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The effect of SiC and Cu weight fraction on the characteristics of Al 6061 composite

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Abstract

Composites are made of multiple materials that are combined to create new materials with better properties. The purpose of this study is to determine the effects of SiC and Cu weight fractions on hardness, tensile strength, microstructure and Scanning Electron Microscopy (SEM) of Al 6061 composites. The manufacturing method used for creating composites in this study was stir-casting. Each composite component and its functions are as follows: aluminum 6061 as the matrix, silicon carbide (SiC) as a reinforcement, and copper (Cu) functions to improve the characteristics of the composite. Variations were made by weight composition of SiC (1%, 3%, and 5%) and Cu (5% and 8%). Observations were carried out on their hardness, tensile strength, and microstructure; each of which using Rockwell hardness test B (ASTM E 18 standard), a multipurpose tensile testing machine, and SEM, respectively. The results of this study indicate that the addition of SiC and Cu affects the aluminum 6061 characteristics. The best result of the hardness test was shown at Al6061 + 5% SiC + 8% Cu (109.37 HRB). The best Ultimate Tensile Strength (UTS) test result was shown at Al6061 + 5% SiC + 8% Cu (211.8 MPa) with elongation number of 2.8%. There has been a significant reduction in grain size under micro observations that occurred very well but was still relatively not uniform. The result of several SEM observation phases formed by the combination of Al6061 and the addition of 5% SiC + 5% Cu and 8% Cu showed an observation phase of AlZnMgCu, α (Al) + AlZnMgCu, Al_2Cu, and Al_2CuMg.

Keywords:
Metal Matrix Composites, stir casting, Al6061, SiC, Cu.

1 Introduction

Technological advances require materials that have good mechanical properties and are inexpensive and lightweight. Thus, the highest quality of work can be achieved. One way to meet these criteria is to combine different materials, known as composites, by mechanically joining them together [1].

One of the commonly used metals for the implementation of Metal Matrix Composite (MMC) is aluminum. Aluminum Matrix Composite (AMC) has been widely applied in daily life [2]. Other elements are added to improve the properties of the Al6061 composite. These elements added to Al6061 are SiC and Cu. Silicon carbide (SiC) can improve the overall strength and hardness of the composite [3] [4], protect against corrosion [5] and also increase compressive strength [4]. The grain size of the SiC reportedly resulted in a different Young's modulus and hardness of the Al composite [6]. The addition of both SiC and Cu to the Al6061 composite improves the properties of the Al6061 itself [7].

According to Lal et al. (2022) [8], the addition of 15% silicon carbide (SiC) is related to tensile strength by 31% and hardness by 32% compared to normal casting of Al/SiC composites. Rana et al. (2012) [9] found that the addition of copper, with or without heat treatment, had the greatest impact on the strength and hardness of aluminum composite castings at ambient and service temperatures. Cu also helps improve casting density results for Al/Cu/Si alloys. The Al/15Cu/10SiC sample shows the highest relative density of 97% and the Al/45Cu/20SiC shows the lowest relative density of 90% [10]. The research team also conducted previous research on a similar topic and found that adding 8% Mg could achieve a maximum hardness of 87.67 HRB. In contrast, an ultimate tensile strength of 174.26 MPa was achieved with the addition of 5% Mg [11]. Further investigation revealed an ultimate tensile strength of 196.36 MPa and a hardness of 66 HRF (Rockwell Hardness Scale F) for a composition of 10% SiC [7].

The previous study observed that the hardness value increases with the addition of weight fraction of SiC [12]. Additionally, adding Cu can also increase the hardness value [13]. Therefore, the weight fraction can be used as a parameter in further studies to determine an optimum hardness value and tensile strength. The aim of this study is to determine the effect of weight fractions of SiC and Cu on the hardness, tensile strength, microstructure and SEM of Al 6061 composite.

2 Research method

The method used in this study was stir casting. Stir casting is a typical process using pure metallic material, usually aluminum, and reinforcement. Liquid pure metal dissolved and stirred in a whirlpool. Then the vortex gradually intensified. A schematic representation of how stirred casting works is shown in Fig. 1. The hardness test was conducted with reference to the ASTM-E18 standard, and the ASTM-E8 standard conducted the tensile test.

