

## Physical and mechanical properties of aluminum matrix composites reinforced with copper powder via Stir casting method

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### Abstract

The stir casting method is a widely used technique for producing metal matrix composites by incorporating reinforcement particles into molten metal. This study investigates the effect of copper (Cu) powder 2/4 reinforcement on the microstructure and mechanical properties of aluminum matrix composites fabricated using the stir casting method. The base material consists of recycled aluminum from vehicle wheels, with copper added as a reinforcement to enhance the mechanical characteristics of the cast material. The casting process involved melting aluminum waste at 650°C, followed by the gradual addition of Cu powder in varying volume fractions (2.5%, 5%, and 7.5%) while stirring at a constant speed of 500 rpm for 5 minutes to ensure uniform distribution. The microstructural analysis was conducted using optical metallography, while tensile and hardness properties were evaluated using a Universal Testing Machine. The results indicate that the most uniform powder distribution was achieved at 5% Cu reinforcement, whereas the highest porosity was observed at 7.5% due to particle agglomeration. The highest hardness value (42.52 BHN) was observed at 2.5% Cu reinforcement, while the maximum tensile strength (111.7 MPa) was obtained at 5% Cu. However, an increase in Cu content beyond 5% led to a decline in mechanical properties due to increased porosity and reduced bonding efficiency. These findings highlight the importance of optimizing Cu content in aluminum matrix composites to balance mechanical strength and structural integrity

### Keywords:

Aluminum, stir casting, copper powder

### 1 Introduction

Aluminum is a non-ferrous material that has lightweight properties [1]. Aluminum can be found in alloy form with various other elements such as magnesium, silicon, copper, zinc and other elements [2]. Aluminum alloys that are very commonly used in the industrial world are aluminum with 6061, 7075, and 2024 series [3][4]. With lightweight properties and good rust resistance, aluminum materials are often applied to the manufacture of cars, aircraft, ships, trains, and household needs [5].

Recycling is the process of turning a used material into a new material to prevent waste that can become something useful, reducing the use of new raw materials, reducing energy use, reducing pollution, land damage, and greenhouse gas emissions, when compared to the process of making new goods [6]. Recycling is one of the strategies in solid waste management that consists of sorting, collecting, processing, distributing, and making used

products/materials and is a major component in modern waste management and part of the 3R (Reuse, Reduce and Recycle) waste hierarchy process [7]. One way to manage aluminum waste is by smelting at a certain temperature in a crucible furnace [8]. Ingots from smelting still have standard physical and mechanical properties, so they are not good when used as raw materials. So to improve the characteristics of ingot raw materials, the right aluminum waste processing method is needed. In this study using the stir casting method [9][10]. The stir casting method allows the ingot of aluminum waste to be mixed in the crucible furnace by stirring and adding copper powder as reinforcement little by little until evenly distributed [11][12]. This stir-casting method is also often used to process aluminum solid waste by adding powder reinforcement to produce a new product according to needs [3]. Previous research on the stir-casting method of aluminum waste with powder reinforcement materials has been carried out by researchers around the world over the past decade. One of them was conducted by Nagpal on the fabrication of AA2024 aluminum composites with SiC powder reinforcement and egg caking. The results of the study showed an even distribution of SiC powder at 3 and 6%, respectively. Observation of aluminum waste processing by stir casting method with Alumina powder reinforcement with speed variation has also been researched by Nur Kholis et al, the results showed the best hardness occurred at 500 rpm speed with a hardness value of 87.65 HRB [1]. In addition, the use of powder material reinforcement can also improve the mechanical properties of the product, such as tensile strength, hardness, and toughness [13]. Some types of powder material reinforcement that have been used in aluminum waste stir casting research include SiC, TiB, Al<sub>2</sub>O<sub>3</sub>, zirconia, and B<sub>4</sub>C [14][15], [16][17][18][19]. Research has shown that selecting the right type of powder material reinforcement can improve the mechanical properties of products. In addition, the size of the powder material reinforcement also affects the mechanical properties of the product. Research has shows that the use of powder material reinforcement with a smaller size can improve the mechanical properties of the product [20]. Reinforcement such as Cu is expected to increase mechanical strength and also be able to produce a homogeneous microstructure [21].

