INFLUENCE OF HEAT TREATMENT ON THE MECHANICAL PROPERTIES OF LM6 REINFORCED WITH 6WT.% COPPER

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Abstract - *In this experimental study, the effect of copper powder (Cu_p) addition and solution heat treatment (T6) on the hardness, and tensile strength of aluminium-silicon eutectic alloy (LM6) was investigated. In order to produce tensile test specimens, 6wt.% of Cu_p was added into molten LM6 using carbon dioxide sand casting with stirring technique. To enhance the effectiveness of copper, T6 was conducted at 490 ^{0}C for 6h, followed by quenching in warm water (60 ^{0}C), and ageing at 155 ^{0}C for 5h. Tensile and hardness tests were conducted on all non-heat-treated and heat-treated samples. The results showed that the mechanical properties of LM6 were enhanced by the addition of 6wt.% of Cu_p after T6 has applied. The obtained results showed that the hardness value increased by 20.7% when T6 was applied to the LM6 composite reinforced with 6wt.% Cu_p. The results also displayed that the tensile strength increased by 16.9% by adding 6wt.% Cu_p into LM6 followed by T6 application. The influence of copper contents and heat treatment on the mechanical properties of LM6 composite have been evaluated by two-way ANOVA using statistical software MINITAB 17. The statistical results revealed that interaction between the two factors, 6wt.%Cu and heat treatment, gave the optimal hardness and tensile properties. The hardness reached 53.84 HRB, and the tensile strength reached 152 MPa.*

Key Words: Tensile strength, Hardness, Stir casting, T6 heat treatment, LM6, Copper powder

1.INTRODUCTION

Aluminium-silicon eutectic alloy is considered one of the most important Al-Si alloys which contains11-13% Si, about 85.9% Al, and a small amount of other alloying elements and impurities. It has outstanding properties, such as high corrosion resistance and good fluidity, but only has medium strength. It is widely used for sand casting due to its cast-ability and fluidity. According to British standard 1490–1988, the code of aluminium-silicon eutectic alloy is LM6, [1] and it is vastly selected as a matrix in metal matrix composites [2][3][4].

The mechanical properties of Al-Si alloys are affected by the chemical composition, microstructure features, and precipitation hardening during heat treatment [5]. To enhance the mechanical properties of Al-Si alloys, some alloying elements could be added, such as magnesium, copper, and nickel. Copper has a relatively high solubility in Al [6]. Adding copper to aluminium alloys makes them more heat treatable. This allows the tensile strength and hardness of aluminium alloys to be improved through heat treatment [7]. The key requirement for alloy systems for responding to heat treatment is through reduction in the solid solubility of the alloying elements with reduced temperature. Therefore, copper addition with heat treatment have increased influence on the mechanical properties of the composite.

Some studies were concerned about the influence of adding copper with pure aluminium as reinforcement to enhance certain mechanical properties, including strength, hardness, and fatigue. Alshabatat and Al-qawabah [8] studied the effect of copper addition on the mechanical properties of pure aluminium by adding 4wt.% copper. The results showed that copper addition significantly refined the aluminium grain size, which resulted in improved strength, fatigue, and hardness. By adding 5% and 15 wt.% copper particulates into the aluminium matrix using a stir-cast technique, Madhusudan et al. [9] produced composite metallic materials (CMMs). The composites behaviour was also contrasted with similar composition alloys. The results showed that hardness increased with increasing copper content. In comparison with the alloy, composites dropped 13% in strength, and 15% in strain. As the reinforcement content increased, the strength increased then decreased. The explanation for the decrease in strength values could be due to agglomeration because of increased reinforcement content.

Copper addition might need support by other parameters such as heat treatment and vibration to influence the mechanical properties more. In this regard, Salleh and Omar (2015) [10] studied the effect of copper on the microstructure and mechanical properties of Al-6Si-xCu-0.3Mg (x= 3, 4, 5, and 6%) alloys using thixoforming process. Some samples were subjected to T6 heat treatment and compared with non-heat treated ones. The results revealed that hardness and tensile strength were increased with increasing copper content. Zeren and Karakulak (2009) [11] investigated the influence of Cu content and solution heat treatment on the hardness of Al–Si–Cu cast alloy. For this purpose, 2% and 5% of copper were added into Al-Si alloy using a green sand mould. The result indicated that by increasing copper content, the hardness was increased owing to precipitation hardening that occurred during the solution treatment process. The observed result also revealed that increasing the Cu content in the alloys increased the hardness even without applying heat treatment. However, hardness was remarkably increased after applying heat treatment on the alloys added with high copper content. Muhammad Sayuti et al. (2020) [12] applied 10 Hz vibration on the sand moulds during pouring and solidification of LM6 reinforced with a variety of copper contents to improve hardness and tensile strength. They found the tensile under static conditions better than under vibration conditions at all copper contents, while hardness improved by vibration gradually with increasing the copper contents.

