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Effect of Copper on Tensile and Hardness of Al-Si Alloy in Automotive Application

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Abstract

In current research Copper was employed for preparing a ternary system of Al–Si alloy in different (0.2–2.5 wt. %) the best was taken is (1.5%wt) of copper that circumstances of solidification for improving the mechanical performance of the available in aluminium alloy. Cast iron molds were prepared to obtain tensile strength testing specimens. Alloys were prepared by employing gas furnaces. The molten metal was poured into a preheated cast-iron mold. The obtained alloy structures were studied using an X-ray diffractometer and optical microscopy. The mechanical performance of the prepared alloys was examined under the influence of different hardening conditions in both heat and non-heat-treated conditions. The outcomes showed at the ideal input status of friction stir processing, the cast alloy microstructure was enhanced in terms of refinement of eutectic and primary Si particles, homogeneous dispersion of Si, and the reduction in porosity. The mineral compounds formed during the hardening process were examined using an optical microscope. The highest maximum tensile strength (UTS) was 120 MPa for sample Al-22.5Si, and 147 MPa for sample Al-21Si-1.5Cu, while the highest hardness was 77 HB for sample Al-22.5Si, and 90 HB for sample Al-21Si-1.5Cu.

Article info.

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1. Introduction

In the field of construction of motor vehicles, there are some improvements have been made. Demand for automotive structures with increasing lighter materials is still high. Modern alloys of aluminium according to their low cost, high ratio of power-to-weight, and high wear resistance have been broadly used in several structural components, both in the automotive and aviation industries. Economical and simple methods for making most Al alloys are essential for more expansion of their applications [1]. Aluminium-silicon alloy is a unique alloy with a wide range of applications, particularly in the automotive and aerospace industries. These alloys have an outstanding combination of casting and mechanical properties [2].

The recently environmental and legislative demands on the auto industry pushed car companies to produce fuel-efficient and lightweight vehicles that have fewer toxic emissions of gas. The most-effective method to produce lighter weight is using lightweight materials, like Al alloy. Al-Si-Mg-Cu alloys as cast, are important as light metals [3]. As the concentration of copper reaches 12 wt. %, the strength of an alloy can be promoted through precipitation hardening, with or without the existence of Mg;

the hardening can be reached through the precipitation of Al_2CuMg or Al_2Cu intermetallic phases during aging, which consequently leads to strengths second only to the highest strength 7xxx (Al-Zn) series alloys [4].

It can be noticed that the increment in copper also leads to an increase in the heat treatability of an alloy. Moreover, copper considerably minimizes the melting point and eutectic temperature of the alloys. Therefore, copper increases the hardness of the alloy and also increases the porosity formation [5]. The strength of the industrial broadly used cast Al–Si–Mg–Cu alloys enhanced monotonously with increasing the copper contents by cast Al9Si0.5MgxCu (x=0, 0.2, 0.4, 0.6, 0.85, 1.0, and 1.25) wt.% alloys under T6 heat-treated condition. The hardness and yield strength of the heat-treated alloys appeared a platform in the composition between 0.4 wt.% to 0.85 wt.% Cu [6].

ZerenandKarakulak et al. [7] have studied the impact of copper contents on the microstructural and hardness characteristics of sand cast Al–Si–Cu alloys. Al–Si alloys with 2% and 5% Cu have been used for this purpose. Solidification of Al–Si–Cu alloys has been achieved by melting in a gas furnace with a crucible and casting in green- sand molds at temperature of 690°C. The solution treatment was performed at temperature of 500°C for 7 hours, then specimens were quenched in water. The prepared samples were aged at temperature of 190°C for 15 h to show the impact of aging on the mechanical properties.

Verma et al. [8] used aluminium alloys in automotive industries, according to the need to saving the weight for more reduction of fuel consumption. Typical alloying elements are magnesium, copper, zinc, manganese, and silicon. Aluminium alloys surfaces have a brilliant luster in dry environment because of the formation of a shielding layer of aluminium oxide. Aluminium alloys of the 4xxx, 5xxx and 6xxx series containing major elemental additives of Mg and Si, now a day are being used to replace steel panels in different automobile industries. In this work, the mechanical properties of Al alloy were investigated by varying the silicon percentage and copper concentration. In addition, studying the imapct of varying the composition of Cu on the mechanical properties like corrosion resistance, hardness, and tensile strength in an Al-Si-Cu alloy.

