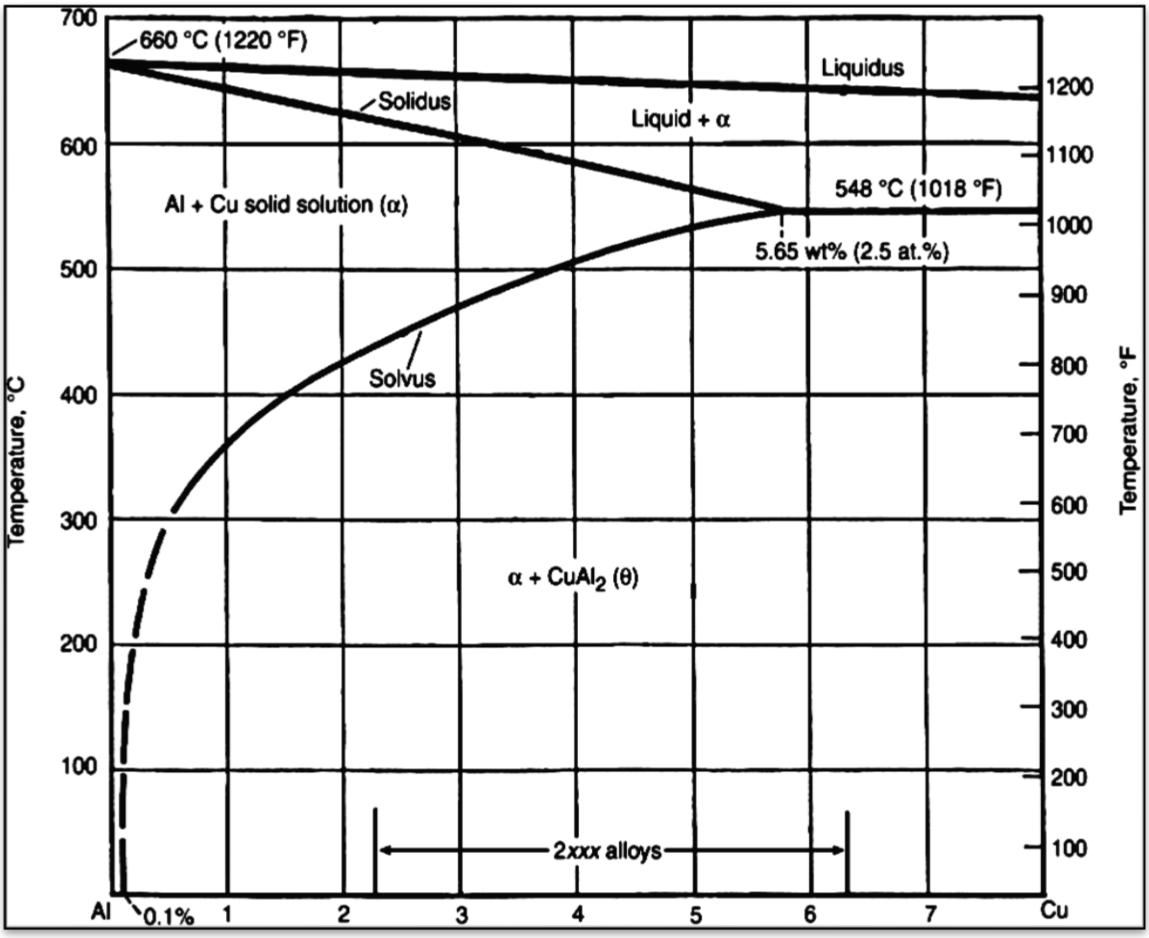

Fig. (3): Phase Diagram for Al-5.65Wt%Cu

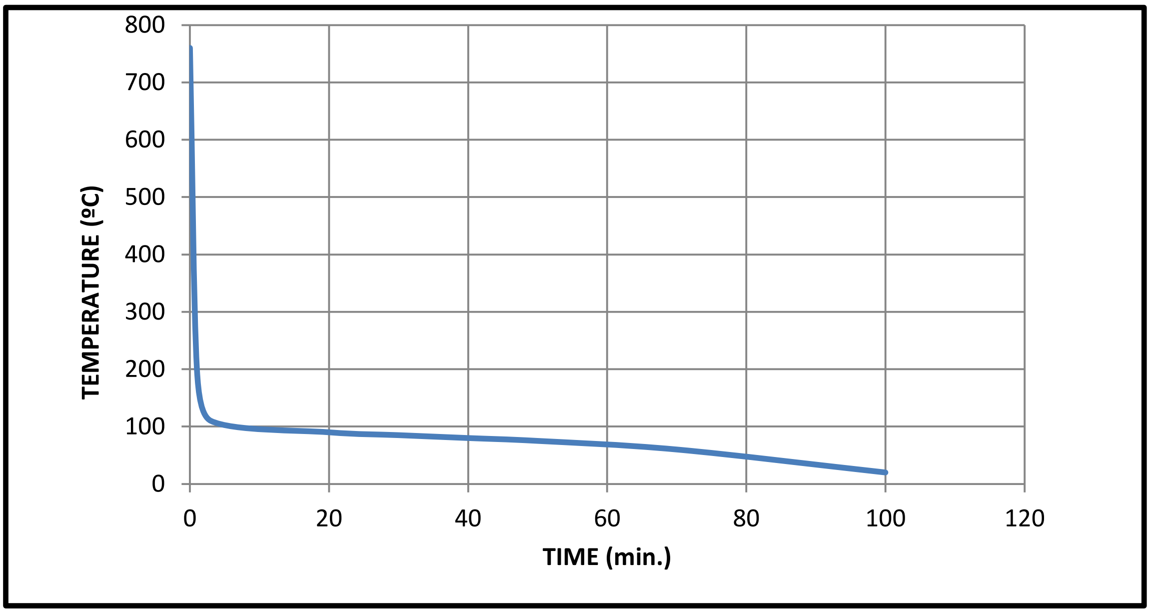

Fig. (4): Cooling Curve of Al-6Wt%Cu

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4.2. Hardness:

Hardness is one of the most important mechanical properties, which is commonly used to give a general indication of the strength of a material. In this work, the addition of Cu resulted in linear increase of the hardness of aluminum, and the (1Wt%Cu) alloy showed minimum value of Brinell hardness (27BHN) and the (6Wt%Cu) alloy showed the maximum value of Brinell hardness (60 BHN). Increasing (Al_2Cu) content led to the observed increase in hardness, as is shown in Fig. (5) and proved by the researcher [7].

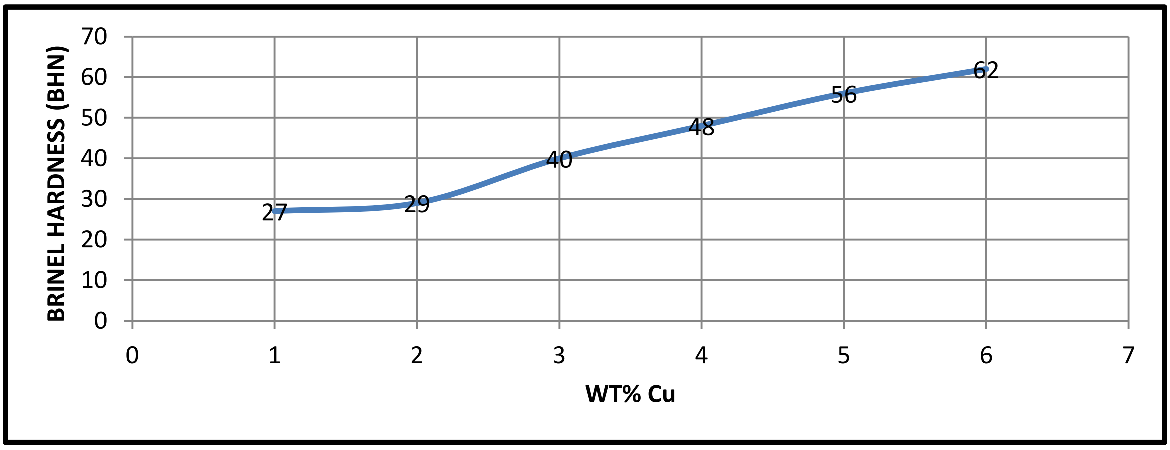

Fig. (5): The relation between copper content and Brinell hardness test

4.3. Thermal Conductivity:

Thermal conductivity of the (Al-Cu) alloys is in direct relationship with the Wt%Cu addition which shown in Fig. (6). The minimum value for it was at the 1wt%Cu (266.2 W/m.K) and the maximum value was at 6wt%Cu (295 W/m.K). This can be attributed to the high thermal conductivity of copper (400 W/m.K) compared with that of aluminum (244 W/m.K). Similar result is found in previous works [9,13] and is attributed to the formation of (Al_2Cu) particles.

Thermal conductivity values were obtained by using the following equation :

$$k = 5.02\,\lambda T\times10^{-9} + 0.03 \qquad (1)$$

Where:

K: is the thermal conductivity.

λ: is the electrical conductivity.