In this experiment, aluminium eutectic silicon composites reinforced with 6wt.% of Cu_p were prepared using carbon dioxide sand casting mould with stirring technique. The produced specimens were subjected to solution heat treatment followed by artificial ageing process. This study aimed to identify the effects of copper addition and heat treatment on the mechanical properties of LM6 composites. Therefore, the hardness and tensile strength of LM6 composites were tested and the results were compared with un-reinforced alloy.

2. METHODOLOGY AND EXPERIMENTS

The methodology adopted to implement this experimental work includes the following steps: materials preparation, fabrication of sand moulds and casting of specimens, heat treatment application, mechanical tests procedure, and statistical analysis.

2.1 Materials Preparation

In this experimental work, Al-Si eutectic alloy was used as a matrix. The chemical composition of Al-Si eutectic alloy is listed in Table 1. Cup with particle size of 62 μm, supplied by CNPC Powder Group, Malaysia, was used as reinforcement material in the present investigation with composition as shown in Table 2. Aluminium metal matrix composites were prepared using CO_2 sand casting method to produce tensile test specimens according to ASTM B557M standard, as shown in Figure 1.

Table -1: Chemical composition of LM6 alloy by weight %, [12]

Element	Al	Si	Cu	Mg	Fe	Mn	Ni	Zn	Sn	Ti	Pb	other
Wt.%	85.95	12.0	0.1	0.1	0.6	0.5	0.1	0.1	0.05	0.2	0.1	0.2

Table -2: Chemical composition of copper powder by weight %

Element	Cu	Fe	Pb	S	Zn	Sn	HL
Wt%	99.4	0.023	0.029	0.003	0.006	0.003	0.32

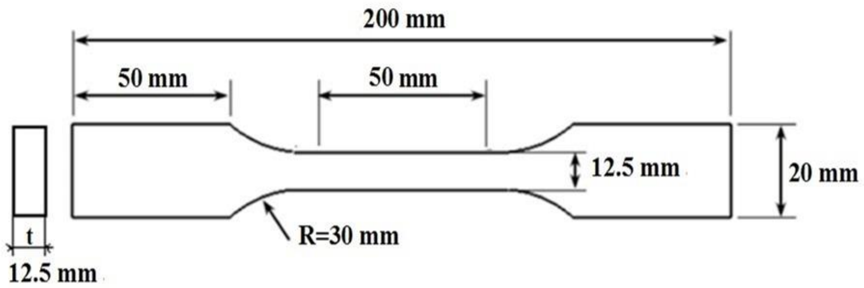

Fig -1: Tensile specimen, [13]

2.2 Sand Moulds Preparation

The casting moulds used in this work were prepared by mixing 20Kg sand with 800ml sodium silicate and 400ml water. The mixture was then poured and rammed in a prepared wooden frame containing patterns of tensile specimens. Finally, CO_2 was injected to further harden the sand , thus obtaining the sand mould, as shown in Figure 2.