2. Experimental work

Six specimens of aluminium-silicon alloy were melted in various proportions in a gas furnace at 735°C using a graphite crucible as shown in Table 1. The obtained material was poured into a cast iron metal mold preheated to 300°C because it has about the best thermal fatigue resistance. 1.5% by weight of copper was added to each sample while reducing 1.5 of the weight of silicon without changing the weight of aluminium. The tensile and hardness tests were performed for each sample. Table 1 shows the concentration in terms of weight fraction of different elements existing in the prepared specimens.

Table 1: Weight fractions related to different elements existing in the Al-Si-Cu specimens.

Specimen No.	Al%	Si%	Cu%
1.	80.5	19.5	_
2.	79	21	_
3.	77.5	22.5	_
4.	80.5	18	1.5
5.	79	19.5	1.5
6.	77.5	21	1.5

2.1. X-Ray diffraction

Philips vertical powder diffract meter type pw1963/50 was used Diffract grams were obtained using Ni filtered CuKa radiation 0.15418 =ג nm operated at 30k V and 20mA. The scan range 20 was in the range (25-100) degrees. Powder specimens were ground by agate and mortar and then screened through 100 um mesh to ensure random orientation of grain distribution.

2.2. Optical Microscopy

The samples microstructural features were observed by optical microscope from Olympus on polished surfaces of the alloys. Polishing was carried out with graded abrasive (180, 220, 320, 400, 600, 800, 1000, 1200, and 1500) grits, then followed by diamond paste of 1.5 and 1 micron. The etching process was carried out with Keller's solution (1 volume part of hydrofluoric acid (48%), 1.5 volume part of hydrochloric acid, 2.5 volume parts of nitric acid, and 95 volume parts of water) for about 30 - 50 sec, to reveal the microstructure with grain boundaries. Photomicrographs were shot with a 5 mm Olympus camera. The area of the grey silicon grains before and after annealing were measured by Reichert optical microscope at a magnification of 100X on polished surfaces of the alloys.

2.3. Tensile strength Test

The tensile properties of the alloy were carried out with universal testing machine (Model: WP 310 Materials testing, 50kN, Germany). The dimensions of the sample were taken according to ASTM B-557 [9] as in Fig. 1. For the purpose of uniaxial tensile test, Young's modulus (E) is defined as the ratio between stress and strain during the elastic region. For metallic specimens, Young's modulus is given in Eq. (1):

$$\mathbf{E} = \frac{\mathbf{P}}{\mathbf{A}^{x}\varepsilon} \qquad \textbf{(1)}$$

where P represent the load measured during the elastic region through a load cell, A represent the cross-sectional area of the specimen, and ε represent the elastic strain.

Figure 1: Sample of Tensile test.

2.4. The Brinell hardness test

The Brinell hardness number is achieved by dividing the applied load by the indentation surface area. When the indentation is drawn, d1 and d2 are two diameters of the impression, were measured by a special microscope with a calibrated graticule, then the average values were calculated using Eq. (2) and for ASTM b-308, and shown in Fig. 2 [10].

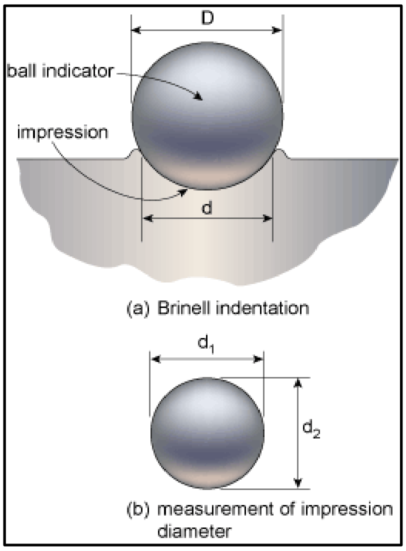


Figure 2: Sample of Brinell hardness Test [10].

$$\mathbf{BHN} = \frac{\mathbf{P}}{\frac{\pi \mathbf{D}}{2}[\mathbf{D}-\sqrt{\mathbf{D2}}-\mathbf{d2}]} \quad \mathbf{(2)}$$

where P represent the test load in kg, D represent ball diameter in mm, and d represent the average impression diameter of indentation in mm.

