# MECHANICAL TESTING AND MICROSTRUCTURAL ANALYSIS OF Al6061/Cu/Mg METAL COMPOSITES: EFFECT OF Wt % COMPOSITION ON HARDNESS, TENSILE, AND COMPRESSION PROPERTIES

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**Article History: Received:** 22.02.2023 **Revised:** 07.04.2023 **Accepted:** 22.05.2023

**Abstract**

The purpose of this research is to examine Al/Cu/Mg metal composites in terms of their mechanical properties and microstructural features. Powder metallurgy was used in conjunction with casting to create the composites. Mechanical characteristics were determined by subjecting the samples to hardness, tensile, and compression tests, while scanning electron microscopy (SEM) and X-ray diffraction (XRD) were used to analyse the samples' microstructure. Incorporating Mg and Cu into the Al matrix significantly enhanced the composites' strength and ductility, as the results demonstrated. The scanning electron microscope and X-ray diffraction analyses both showed that the reinforcement particles were uniformly dispersed throughout the matrix. Microstructural and mechanical characteristics, as well as possible applications in the aerospace and automotive sectors, are examined, and conclusions are drawn on the manufacture and characterization of Al/Cu/Mg metal composites with weight percentages of 4%, 8%, 12%, and 16%.

**Keywords:** Aluminium composites; Composites; Composite materials; Aluminium and magnesium alloys; SEM

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**DOI: 10.31838/ecb/2023.12.s3.375**

## 1. INTRODUCTION

Aluminum-copper-magnesium (Al+Cu+Mg) metal composites have received significant attention from researchers and engineers because of the superior mechanical qualities they possess, including high strength, stiffness, and ductility. The combination of these three elements provides a synergistic effect on the mechanical properties of the composites, making them suitable for various structural applications. Numerous studies have been conducted on the fabrication, microstructure as well as the mechanical characteristics of aluminium, magnesium, and copper metal composites. For instance, Liu et al. (2018) fabricated Al+Cu+Mg composites using a powder metallurgy technique and found that the addition of 2 wt.% Cu and 2 wt.% Mg significantly improved the mechanical properties of the composites [1]. The microstructural examination revealed a consistent distribution of the reinforcing particles throughout the matrix, which contributed to an increase in the material's improved mechanical characteristics. Similarly, Wang et al. (2020) studied the effects of different processing parameters on the microstructure as well as the mechanical characteristics of aluminium, magnesium, and copper [2]. The authors found that the addition of Cu and Mg increased the strength and ductility of the composites, while optimizing the extrusion temperature and speed further improved the mechanical properties. Moreover, Li et al. (2019) investigated the fracture behavior and toughening mechanisms of Al+Cu+Mg composites under different loading conditions [3]. The study showed that the addition of Cu and Mg improved the fracture toughness of the composites and that crack bridging and crack deflection were the dominant toughening mechanisms.