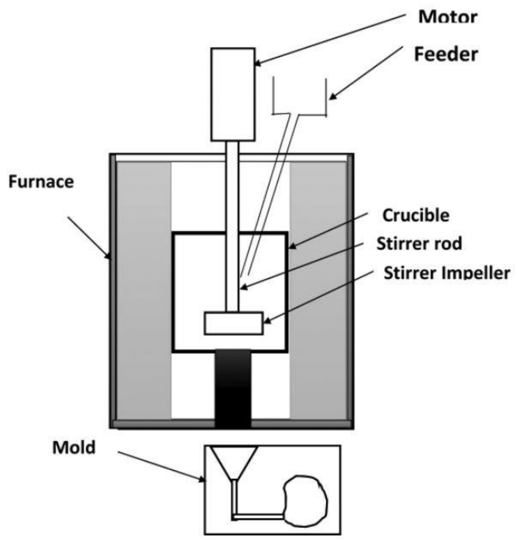


Fig. 1. Schematic of stir casting setup [14]

2.1 Material

Aluminum 6061 is used as a matrix, silicon carbide (SiC) as a reinforcement, and copper (Cu) functions to improve the properties of the Al6061 composite. The tensile test specimen is shown in Fig. 2. Fig. 2 shows dimensions of the specimens to be used should be adjusted to table 1 shown.

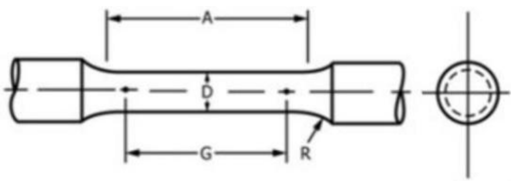


Fig. 2. Dimension of tensile strength specimen ASTM E8.

Table 1. Dimensions of tensile test specimen

Numbers Description	Dimensions		
	Plate-Type,40mm	Sheet-Type,12.5mm	6-8 mm
G-Gauge length	200.0 ± 0.2	50.0 ± 0.1	25.0 ± 0.1
R-Radius	25	12.5	6
L-Overall length	450	200	100
A-Length of reduced section	225	57	32

2.2 Sample preparation

The first step in this study is measuring the weight of aluminum 6061, then add the weight fraction of SiC and Cu. These additional masses are SiC (1%, 3%, 5%); this variation is roughly the same as [3]. The addition of Cu (5% and 8%) was chosen to increase the wettability. Previous research improves the mechanical properties of aluminum composites by 2% [13]. Therefore, in this study, we increased the Cu content. In the next step, the crucibles should be coated with mortar. Furthermore, the melting furnace must be preheated to lose water content before reaching the required temperature of 800°C for the melting process. When the 6061 aluminum melts, Cu was added, and then followed by SiC after both materials melted. After adding SiC, a melting process is performed by holding the same temperature for 30 minutes. Lower the blender to the bottom of the crucible by flowing argon gas for 45-60 seconds, then removing the blender from the pouring furnace. Mix the melt for 30 seconds at 400 rpm, then raise the handlebars. After that, throw the slag into the cast iron. Heat the mold to 200°C with a heating burner. Spray the top of the cast iron with argon gas, then pour the alloy into the mold. When the alloy has solidified, open the mold and the sample is ready for testing.

2.3 Hardness test

The results of this test are provided with hardness test numbers with weight fractions of SiC (1%, 3%, 5%) and copper (5% and 8%). The TH120 hardness tester is used to perform this test. Figure 3 shows three samples after testing.

Fig. 3.Indentation marks on specimens after being hardness tested

2.4 Tensile strength

Tensile strength test results with weight fractions of SiC (1%, 3%, 5%) and copper (5% and 8%) will be provided. The Zwick/Roell Z100 tool is used to perform this test

2.5 Micro observation

The Micro Observation test results will be provided with figures of micro test with weight fractions of SiC (1%, 3%, 5%) and copper (5% and 8%). The Microscope Olympus BX41M is utilized to conduct this test.