3. Results and discussion

X-ray diffractometer (XRD) is majorly utilized to investigate the composition of different materials. A range of 20º to 80º with a scan rate of 2ϴ/minute is used for scanning the samples. Fig.3 demonstrate the XRD pattern of the alloy reflecting the presence of aluminium and silicon that appear at 2ϴ = 38º, 45º, 66º and 78º for Aluminium and 2ϴ = 28º, 47º and 57º for silicon. These findings agree with those of Madlul et al. [11] and Md. Tanwir Alam et al. [12].

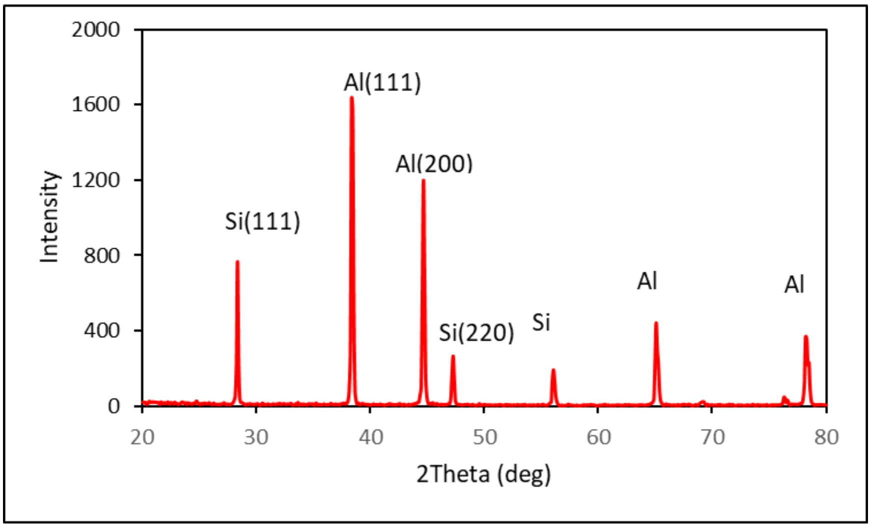


Figure 3: XRD pattern for Al-19.5wt%Si recycled alloy.

In Fig. 4, XRD pattern related to Al-Si /Cu alloy shows that the peak is small for Al-Si-1.5% wt% Cu alloy which shows the peaks of Al and Si and Al_2Cu. Copper is partially soluble in α – Al solid solution with a maximum solubility of 5.65 wt% at temperature of 550 °C. Alloys with Al from 1 to 4 wt% copper, Cu-rich intermetallic phase (Al_2Cu) typical form in the structure that agree with the chart of X-Ray of Yasir M. Abdulsahib [13].