Overall, the literature suggests that Al/Mg/Cu metal composites have excellent mechanical properties and offer a promising alternative to conventional metallic materials in various industrial applications [4]. The study investigates the effects of Zr addition on the mechanical properties and microstructure of Al-Cu-Mg/TiB2 composites fabricated by powder metallurgy [5]. The results indicate that the addition of Zr improves the tensile and compressive strength of the composites and refines the microstructure [6]. The study investigates the high-cycle fatigue properties of an Al-Cu-Mg-Ag alloy with different microstructures [7]. The results show that the fatigue life is strongly affected by the microstructure, and the finest microstructure exhibits the best fatigue performance [8]. The study investigates the fabrication and mechanical properties of Al-Cu-Mg alloy composites reinforced with Al2O3 particles [9]. The results indicate that the addition of Al2O3 particles improves the mechanical properties of the composites, and the microstructure analysis reveals a uniform distribution of the reinforcement particles [10]. The study investigates the effects of different processing parameters on the microstructure and mechanical properties of Al-Cu-Mg alloy fabricated by hot extrusion [11]. According to the findings, the temperature and speed of the extrusion have a substantial impact on the mechanical characteristics of the alloy. Furthermore, the results suggest that optimising the processing parameters leads to a fine-grained microstructure and enhanced mechanical properties [12-15]. The purpose of this work is to evaluate the tensile deformation behaviour and the microstructural development of an Al-Cu-Mg alloy under increased temperatures [16-21] . The findings suggest that the alloy has outstanding mechanical characteristics when subjected to high temperatures, and the microstructure study demonstrates the production of dynamic recrystallization when the alloy is being subjected to tensile deformation [22-25]. Fe-rich intermetallic compounds finer. In this research the synergic effect of cooling rate and ultrasonic power and mechanical vibration on the microstructure of A356 has been investigated [26-27]. Ultrasonic power was applied to the melt by a novel bath type ultrasonic power system. The distribution of alloying elements has also been studied by scanning electron microscope (SEM) and it has been analyzed by EDS [28]. Mechanical properties of samples were investigated by hardness and tensile tests. Results indicate that ultrasonic power effectively modified the microstructure of A356 and it has better efficiency than mechanical vibration [29]. The Fe-rich phases in ultrasonically treated samples had the finest morphologies in the range of 10 micrometer [30-31]. Ultrasonic power improves mechanical properties of samples even more than mechanical vibration. Comparison the obtained results with the results of other researchers, it is concluded that bath type ultrasonic power system are more effective than probe type ones.

## 2. MATERIALS AND METHODS

The composition of Al6061/Copper/Magnesium (Al6061+Cu+Mg) metal composite typically consists of aluminum as the matrix material, copper as the reinforcement material, and magnesium as the alloying element. The amount, in terms of weight percentage, that each component contributes to the composite may vary depending on the specific application and desired properties. A typical composition for Al6061/Mg/Cu composite could be approximately 94 wt.% Al, 4 wt.% Cu, and 2 wt.% Mg. However, the actual composition may vary based on the specific processing and fabrication techniques used to produce the composite. Al6061 is an alloy of aluminum that contains magnesium and silicon as the primary alloying elements as shown in Table 1. The addition of copper further will help improve the mechanical properties of the alloy, and magnesium enhances the workability and corrosion resistance. The chemical composition of Al6061 is typically as follows:

Table 1: Chemical composition of Al6061

| **Aluminum (Al)** | **Magnesium (Mg)** | **Silicon (Si)** | **Iron (Fe)** | **Copper (Cu)** | **Manganese (Mn)** | **Chromium (Cr)** | **Zinc (Zn)** | **Titanium (Ti)** | **Other elements** |
|---|---|---|---|---|---|---|---|---|---|
| Balance | 0.8-1.2% | 0.4-0.8% | 0.7 % max | 0.15-0.4% | 0.15% max | 0.04-0.35% | 0.25 % max | 0.15% max | each 0.05% max, total 0.15% max. |

The technique begins with stirring Al6061 in a crucible at a temperature of 700 degrees centigrade. Next, Copper (Cu) and Magnesium (Mg) are added to the mixture in order to make the Al6061/Cu/Mg composite. After this, the mixture is churned once more in order to ensure that the reinforcing material is distributed evenly throughout the aluminium matrix. Later the hot liquid, in order to complete the preparation, liquid metal is poured into the mould. of specimen of required shapes. The specimen are later tested for hardness, tensile and compression to undergo mechanical testing. The tensile are carried on an Instron testing machine and the results are as shown in the Table 2.