2.6 Scanning Electron Microscopy Observation

The *SEM* test results will be provided with figures of SEM with weight fractions of aluminum 6061 + 5% SiC + 5% Cu and aluminum 6061 + 5% SiC + 8% Cu. The tool equipment used for this test is the SEM (scanning electron microscope) G2 Phenom Pro.

3 Result and discussion

3.1 Hardness test

The hardness test of composite material was conducted to determine the effect of weight fractions of SiC and Cu on the hardness of the Al6061 composite. The results obtained through the hardness tests are shown in Fig. 4.

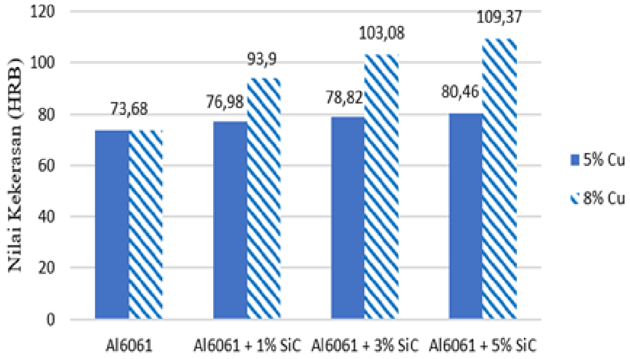


Fig. 4. Results of hardness tests

It is shown in Figure 4 that additions of SiC (1%, 3%, 5%) and copper (5% and 8%) weight fractions affect the hardness value of the Al6061 composite. A pure Al6061 would have a hardness value of 73.68 HRB. With the addition of SiC and Cu, the lowest hardness value obtained from the composite with the addition of 1% SiC on 5% Cu and 8% Cu are 76.98 HRB and 93.9 HRB, respectively. Meanwhile, the maximum hardness value of the composite with the addition of 5% SiC on 5% Cu and 8% Cu, respectively, is 80.46 HRB and 109.37 HRB. From Agnihotri and Dagar (2017) [1], during the preheating, SiC undergoes an oxidation process and creates a silicon dioxide (SiO_2) layer. This SiO_2 layer maximizes the work of SiC to improve the hardness of the Al6061 composite. Therefore, the higher the percentage amount of SiC in Al6061, the higher the hardness value. These results also are supported by a study done by Tekmen and Cocen (2003) [15]. Adding SiC particles could improve the hardness of Aluminum Metal Matrix Composite (AMMC) material.

Increasing the weight fraction affects the hardness test results. Fig. 4 shows that adding Cu also affects the hardness value. The addition of 8% Cu shows a greater increase in hardness value than the addition of 5% Cu. With the addition of copper, the hardness value of aluminum silicon (Al-Si) alloy will increase with the amount of copper. The greater the amount of copper added to the alloy, the greater the hardness value [7].

3.2 Ultimate Tensile Strength

Tensile testing is performed to determine the strength of a material under tensile force. In the test, the specimen is stretched until it tears. Thus, the tensile strength of the material could be analyzed. The results of the effect of SiC and Cu on the composite are shown in Fig. 5.