T: the absolute temperature in degrees Kelvin. [11]

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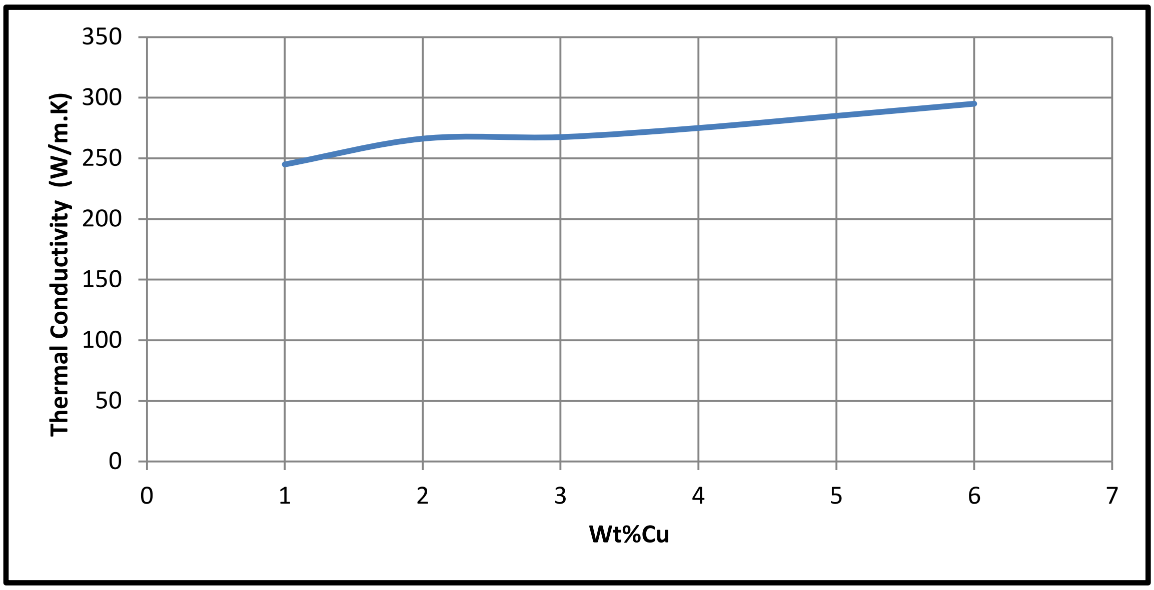

Fig. (6): The Relation Between Cu% and Thermal Conductivity

4.4. Compression Strength:

In compression strength test for the (Al-Cu) alloys which were used in this work the minimum value was (70Mpa) for (99Wt%Al-1Wt%Cu) and the maximum value was (150Mpa) for (94Wt%Al-6Wt%Cu). Fig. (7) shows the relation between the compression strength and the copper content. This behavior can be attributed to the solid solution hardening mechanism and to the presence of hard (Al_2Cu) particles dispersed in the alloy.

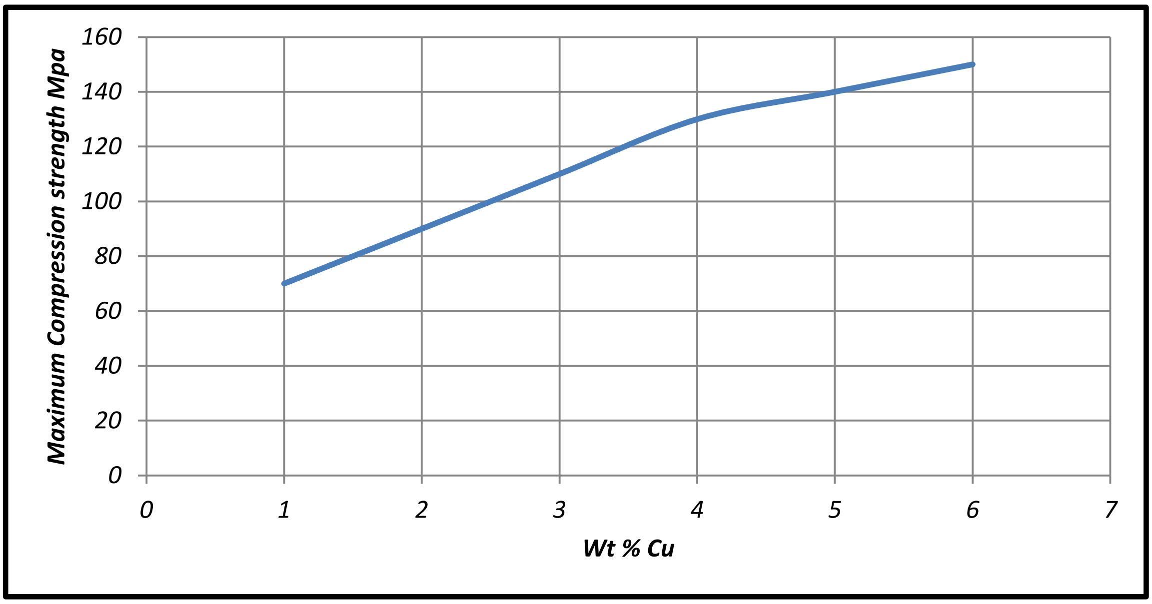

Fig. (7): The Relation Between Maximum Compression Stress And Wt%Cu

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5. conclusions

1. Carbon steel die caused rapid drop in temperature.

2. The copper addition caused linear increasing in the hardness, compression strength and thermal conductivity of the (Al-Cu) alloys.

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