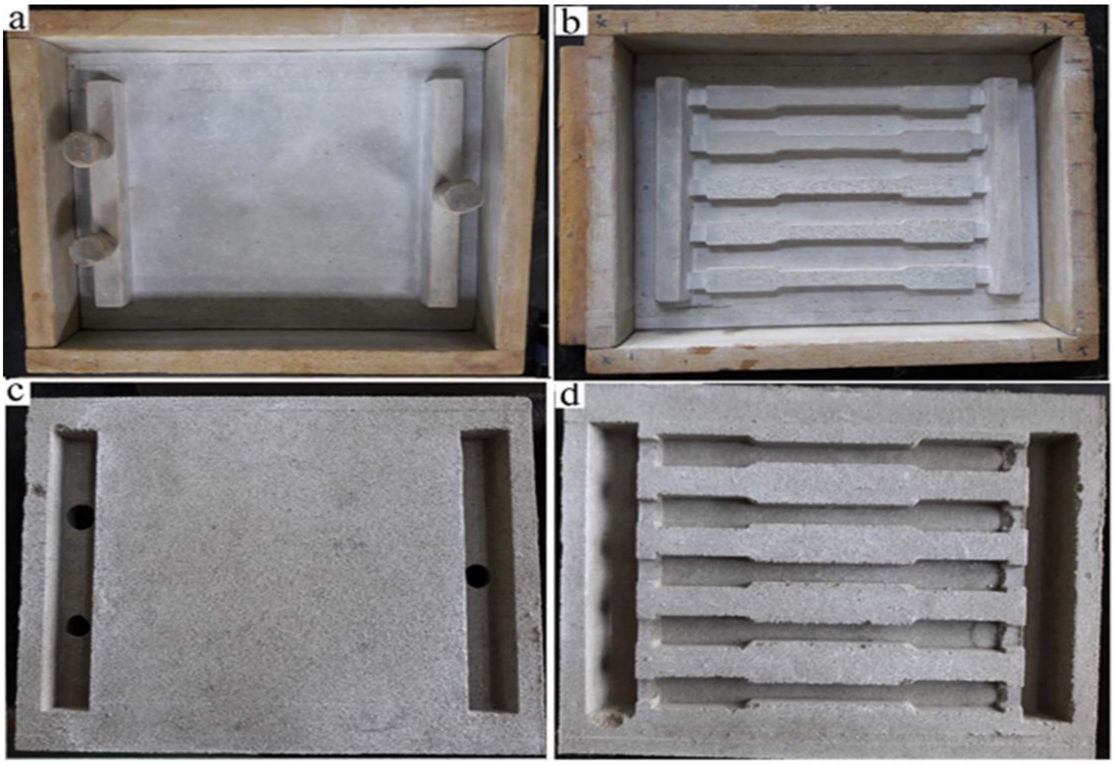

Fig -2: Wooden pattern; a) Cap consisting gate and risers, b) Drag consisting 5 patterns of dog-bone shapes. Sand mould; c) The upper half Mould, d) The lower half mould

2.3 Melting and Pouring

In the induction furnace, 3.6 kg of LM6 was melted at about 700±5 ^{0}C. The molten metal was poured into the moulds. The Cu_p was weighed at 406 g and preheated at 200 ^{0}C before being added into the molten metal. The mixture was then stirred for 2 minutes at 200 rpm. The molten metal has poured into the moulds then left to solidify and cool. Next, the sand mould was broken to eject the castings. The castings were then cleaned using a grinding machine.

2.4 Heat Treatment

After the specimens were produced, half of them were subjected to solution heat treatment (T6) to study the effect of solutions treatment and aging hardening on the mechanical properties of the as-cast LM6 and LM6 composite reinforced with Cup. The aim of the conducted heat treatment was to precipitate copper particulates in the grain matrix instead of concentrated in grain boundaries, and to obtain a more homogenous distribution for the inter-metallic phase. Copper is one of the few elements that have relatively high solubility in Al. The maximum solubility of copper in aluminium is 5.65 wt.% at 548 ^{0}C [14]. Solution heat treatment was carried out in a muffle furnace at 490±2 ^{0}C for 6 hours followed by quenching in warm water (60±2 ^{0}C), immediate ageing at 155±2 ^{0}C for 5 hours, and lastly air cooled. After that, mechanical tensile and hardness tests were conducted on all specimens.

2.5 Mechanical Properties

Mechanical properties of different copper content composites were investigated in both heat-treated and non-heat treated conditions. The specimens were subjected to mechanical tests include; tensile test and hardness test. These tests were conducted on all samples of Al-Si composites reinforced with different copper contents, and on the base alloy LM6 heat treated and non-heat treated.

2.5.1 Tensile test

By using universal testing machine, the tensile properties for fabricated specimens were tested. Tensile tests were performed at a 1mm / min crosshead speed under the capacity of 10 Tons. The applied load and responded elongation data were collected by the software attached to the testing machine for further analysis. The tensile test was performed for tension testing of cast aluminum alloys according to ASTM B577M.

2.5.2 Hardness test

Rockwell hardness test was conducted on each specimen using a hardness testing machine. The test scale was set at HRB, meaning 100 kgf. Ten hardness readings were taken at random for each sample. Rockwell hardness number was gained by calculating the average amount of obtained data. The Rockwell hardness test was conducted according to ASTM E183.

3. RESULTS AND DISCUSSION

This section presents the results from laboratory experiments through the mechanical tests which represented by the hardness test and tensile test. Figures 3, and 4 show the tensile strength and hardness test results of as-cast LM6 alloy and LM6 reinforced with 6wt.% Cu_p under solution heat treatment condition. Figure 3 represents curves obtained from the tensile test machine, which represented the relation between the applied loads and extension of specimens until failure. These curves show that the maximum load that the LM6 composites reinforced with copper heat-treated were able to withstood 28,800N before fracture, while the as-cast LM6 failed at 21,500N.