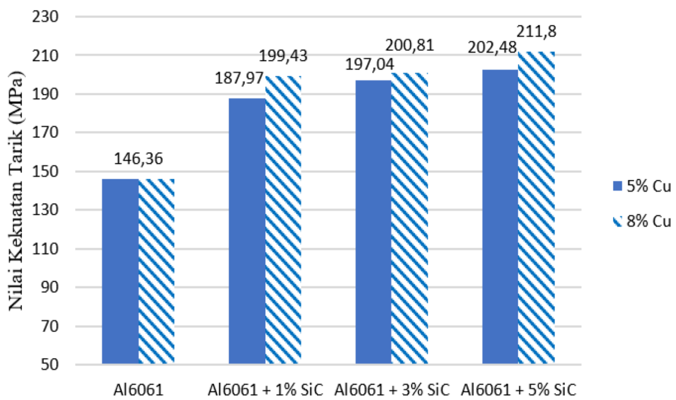


Fig. 5. Tensile strength results

It is shown in Fig. 5 that the addition of SiC (1%, 3%, 5%) and copper (5% and 8%) weight fractions affect the ultimate tensile strength of the Al6061 composite. Al6061 would have an ultimate tensile strength of 146.36 MPa. With the addition of SiC and Cu, the lowest tensile strength obtained from the composite with the addition of 1% SiC on 5% Cu and 8% Cu are 187.97 MPa and 199.425 MPa, respectively. Meanwhile, the ultimate tensile strength of the composite with the addition of 5% SiC on 5% Cu and 8% Cu, respectively, are 202.48 MPa and 211.8 MPa. Therefore, the higher the percentage amount of SiC in Al6061, the higher the tensile strength value. These results are also supported by a study by Adisetiaji & Sulardjaka [16], where the addition of SiC particles could increase the ultimate tensile strength.

Fig. 5 shows the effect of adding 5% and 8% Cu on the UTS of Al6061 material. An increase in the weight fraction affects the results of the tensile test. The higher percentage of Cu in Al6061 affects the ultimate tensile strength. Adding 8% Cu gives a greater increase in tensile strength value than adding 5% Cu. From the results shown in Figure 5, adding 5% Cu to the Al6061 composite improves the tensile strength by 38.34%, higher than the tensile strength of pure Al6061. Adding 8% Cu to the Al6061 composite improves the tensile strength by 44.71%, higher than the tensile strength of pure Al6061. The addition of Cu to the aluminum-silicon (Al-Si) alloy improves the tensile strength with the percentage of Cu in the alloy [15].

3.3 Elongation

The elongation value is the change in length of a specimen before it breaks after experiencing tensile force. In the test, the specimen is stretched until it tears. Therefore, the tensile resistance of the material could be analyzed. After the elongation test, the effect of SiC and Cu on the composite is shown in Fig. 6.

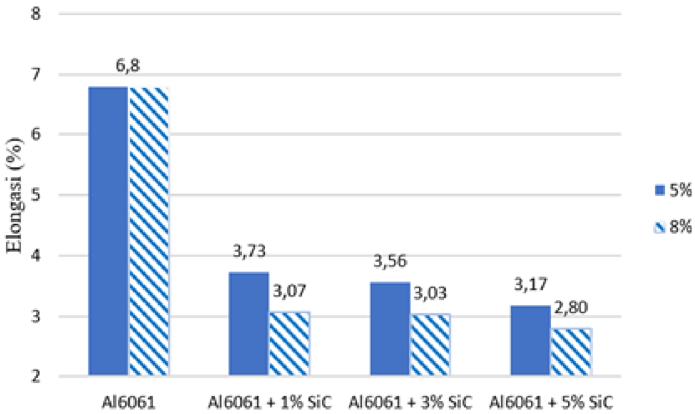


Fig. 6. Elongation test results

Fig. 6 shows the addition of SiC (1%, 3%, 5%) and copper (5% and 8%) weight fractions affect the elongation value of the Al6061 composite. Al6061 would have an elongation value of 6.8%. With the addition of SiC and Cu, the highest elongation value obtained from the composite with the addition of 1% SiC on 5% Cu and 8% Cu are 3.733% and 3.067%, respectively. Meanwhile, the lowest elongation value of the composite with the addition of 5% SiC on 5% Cu and 8% Cu, respectively, is 3.167% and 2.8%. Elongation is closely related to the ductility of a material. The lower the elongation value, the lower the ductility of that specimen. The addition of SiC lowers the ductility of the composite [17]. The higher the percentage amount of SiC in Al6061 composite, the lower the elongation.

Fig. 5 shows the effect of adding 5% and 8% Cu on the UTS of Al6061 material. An increase in the percentage amount of Cu affects the decrease in the strain value. The addition of Cu increases the tensile strength. Increasing the tensile strength of a specimen means a decrease in ductility, which also means a lower strain value. Therefore, the higher the percentage amount of Cu, the lower the strain value in the Al6061 composite.