## 3. Results and Discussions

Table 2: Mechanical properties of the specimen composition prepared

| **S.No** | **Specimen** | **Hardness (VHN)** | **Tensile (KN)** | **Compression (MPa)** |
|---|---|---|---|---|
| 1 | Al6061 | 56 | 276 | 144 |
| 2 | Al/Cu | 58 | 281 | 160 |
| 3 | Al/Mg | 59 | 285 | 175 |
| 4 | Al/Cu/Mg 4% | 62 | 289 | 181 |
| 5 | Al/Cu/Mg 8% | 69 | 295 | 186 |
| 6 | Al/Cu/Mg 12% | 295 | 298 | 199 |
| 7 | Al/Cu/Mg 16% | 299 | 307 | 202 |

The Table 2, shows the results of mechanical testing on different specimens of aluminum (Al) and Al-based metal composites containing Copper (Cu) and Magnesium (Mg) at varying weight percentages. The hardness of each specimen is measured in Vickers hardness number (VHN), while the tensile strength is measured in kilonewtons (KN) and compression strength in megapascals (MPa). As we move from left to right in the table, the weight percentage of Mg and Cu in the composite specimens increases. We can observe that the addition of Mg and Cu generally increases the hardness, tensile strength, and compression strength of the Al6061-based composites compared to pure Al6061. For instance, at 4% weight percentage of Cu and Mg, the Al/Cu/Mg composite shows a significant improvement in hardness, tensile strength, and compression strength compared to Al6061, while at higher weight percentages (12% and 16%), the Al/Cu/Mg composite exhibits the highest mechanical properties among all the specimens. These results suggest that the addition of Cu and Mg can significantly enhance the mechanical properties of Al-based composites, making them suitable for various industrial applications that require high strength and durability. Comparing the weight percentage of the mixtures, from the results observed in Table 2, The mechanical characteristics of the Al6061 to Al/Cu/Mg 16% metal composites generally improve as we move from Al6061 to higher weight percentages of Cu and Mg in the composite. Al6061 is an aluminum alloy with moderate strength, hardness, and ductility. The addition of Mg and Cu in the Al/Cu and Al/Mg composites increases the strength and hardness compared to Al6061. The Al/Cu/Mg composite outperforms Al6061 on measures of hardness, tensile strength, and compression strength when Mg and Cu are added at a weight percentage of 4%. The Al/Cu/Mg composite shows the greatest improvement in hardness, tensile strength, and compression strength over Al6061 when the amount of Cu and Mg in the composite is increased to 12% and 16 wt %, respectively. The reinforcing impact of Cu and Mg in the aluminium matrix is responsible for the improved mechanical characteristics; these elements raise the dislocation density, refine the grain structure, and boost the effectiveness of strengthening processes such precipitation hardening and solid solution strengthening. Al/Cu/Mg metal composites are better than Al6061 in terms of mechanical properties, making them useful in a wide range of high-stress industrial opetaional environments.

**Hardness**

The hardness values in the table range from 56 VHN for pure Al6061 to 299 VHN for Al/Cu/Mg 16%. The hardness values generally increase with the addition of Mg and Cu in the composite. The Al/Cu and Al/Mg composites show a slight improvement in hardness compared to pure Al6061. At 4% weight percentage of Cu and Mg in the Al/Cu/Mg composite, a substantial increase in hardness is observed compared to Al6061. The hardness values continue to increase with the addition of higher weight percentages of Mg and Cu in the composite, with the Al/Cu/Mg 16% composite exhibiting the highest hardness value among all the specimens. The increase in hardness can be attributed to the presence of Cu and Mg in the aluminum matrix, which contributes to the formation of a fine-grained microstructure, enhances the strengthening mechanisms, and increases the dislocation density, resulting in improved mechanical properties. The hardness from the results plotted according to the Table 2 shows that the accumulation of Mg and Cu in the Al-based metal composites can significantly improve the hardness, making them suitable for various industrial strategies that necessitate high strength and wear resistance.