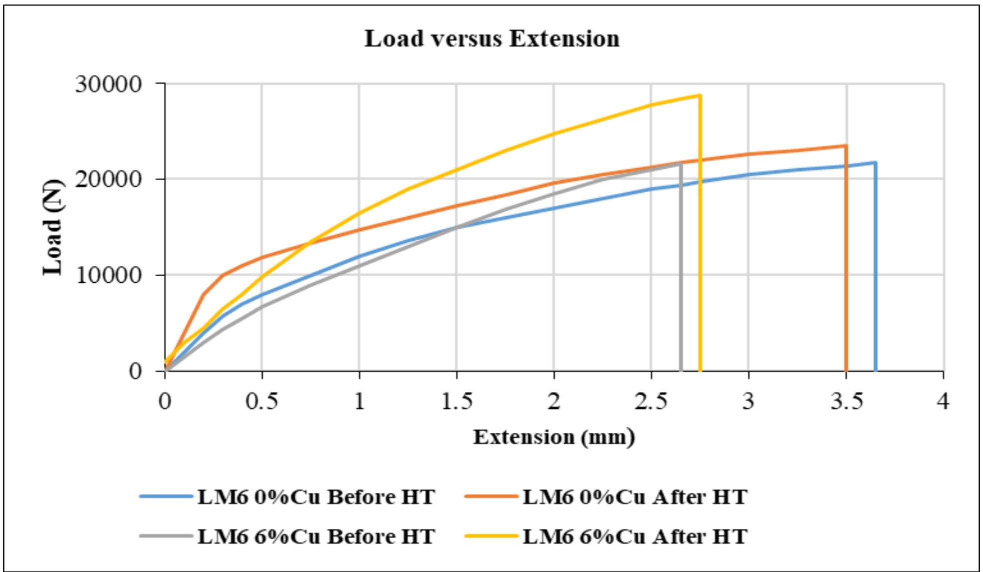

Fig -3: Extension and failure the specimens

Figure 4 illustrates the values of mechanical properties obtained from both tensile and hardness tests. These values display different effects of 6wt% Cu_p addition and T6 heat treatment application on the mechanical properties LM6.