3.4 Microstructure analysis

Microstructural analysis can show the mechanical properties of 6061 aluminum composites with the addition of SiC and copper Cu. Microstructure analysis uses an optical microscope with 200× magnification of the particles. Therefore, this observation can be used as evidence to improve the properties of a composite by showing the main phase element, porosity and other phase elements.

Fig. 7 shows the microstructure of pure aluminum 6061 after it was melted and frozen. It does not show a sign of being dendritic. Dendritic grains were not formed much on the aluminum 6061 because of the quick solidification effect, that most of the metal underwent a formation of large grains.

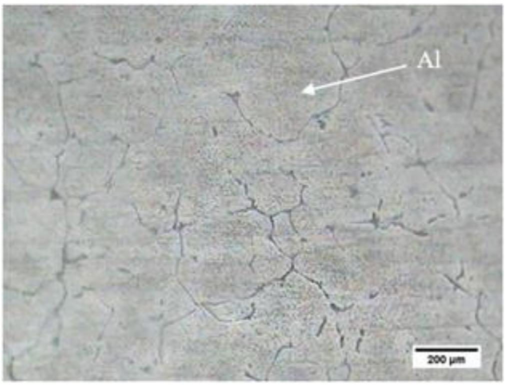
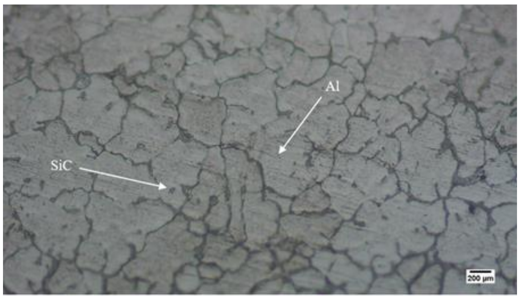
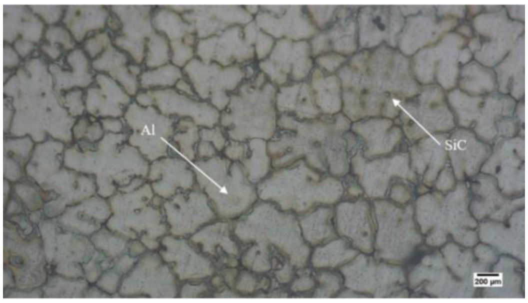


Fig. 7. Microstructure of Al6061

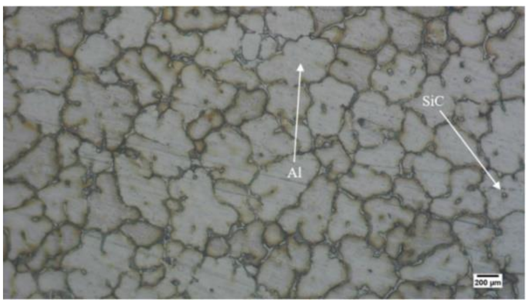
Fig. 8 and 9 show the microstructure analysis results on adding SiC and Cu. Columnar grain and cracking increased with increasing amount of SiC and Cu.



(a)



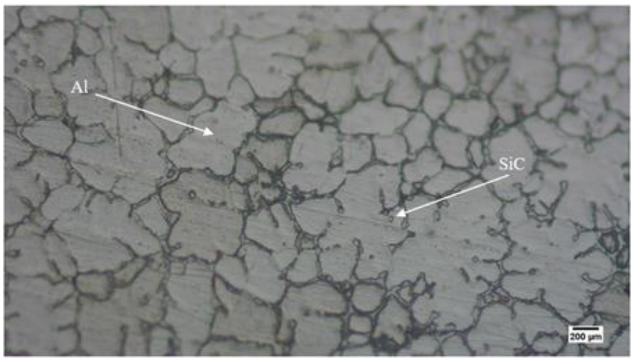
(b)