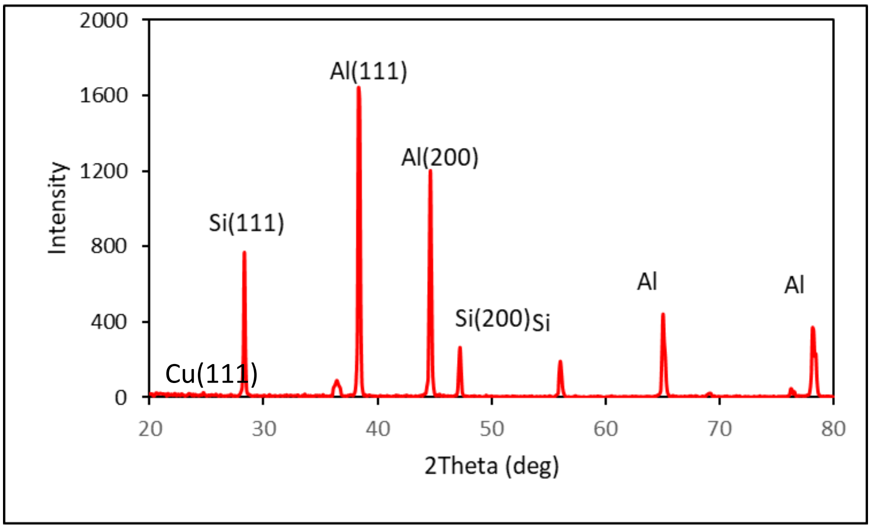
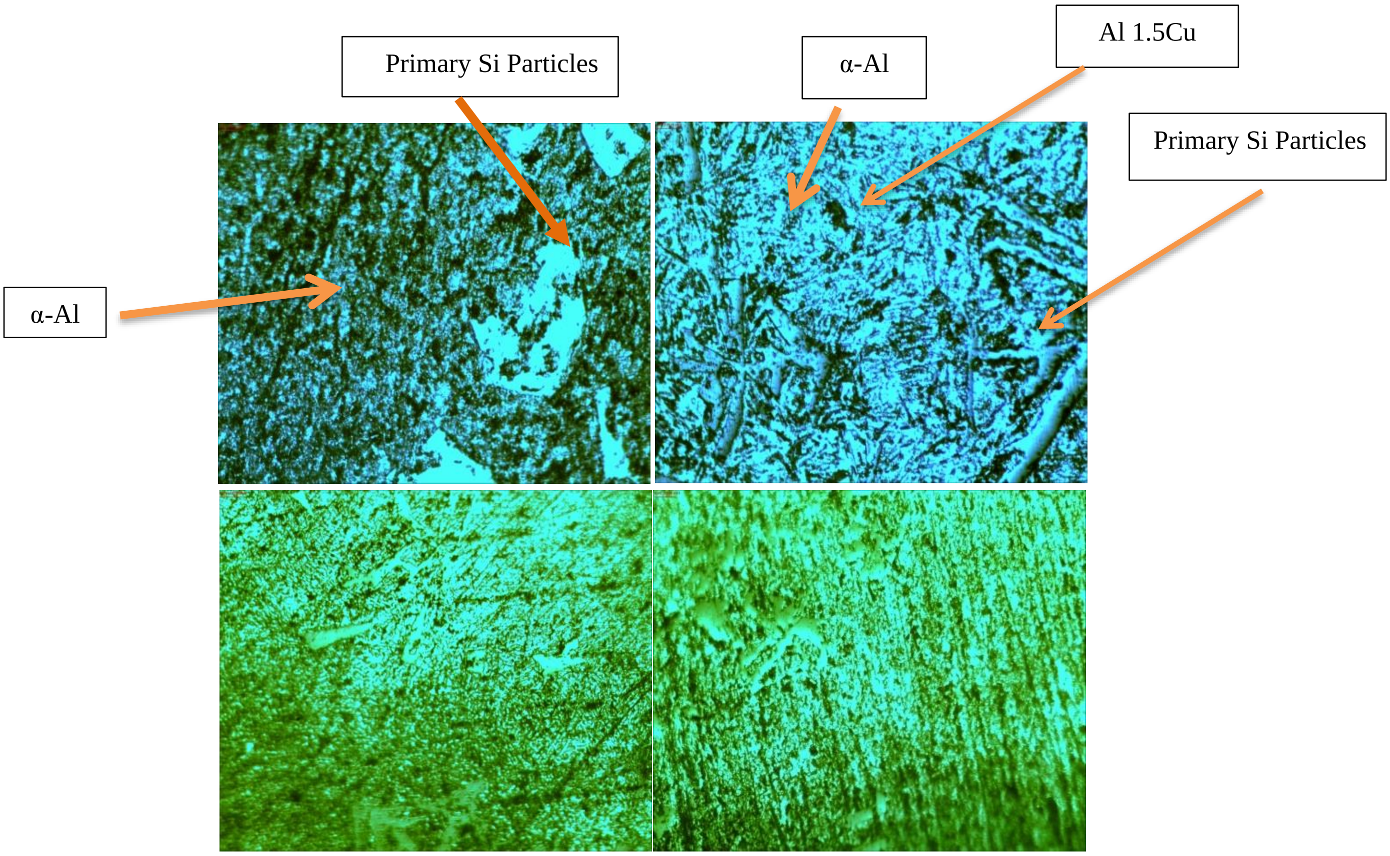


Figure 4: XRD pattern for Al-19.5wt%Si-1.5wt%Cu alloy.

Fig. 5(a) demonstrates the images taken with an optical microscope for the Al–Si alloys obtained using casting method of levitated melts for 20.5 wt. %. The images of alloy show anomalous finest-grain eutectic structure and also that Si wt. The percentage in the aluminium-silicon alloys can be classified into three main classes: Hypoeutectic (<12 wt. % Si), Eutectic (12-13 wt % Si), and Hypereutectic (14-25 wt. % Si) [7].



(a) Al-Si alloy **(b) Al-Si-Cu alloy**

Figure 5: As received microstructure.