Considering the importance of this, it is appropriate to conduct further research on the development of aluminum waste-based alloy materials using the stir casting method with copper (Cu) powder reinforcement to improve material characteristics. Therefore, the weight fraction can be used as a parameter in further research to determine the microstructure, hardness value, and optimum tensile strength. The purpose of this study is to determine the effect of Cu weight fraction on microstructure, hardness, and tensile strength.

### 2 Research methods/materials and methods

In this study using materials with aluminum waste raw materials, the aluminum waste used is damaged car wheels. The basic car wheels are made of Si alloy aluminum, as shown in Fig. 1.



Fig. 1. Wheel material

The composition test results on the wheels are shown in Table 1. The copper powder material is a reinforcing material in blending with base metals such as aluminum and magnesium, to increase the strength and wear resistance of the final product as shown in Fig. 2(a).

Table 1. Chemical composition

Element	Prosentase (%)	Element	Prosentase (%)
Si	12.2	P	0.3
Fe	1.38	Sr	0.13
Mn	0.24	Cr	0.07
Ni	0.66	Ti	0.41
Cu	0.69	Al	Bal
Zn	0.78		

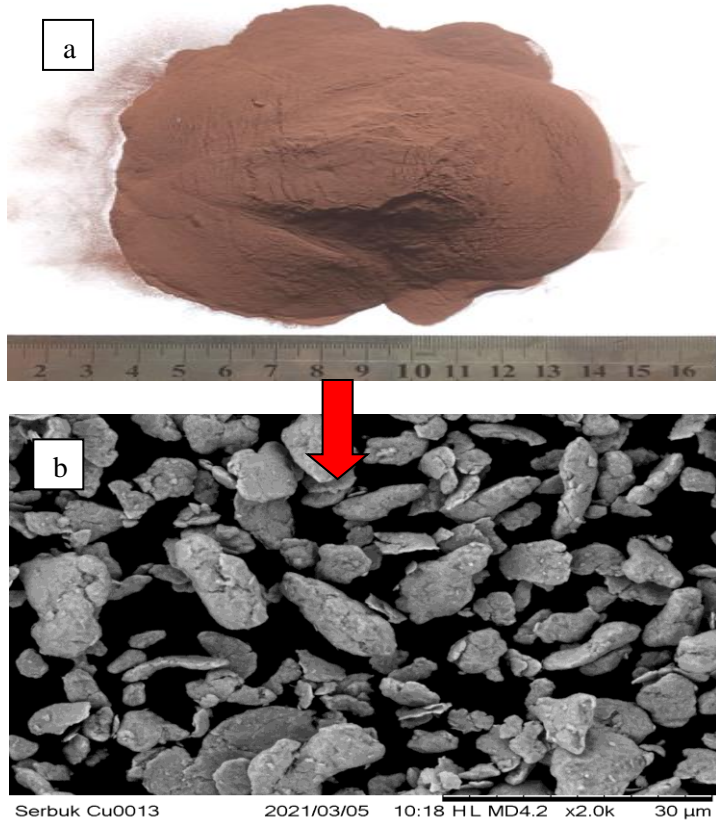


Fig. 2. Copper (Cu) powder

Copper powder is a material used as a reinforcement in the stir casting or liquid metal mixing process. The mass of copper powder (Cu) added in this study was 2.5%, 5%, and 7.5%. Scanning Electron Microscope was used to measure the dimensions of Cu particles, as for the dimensions of copper powder of 12μm, as shown in Fig. 2(b).