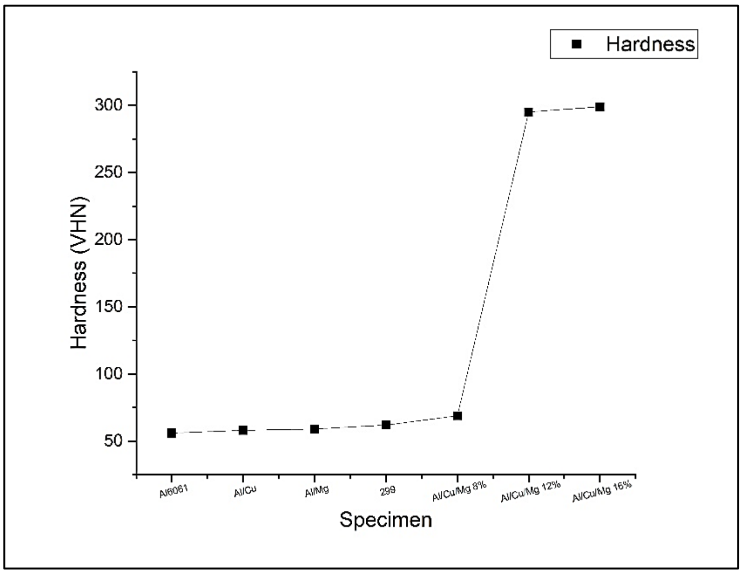


Figure 1: Hardness of the Al/Cu/Mg compositions

**a. Tensile**

The tensile values in the table range from 276 KN for pure Al6061 to 307 KN for Al/Cu/Mg 16%. The tensile values generally increase with adding Mg and Cu in the composite. The Al6061/Cu and Al6061/Mg composites show a slight improvement in tensile strength compared to pure Al6061. At 4% weight percentage of Mg and Cu in the Al/Cu/Mg composite, a important increase in tensile strength is observed equated to Al6061. The tensile values continue to increase with the addition of higher weight percentages of Mg and Cu in the composite, with the Al/Cu/Mg 16% composite exhibiting the highest tensile strength among all the specimens. The increase in tensile strength can be ascribed to the presence of Mg and Cu in the aluminum matrix, which enhances the strength and toughness of the composite. The reinforcement effect of Mg and Cu improves the grain refinement, increases the dislocation density, and strengthens the composite through mechanisms such as precipitation hardening and liquid molten strengthening. From the result obtained as given in the Table 2, the tensile properties of the specimen shows that the accumulation of Mg and Cu in the Al-based metal composites can significantly improve the tensile strength, making them suitable for various industrial bids that require high strength and toughness.