Fig. 5(b) demonstrates the images of the alloy containing 1.5 wt% Cu. The presence of star-shaped Si elemental crystals is shown background eutectic structure to form Si 20.5 by weight; Copper is frequently added as a secondary element in alloying for excess. The strength of cast alloys, especially when heat treatment is applied. In Si alloys, copper is usually was added at 1.5% by weight, thus forming the metallic phase Al_2Cu.Significantly reduces the solid temperature and eutectic of the alloy. Therefore, copper swells Alloy hardening interval and facilitates porosity formation condition [6].

Tensile strength findings are shown in Fig.6 and the related Table 2. The tensile strength increases proportionally with increasing Si content. The highest UTS was 120MPa, for sample 3 of 22.5% Si content 22.5% Si), which is due to the dependence on the shape, size, as well as the distribution of particles enhance on the strength properties of the Al-Si alloy.

The results of adding copper at 1.5% wt. led to a significantly increasing in the tensile strength in comparison to the Al-Sialloy as shown in Fig.6. The values of the tensile strength were 103, 123, and 147 MPa for the samples 4, 5 and 6, respectively. The alloys mechanical properties rely on the size, shape, as well as the distribution of the eutectic silicon, α-Al grains/dendrites, and the presence of alloying element in case of Al-Si alloys. This agrees with the results of ZerenandKarakulak [7].

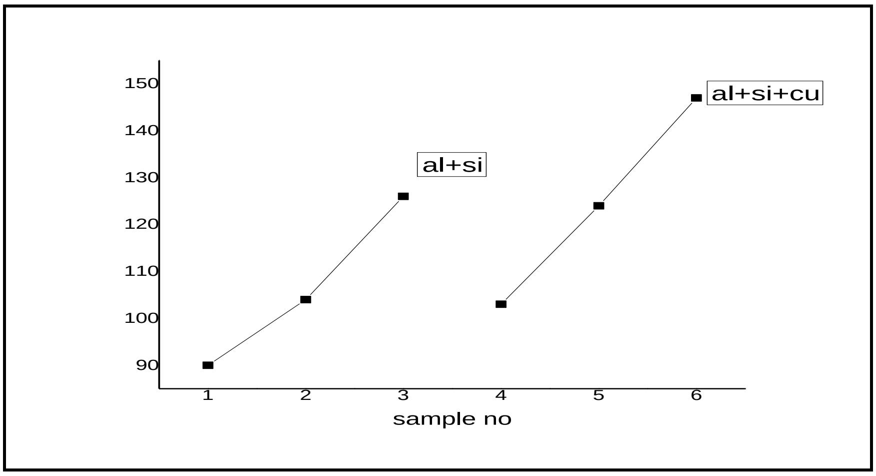


Figure 6: Curves are showing variation of Tensile Strength with sample no (Al19.5wt%Si, Al21wt%Si, Al 22.5wt% Si, Al18wt %Si+1.5wt% Cu, Al19.5wt%Si +1.5wt%Cu, Al21wt%Si +1.5wt% Cu).

Table 2: Tensile Strength [Al-Si, Al-Si-Cu] of alloys.

Specimen No.	**Al%**	**Si%**	**Cu%**	**Tensile Strength (MPa)**	**Strain**	**Elongation %**	**Young's modulus (GPa)**
1	80.5	19.5	_	90	0.045	4.5	3.14
2	79	21	_	104	0.052	5.2	3.29
3	77.5	22.5	_	120	0.056	5.6	3.38
4	80.5	18	1.5	103	0.07	7	2.42
5	79	19.5	1.5	123	0.075	7.5	2.51
6	77.5	21	1.5	147	0.079	7.9	2.63

The elongation results for all samples of aluminium-silicon alloys increased which explains the increased deposition hardening caused by the increase of silicon content in the aluminium alloys. Increasing the Cu content lead to increasing the amount of Cu-rich intermetallic phases, like block like particles Al_2Cu, which responsible for hardening the aluminium alloys. Therefore, the samples with more Cu content appeared high mechanical strength and low plasticity that appear in Fig.7.