The schematic or research flow is shown in Fig. 3. The initial step in this research is to heat the melting furnace first until the water content disappears before reaching the desired temperature, which is 650oC for the melting process. Aluminum ingots are put into the furnace until melted, then copper powder (Cu) is added Macrostructure Fig. 7 shows a good bond between the copper and aluminum powders, although there is a slight inhomogeneity in some parts. This shows that at low concentrations of copper powder, the mixture is still capable of producing a relatively stable structure with minimal porosity.

little by little and continued with the stirring process. After stirring is complete the Al-Cu composite is poured into the mold and cooled at room temperature. The design of the composite mold is shown in Fig. 4. Al-Cu composites that have hardened are removed from the metal mold. Materials that have been completed and removed from the mold, then carried out microstructure and mechanical testing.

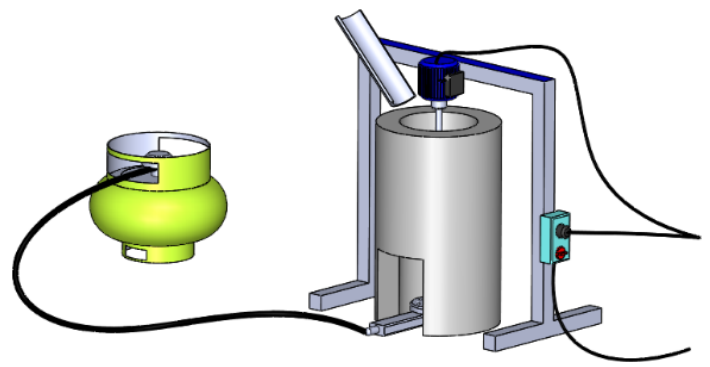


Fig. 3. Schematic of casting

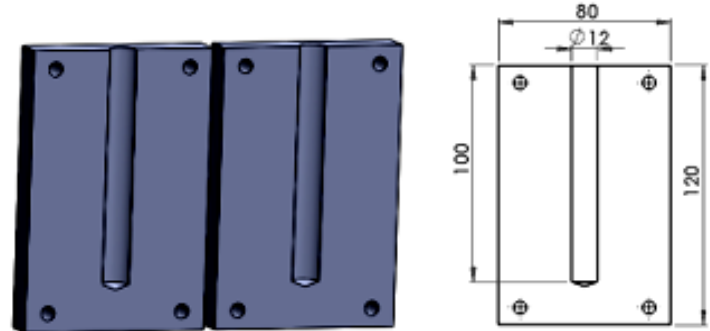


Fig. 4. Mold Design

The material that had been removed from the mold, was then observed the microstructure using an optical metallography tool with the Krisbow™. Microstructure samples were mounted using resin and smoothed with sandpaper measuring 120, 220, 400, 800, 1000, 1500, and 2000 [5][22]. Etching on samples using ASTM E407-07 no.3, namely 2 mL HF, 5 mL HNO<sub>3</sub>, 3 mL HCL, and 190 mL distilled water, then macro and micro observations were made [23]. This has also been done by Kholis et al [1], [9–10]. The testing of mechanical properties is to conduct tensile testing using a Universal Testing Machine (UTM) with the GOTECH brand with a capacity of 10 tons, as for the specimens used for tensile testing as many as 3 specimens (Fig. 5). Standard tensile testing according to ASTM E8M standard [27], Hardness testing using the Brinell hardness test is taken at the intersection of the castings in three parts, namely the tip, center, and base.

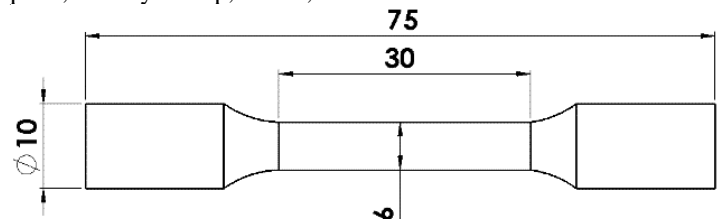


Fig. 5. Standard tensile test specimens

### 3 Results and discussion

#### 3.1 Macro Photo

Aluminum has a relatively clean surface with few scratches or imperfections that may be caused by manufacturing or handling processes. Aluminum exhibits slight porosity which is acceptable within reasonable limits for Raw materials. This porosity may be from the initial melting process but is still within insignificant limits for further casting processes (Fig. 6).