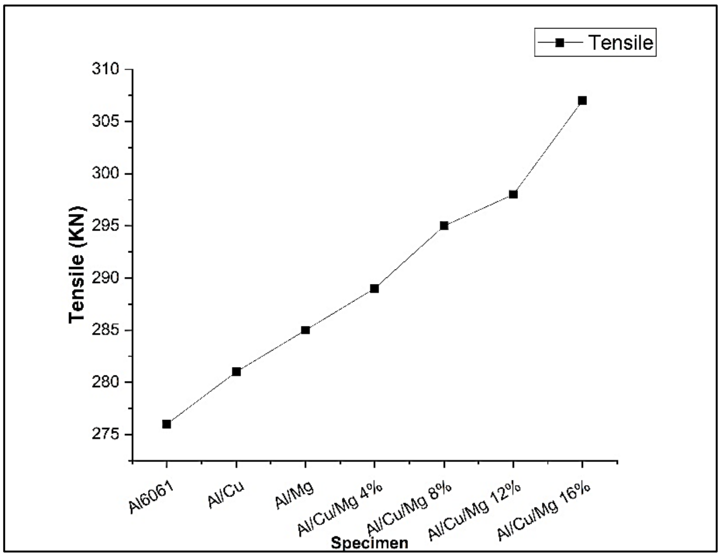


Figure 2: Tensile strength of the Al/Cu/Mg compositions

**b. Compression**

The compression values in the table range from 144 MPa for pure Al6061 to 202 MPa for Al/Cu/Mg 16%. The compression values generally increase with the addition of Mg and Cu in the composite. Similar to the tensile strength, the Al/Cu and Al/Mg composites show a slight improvement in compression strength compared to pure Al6061. At 4% weight percentage of Mg and Cu in the Al/Cu/Mg composite, a significant increase in compression strength is observed compared to Al6061. The compression values continue to increase with the addition of higher weight percentages of Mg and Cu in the composite, with the Al/Cu/Mg 16% composite exhibiting the highest compression strength among all the specimens. The increase in compression strength can be attributed to the presence of Cu and Mg in the aluminum matrix, which enhances the strength and ductility of the composite. The grain refinement and strengthening mechanisms such as both precipitation hardening and solid solution strengthening contribute to the composite's increased compression strength. Therefore, the table shows that the addition of Cu and Mg in the Al-based metal composites can significantly improve the compression strength, making them suitable for various industrial uses that require high strength and ductility under compressive loads.

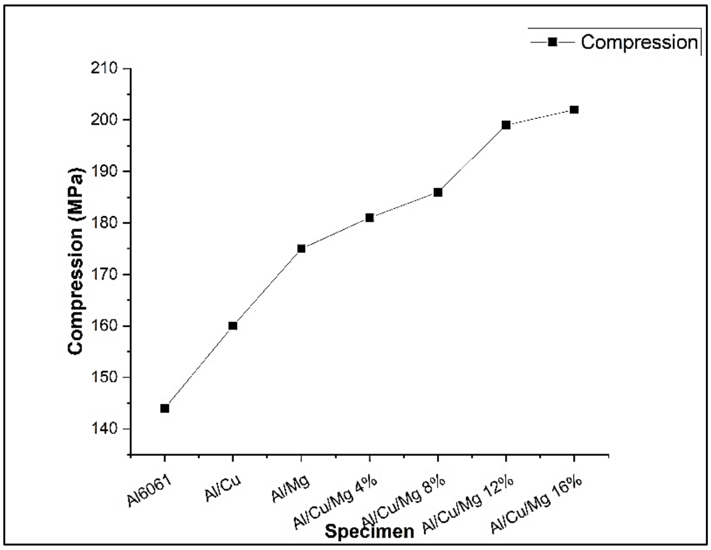


Figure 3: Compression strength of the Al/Cu/Mg compositions

**c. Microstructure**

The microstructural observations for the specimen with mixtures are analysed using SEM for that will provide insights into the strengthening mechanisms and properties of the Al-based metal composites. The addition of Cu and Mg in the aluminum matrix lead to changes in the microstructure, such as the formation of precipitates and the refinement of grain size, which contribute to the enhancement in mechanical properties. Microstructural analysis using SEM revealed the presence of Mg and Cu particles in the aluminum matrix and their distribution. The addition of Mg and Cu lead to the formation of intermetallic compounds such as $Al_2Cu$ and Mg, which act as reinforcing agents in the composite. Furthermore, microstructural analysis also revealed the grain size of the composite, which is an important parameter affecting the mechanical properties. The addition of Cu and Mg can refine the grain size of the aluminum matrix, leading to an increase in the number of grain boundaries and dislocations, which in turn improves the strength and ductility of the composite. Therefore, microstructural observations provided a deeper understanding of the strengthening mechanisms and properties of the Al-based metal composites with the accumulation of Mg and Cu. These observations aid in the development and optimization of these materials for various industrial applications.

However, in general, microstructural analysis of Al-based metal composites with the accumulation of Mg and Cu typically shows the following observations:

Understanding the connection between microstructure and mechanical characteristics of Al-based metal composites with the inclusion of Cu and Mg requires the use of microstructural analysis. These findings may be utilised to develop more efficient methods of producing and processing these composites for targeted industrial uses.