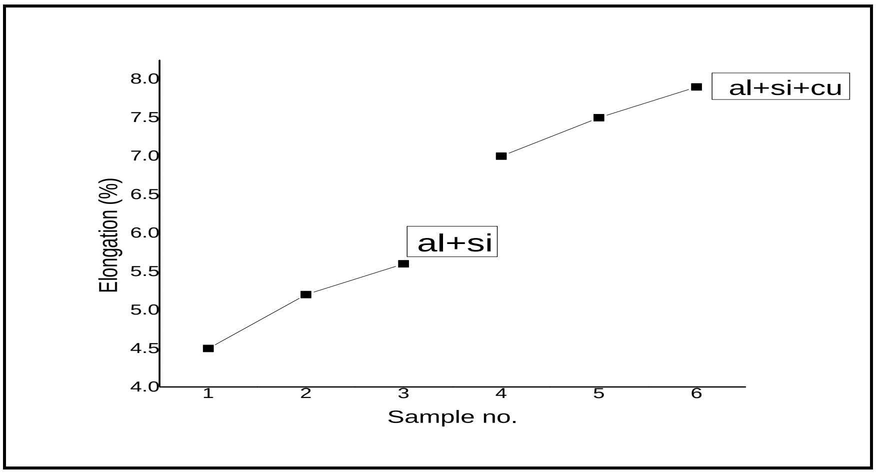


Figure 7: Curve showing variation of Elongation with sample no (Al19.5wt%Si, Al21wt%Si, Al22.5wt% Si, Al18wt %Si+1.5wt% Cu, Al19.5wt%Si +1.5wt%Cu, Al21wt%Si +1.5wt% Cu).

For Young Modulus increased for the Al-Si increased from (3.14-3.38) MPa compared with Al-Si – Cu that increased from (2.42-2.63) MPa in Fig.8 because copper as an alloying element increasing the hardness, strength, creep resistance, machinability and fatigue in an aluminium-copper alloy. Ductility and strength are depending on copper distribution in the alloy. Copper is found dissolved in the dendrite matrix or as aluminium-copper rich phases. Alloys with dissolved copper in the matrix appears the most increase of retains ductility and strength [2].

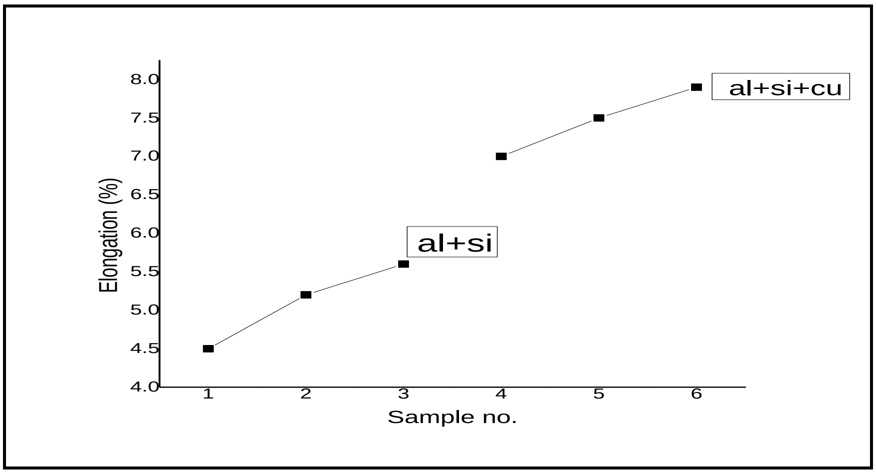


Figure 8: Curve showing variation of Young's Modulus with sample no (Al19.5wt%Si, Al21wt%Si, Al22.5wt% Si, Al18wt %Si+1.5wt% Cu, Al19.5wt%Si +1.5wt%Cu, Al21wt%Si +1.5wt% Cu).

The results of hardness are summarised in Table 3 and Fig.9. The hardness is increased proportionally with the increase of Si contents. The highest hardness value was 77HB, in sample 3 (Si content was 22.5% Si) and this may be due to the increment of silicon amount, which is hard precipitates that increased hardness of Al-Si alloy.

The addition of copper is at 1.5% wt. Also caused increased in values of hardness in 68, 77, and 90 HB in samples 4, 5, and 6, respectively. This increase was due to copper and silicon. The reason behind the increment of the hardness is linked with the creation of intermetallic compound phase Al2Cu [7].

Table 3: Hardness test outcome.