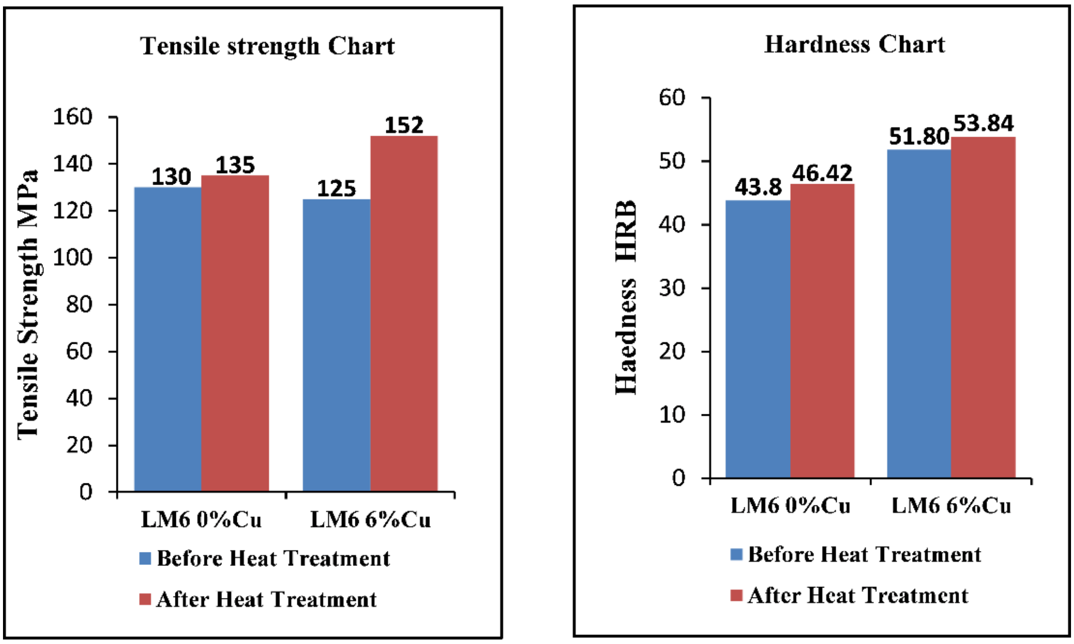

Fig -4: Tensile strength and hardness values of LM6

Figure 4 indicates that adding copper into LM6 without applying heat treatment reduces tensile strength but increases hardness. The tensile strength and hardness changed by -3.8% and +18.2%, respectively. Hardness results confirmed the findings of [15] that obtained 18% increased hardness when 6% copper were added as an alloying element into LM6 without applying heat treatment. On the other hand, applying heat treatment on the as-cast LM6 slightly enhanced tensile strength and hardness. The values of tensile strength and hardness were increased by 3.8% and 5.98%, respectively.

In contrast, improved mechanical properties were obtained from heat treatment application on LM6 composite reinforced with 6wt.% Cup. Tensile strength and hardness increased by 21.6% and 3.94%, respectively. In case of composites, tensile strength was more responsive to heat treatment because copper makes the aluminium silicon alloy more heat treatable. From the above figures, it can be observed that adding 6wt.% of copper powder followed by heat treatment improved the mechanical properties of LM6. The tensile strength and the hardness of LM6 increased by 16.9%, and 22.9%, respectively.

Statistical Analysis

The purpose of the statistical analysis of variance is to investigate which input factors have significantly affected the output responses. The method adopted for analysis is Analysis of Variance (ANOVA) using Minitab software 17. The analysis carried out for the level of confidence is 95% (α= 0.05). Two-way ANOVA was used to compare the main effects and interaction effects of adding 6wt.% of copper and applying heat treatment on the hardness and tensile properties.

Table -3: ANOVA of Tensile Strength

Source	DF	Seq. SS	Contribution	Adj. SS	Adj. MS	F-Value	P-Value
T6 Treatment	1	913.8	34.58%	1065.8	1065.76	2.25	0.374
6wt.%Cu	1	223.5	8.46%	170.3	170.34	0.36	0.656
T6 Treatment*6wt.%Cu	1	473.1	17.90%	473.1	473.10	5.96	0.030
Error	13	1032.2	39.06%	1032.2	79.40		
Total	16	2642.5	100.00%				

Table -4: Means of Tensile Strength

Term		Fitted Mean
T6 Treatment	HT	143.640
	No HT	127.453
6wt.%Cu	0%Cu	132.311

	6%Cu	138.782
T6 Treatment *6wt.%Cu	HT 0%Cu	135.012
	HT 6%Cu	152.268
	No HT 0%Cu	129.610
	No HT 6%Cu	125.297

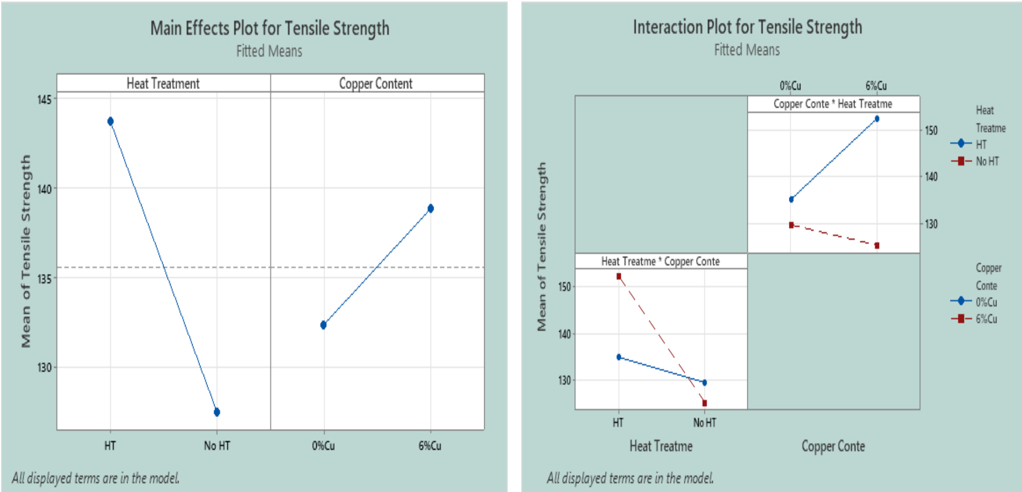

Fig -5: Factorial Plots for Tensile Strength (a) Main effects, (b)Interaction

ANOVA result revealed that the main effects are not significant either the T6 treatment factor or the 6wt.%Cu factor. While interaction is significant that means the effect of copper on the tensile strength depends on the applying heat treatment. The maximum tensile strength was recorded at the heat-treated 6wt.%Cu which reached to 152.268MPa.