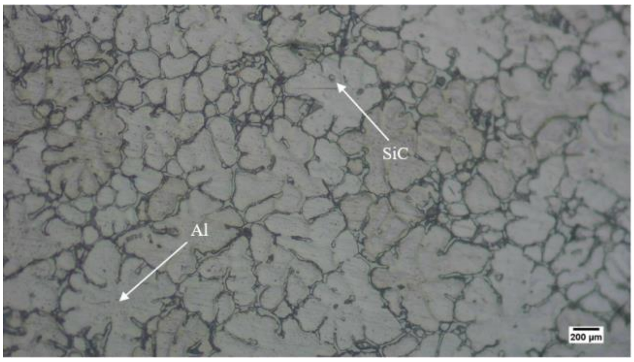
(c)

Fig. 8. Microstructure of Al6061 with the addition of 5% Cu. (a) 1% SiC + 5% Cu, (b) 3% SiC + 5% Cu, and (c) 5% SiC + 5% Cu

The microstructure, with the addition of 5% Cu and (1%, 3% and 5%) SiC, shows that the smallest grains formed after cracking. Grain cracks are created by the addition of SiC and Cu and occur with every addition change. Meanwhile, adding (1%, 3% and 5%) SiC and 8% Cu formed smaller and more uniform grains than adding 5% Cu. The addition of Cu shows a decrease in grain size, which affects the mechanical properties [18]. The smaller the grain, the denser the grain structure and the more complex a dislocation can occur. So the harder the material will be [16]. The result corresponds to the hardness value which increases as the tensile strength increases as the addition of Cu increases.



(a)\



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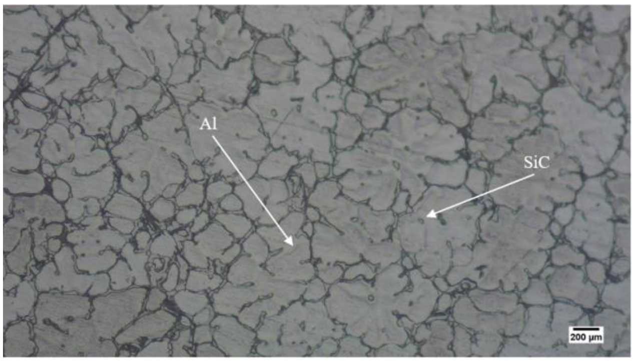

(c)

Fig. 9. Microstructure of Al6061 with the addition of 8% Cu. (a) 1% SiC + 8% Cu, (b) 3% SiC + 8% Cu, and (c) 5% SiC + 8% Cu

The formation of columnar grains and cracking increased as the amount of SiC and copper (Cu) increased. The microstructure with 5% addition of Cu and (1%, 3% and 5%) SiC shows that smaller grains were formed after cracking. Grain cracks are caused by the addition of SiC and copper (Cu) and occur with every variation of addition. Meanwhile, the addition of (1%, 3%, and 5%) SiC and 8% Cu formed smaller and more uniform grains than the addition of 5% Cu. The addition of copper (Cu) shows a decrease in grain size, which affects the mechanical properties [10]. The smaller the grain, the denser the grain structure and the more dislocation can occur. So the harder the material will be [16]. The result corresponds to the hardness value which increases as the tensile strength increases as the addition of copper (Cu) increases.

3.5 SEM analysis

The scanning electron microscopy (SEM) analysis aims to determine the phases on the aluminum 6061 composite sample. This test is applied to two different samples: the aluminum 6061 composites with the addition of 5% SiC + 5% Cu and 5% SiC + 8% Cu. These samples were chosen from their hardness value and tensile strength. Fig. 10 and 11 show the SEM observation.