Specimen No.	**Al%**	**Si%**	**Cu%**	**Hardness (HB)**
1.	80.5	19.5	_	60
2.	79	21	_	67
3.	77.5	22.5	_	77
4.	80.5	18	1.5	68
5.	79	19.5	1.5	77
6.	77.5	21	1.5	90

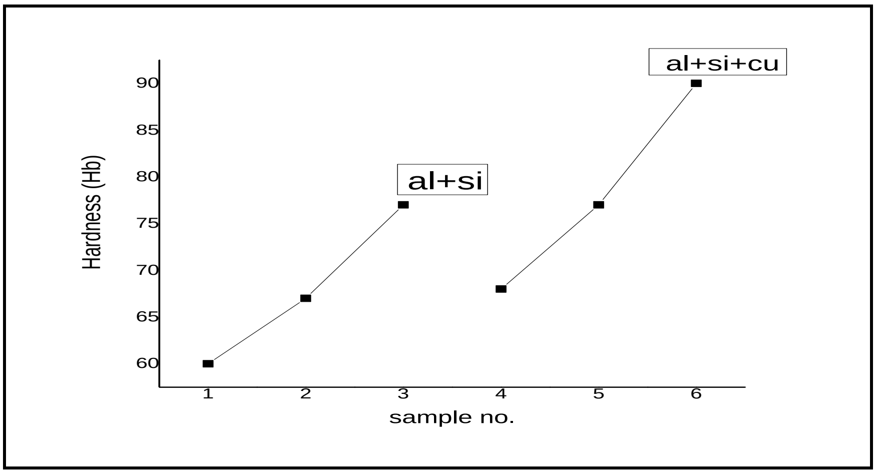


Figure 9: Curve showing variation of Hardness with sample no (Al19.5wt%Si, Al21wt%Si, Al22.5wt% Si, Al18wt %Si+1.5wt% Cu, Al19.5wt%Si +1.5wt%Cu, Al21wt%Si +1.5wt% Cu).

Conclusions

When increasing the silicon content, the ultimate tensile strength was increased. The value of the maximum ultimate tensile strength was 120 MPa in 22.5% of silicon content in aluminium alloy and it was value equal to 147 MPa when add copper 1.5% in Aluminium - silicon alloy. In the percentage 1.5wt% Cu content contributes to the formation of Al-Si phases, which improve mechanical properties at 1.5% wt% that the tensile strength range (103 - 147) MPa and Young Modulus increased from 2.42 to 2.63 MPa. Microstructure investigation revealed significant role of Cu even in early stages of solidification that appear at 1.5wt%.

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Conflict of interest

The authors declare that they have no conflict of interest.

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تأثير النحاس على الشد والصلادة لسبائك الالمنيوم_ سيليكون في تطبيق السيارات

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الخلاصة

في هذا البحث، تم استخدام النحاس بنسب وزنية مختلفة (0.2 – 2.5%) وتم اخذ افضل نسبه هي 1.5% من النحاس لتحضير نظام سبائكي ثلاثي مكون من الألمنيوم – سليكون بظروف تصلد مختلفة لغرض تحسين الخصائص الميكانيكية لسبائك الألمنيوم. تم تحضير قوالب من حديد الزهر للحصول على عينات اختبار الشد. تم تحضير السبائك باستخدام أفران غازية. تم أضافة المعدن المذاب الى قالب الحديد الزهر المسخن سلفا. تم أجراء الفحوصات التركيبية متمثلة باختبار حيود الأشعة السينية والمجهر البصري على السبائك المحضرة. الخصائص الميكانيكية للسبائك المحضرة تمت دراستها تحت تأثير ظروف تقسية مختلفة بعضها معامل حراريا والبعض الآخر غير معامل حراريا. أظهرت النتائج تحسنا في البنية المجهرية التركيبية فيما يتعلق بدقة جسيمات السليكون الأولية واليوتكتيكية، اضافة لتجانس التوزيع لهذه الجسيمات وانخفاض بالمسامية. كافة المعادن المتكونة خلال مرحلة التقسية تمت دراستها بواسطة المجهر البصري. أعلى قيمة مستحصلة لمتانة الشد كانت 120 ميكاباسكال في النموذج Al-22.5Si، والقيمة الأخرى كانت 147 ميكاباسكال في النموذج Al-21Si-1.5Cu. في حين كانت اعلى قيم لصلادة برينل 77 و 90 للنموذجين Al-22.5Si و Al-21Si-1.5Cu على التوالي.