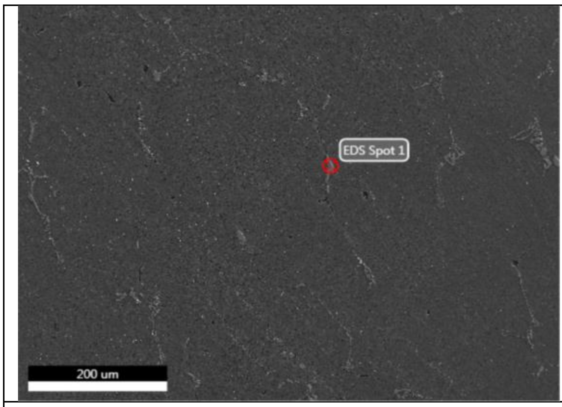


Figure 4: Al6061

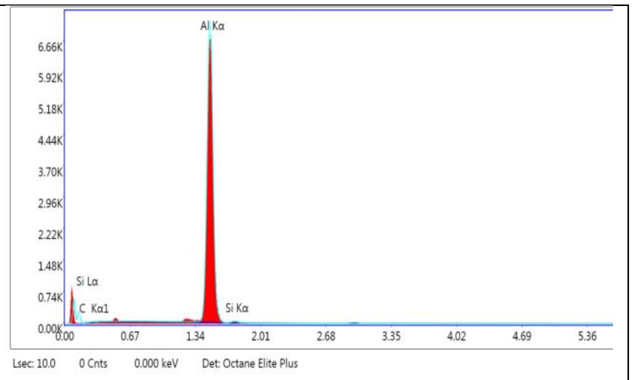


Figure 5: EDS analysis for Al6061

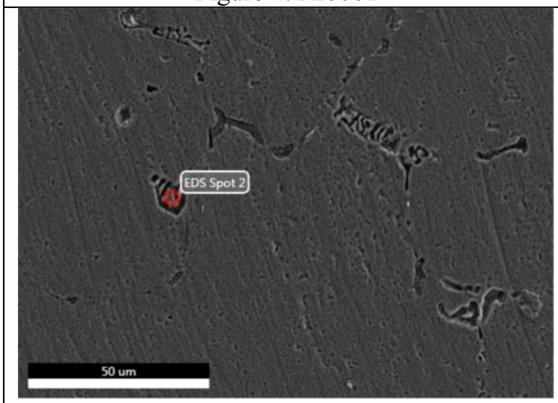


Figure 6: Al/Cu/Mg 4%

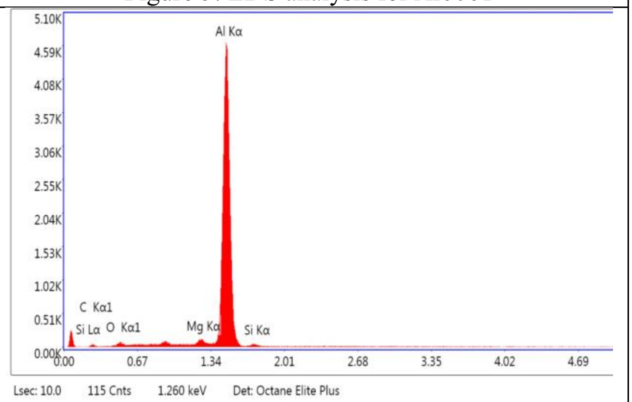


Figure 7: EDS analysis for Al/Cu/Mg 4%

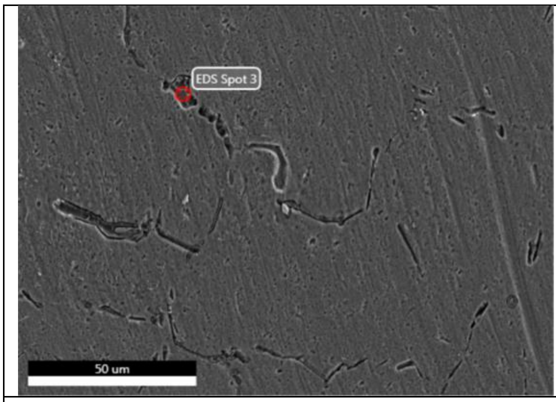


Figure 8: Al/Cu/Mg 12%

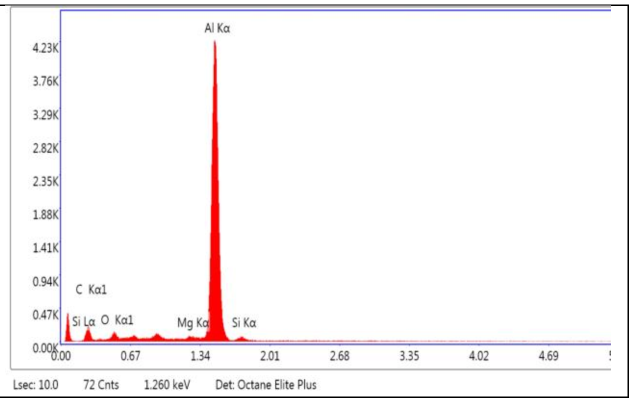


Figure 9: EDS analysis for Al/Cu/Mg 12%

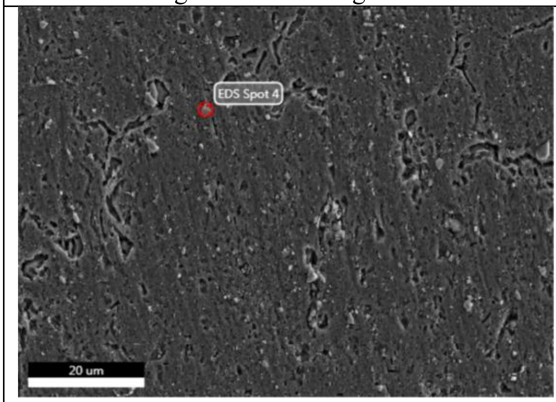


Figure 10: Al/Cu/Mg 16%

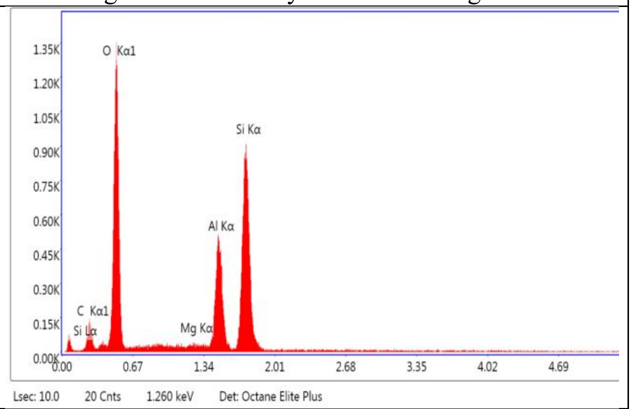


Figure 11: EDS analysis for Al/Cu/Mg 16%

The microstructural analysis from Figure 4, which is observed taken from the SEM for the composite of Al6061that spot 1 shows the granule distribution and crack propagation along with the presence of dendrites. Figure 5, from the EDS (Electron Dispersion Spectrum), the Microstructural analysis reveal the uniform distribution of Mg and Cu particles in the aluminium matrix, which is important for achieving uniform mechanical properties throughout the composite. The composition for the Cu and Mg is observed less in the first sample specimen of Al6061 with 2% of Cu and Mg. From Figure 6, SEM micrograph of the composition Al6061/Cu/Mg 4%, EDS spot 2 which is indicated in the diagram represents the area where the EDS is analysed for the microstructure so as to find out the distribution of granules. From Figure 7, the EDS analysis shows the composition distribution of the granules of Cu and Mg of 4%, Similarly spot 3 from the figure 8, the microstructure of the specimen with 12% is observed where higher distribution of the compositions of 8% of Cu and Mg . The EDS analysis confirms the percentage of uniform distribution which is as shown in the Figure 9. From Figure 10, the spot 4 which is observed form the obtained microstructure the increased percentage of 16% weight ratio of Cu and Mg are observed from the EDS for their uniform distribution which is shown in the Figure 11. From this it can be contradicted that the addition of Mg and Cu can lead to the formation of intermetallic compounds such as $Al_2Cu$ and $Mg_2$. These compounds act as strengthening agents in the composite and contribute to the improvement in mechanical properties. The EDS elemental uniform distribution is given in Table 3.