Table -5: ANOVA of Hardness

Source	DF	Seq. SS	Contribution	Adj. SS	Adj. MS	F-Value	P-Value
T6 Treatment	1	52.44	5.13%	22.441	52.441	62.36	0.080
6wt.%Cu	1	594.44	58.16%	594.441	594.441	706.83	0.024
T6 Treatment*6wt.%Cu	1	0.84	0.08%	00.841	0.841	0.08	0.778
Error	36	374.27	36.62%	374.268	10.396		
Total	39	1021.99	100.00%				

Table -6: Means of Hardness

Term		Fitted Mean
T6 Treatment	HT	50.13
	No HT	47.84
6wt.%Cu	0%Cu	45.13
	6%Cu	52.84
T6 Treatment *6wt.%Cu	HT 0%Cu	46.42
	HT 6%Cu	53.84
	No HT 0%Cu	43.84
	No HT 6%Cu	51.84

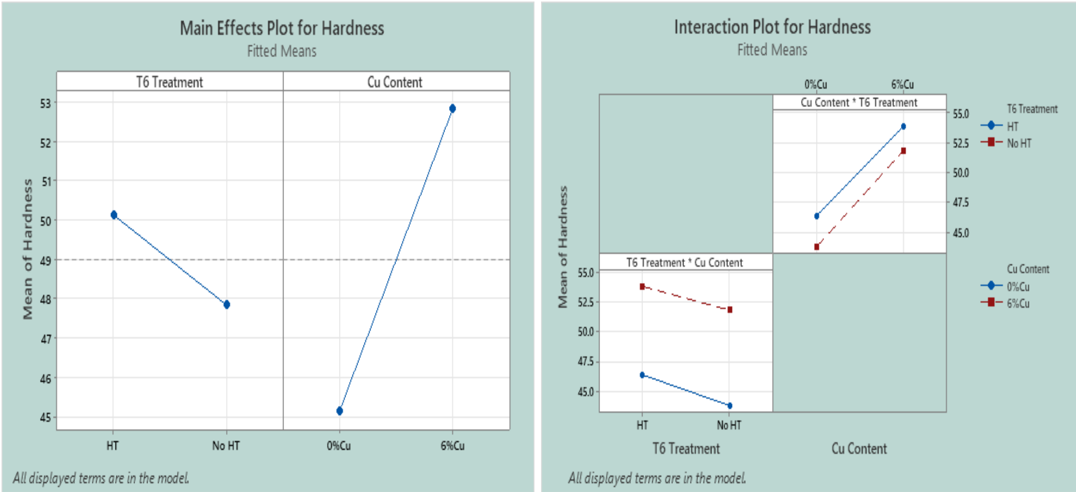

Fig -6: Factorial Plots for Hardness (a) Main effects, (b)Interaction

ANOVA result revealed that the main factors which represent applying the T6 treatment and adding 6wt.% of copper have a significant effect on the hardness. While the interaction between the two factors did not has a significant effect on the hardness that means the effect of copper on the hardness does not depend on the application of heat treatment. The maximum hardness recorded at the heat-treated 6wt.%Cu was 53.84HRB which has not much different from the hardness of non-heat-treated 6wt.%Cu that was 52.84HRB.

4. CONCLUSIONS

From this experimental work, the effect of 6wt.% copper addition followed by heat treatment on aluminium-silicon alloy LM6 was carried out, and the conclusion is listed below:

1. When adding the 6wt.% of copper into the LM6 alloy without applying heat treatment, it has noted that there was an increase in the hardness and a little decrease in the tensile strength. Before applying heat treatment, the hardness has changed from 43.80 HRB to 53.84 HRB. On the other hand, the tensile strength has reduced from 130 MPa to 125 MPa.

2. By applying heat treatment on the LM6 as-cast, the mechanical properties were little affected by heat treatment. Adding copper makes the alloy more heat treatable, which in turn mechanical properties enhanced of LM6 composite. Results displayed that adding the 6wt.% of copper to LM6 followed with heat treatment enhanced the hardness and tensile strength. The hardness reached 53.84 HRB and the tensile strength was 152 MPa.

2. The results of the ANOVA indicated that interaction of T6 heat treatment and 6wt.% of a copper factor was more significantly affected on the hardness and tensile strength than separate main factors. At the combination, the hardness was increased by 22.92% and the tensile strength was increased by 16.92%.

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