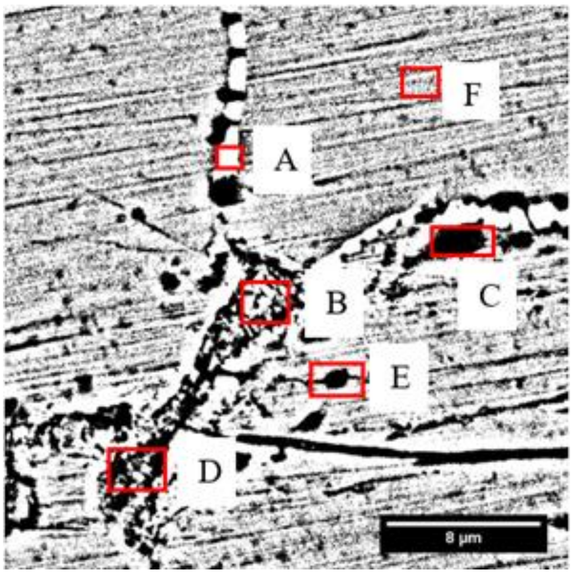

Fig. 10. SEM observation on aluminum 6061 + 5% SiC + 5% Cu alloy.

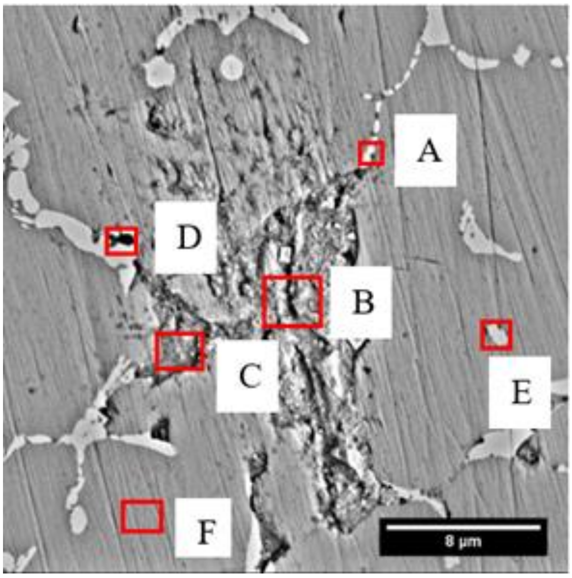

Fig. 11. SEM observation on aluminum 6061 + 5% SiC + 8% Cu alloy.

Square A in Fig. 10 and 11 shows the phase of AlZnMgCu, which is bright white color. Square B shows the α (Al) + AlZnMgCu phase, which has a spot pattern. Square C shows a $CuAl_2$ phase which is light grey coloured and has a pretty small area. Meanwhile, Square D is the Al_2CuMg phase which is dark grey. The descriptions of Figures 9 and 10 are shown in Table 2.

Table 2. Phases formed on Al6061 + 5% SiC with the 5% Cu and 8% Cu additions

Item	Phase
A	AlZnMgCu
B	α (Al) + AlZnMgCu
C	Al_2Cu
D	Al_2CuMg
E	SiC
F	Al (Matrix)

The phases formed in squares A, B, C, and D were due to the addition of copper (Cu) to the Al6061 composite. Meanwhile, square E shows the SiC phase's formation with grains spread over as a matrix.

4 Conclusion

After conducting a study and several data analysis, it is to be concluded that:

1. The additions of SiC (1%, 3%, 5%) and copper (5% and 8%) by weight affect the hardness value of the Al6061 composite. The maximum hardness value of the composite material with the addition of 5% SiC on (5% and 8%) Cu is 80.46 HRB and 109.37 HRB, respectively.
2. Additions of SiC (1%, 3%, 5%) and copper (5% and 8%) by weight affect the tensile strength and elongation value of the Al6061 composite. The tensile strength of the composite with the addition of 5% SiC on (5% and 8% Cu, respectively) is 202,480 MPa and 211.8 MPa, respectively. Meanwhile, the lowest elongation value of the composite with the addition of 5% SiC over (5% and 8%) Cu is 3.167% and 2.8%, respectively.
3. The microtest results show the addition of columnar grains formed by silicon carbide (SiC) and copper (Cu) and cracks in grain size. Columnar grain and cracking increased with increasing amount of SiC and copper (Cu).
4. The scanning electron microscopy (SEM) results show that the addition of SiC and copper (Cu) formed several new phases. These phases formed are as follows: AlZnMgCu, α(Al) + AlZnMgCu, Al2Cu, Al2CuMg and SiC.

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