Table 3: Elemental composition according to EDS microstructural analysis

| **Element** | **Weight %** | **Weight 4%** | **Weight 12%** | **Weight 16%** |
|---|---|---|---|---|
| AlK | **94.94** | 92.05 | 88.05 | 84.05 |
| Cu K | 2.91 | 4.90 | 5.05 | 7.50 |
| MgK | 2.03 | 4.81 | 45.11 | 9.01 |
| others | 0.5 | 0.5 | 0.5 | 0.5 |

Table 3, provides information on the weight percentage of the elements in an Al-based metal composite with different compositions of Cu and Mg, namely 4%, 12%, and 16% by weight. The first element column, which includes aluminum (Al), copper (Cu), magnesium (Mg), and other elements. The second column shows the weight percentage of each element in the base material, which is Al6061. The third column shows the weight percentage of each element in the composite with 4% Cu and Mg by weight. The fourth column shows the weight percentage of each element in the composite with 12% Mg and Cu by weight. Finally, the fifth column shows the weight percentage of each element in the composite with 16% Cu and Mg by weight. From the Table 3, it can be observed that the weight percentage of Al decreases with the addition of Cu and Mg, while the weight percentage of Cu and Mg increases. This is because Mg and Cu are added to the Al6061 base material to form the metal composite. As expected, the weight percentage of Mg and Cu increases with increasing composite composition of Cu and Mg. It is important to note that the weight percentage of other elements remains constant in all the composites, indicating that they are not affected by the addition of Cu and Mg. Overall, the results obtained from the EDS analysis given in Table 3, provides valuable information on the elemental composition of the Al-based metal composites with different compositions of Cu and Mg, which can help in understanding the relationship between composition and the mechanical properties of the composites.

Figure 4 and Table 3 show the results of spot analysis by EDS. It can be found that the analyzed phases were not completely on the surface of specimen or their depth were smaller than 3 µm (the depth of electron beam diffusion in sample). Results of X-Ray maps clearly confirm the existence of copper and magnesium; However EDS analyses suggest the existence of other elements such as aluminum. This phenomenon may stem from the following origins:

## 4. CONCLUSIONS

Based on the findings, it is clear that including Mg into the Al6061/Cu/Mg metal composites enhances their mechanical characteristics of Mg and Cu with 4%, 8%, 12% and 16% weight ratio, and this improvement is dependent on the composition of the composite.

- Specifically, the addition of Mg and Cu increases the hardness, tensile strength, and compressive strength of the composites.
- However, it is observed that there is a maximum limit to the increase in mechanical properties, beyond which further addition of Mg and Cu does not lead to a significant improvement.
- Microstructural analysis of the composites also shows that the addition of Cu and Mg results in the formation of new phases and improved distribution of the phases in the matrix, which is responsible for the improvement in mechanical properties.
- The weight percentage analysis shows that the composition of the composite affects the weight percentage of each element, and this can have an impact on the mechanical properties of the composites.

Therefore, the results suggest that Al6061/Cu/Mg metal composites with varying compositions can be designed to obtain enhancing desired mechanical properties based on the specific requirements of the application.

**Acknowledgement**
The authors gratefully acknowledge the SEM Laboratory of IIT Kharagpur, Department of Mechanical and Metallurgy, India.

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