The macrostructure shows stronger and more consistent bonding, indicating that at this concentration, copper reinforcement is more effective in improving the mechanical properties of aluminum. However, some areas still show slight porosity, albeit in much smaller quantities (Fig. 8). At 7.5% powder concentration, the increased amount of copper powder may have caused some instability in the stirring process. This could be due to the excessive addition of powder, which causes particle agglomeration and increases the likelihood of porosity [28], as shown in Fig. 9.

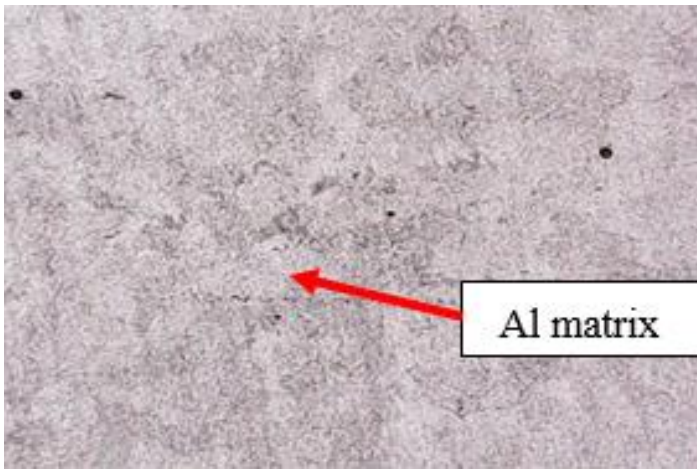


Fig. 6. Macro photo of raw material

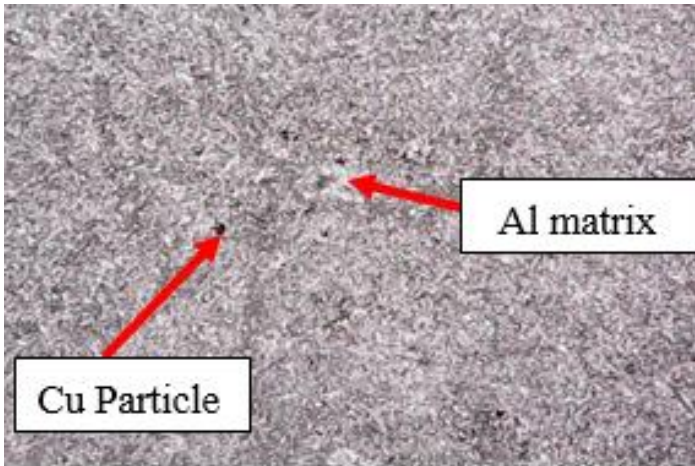


Fig. 7. Macro photo of Al-Cu 2.5%

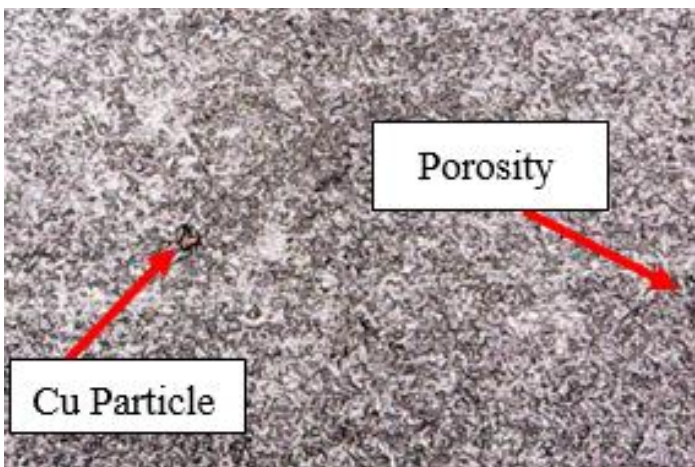


Fig. 8. Macro photo of 5% Al-Cu

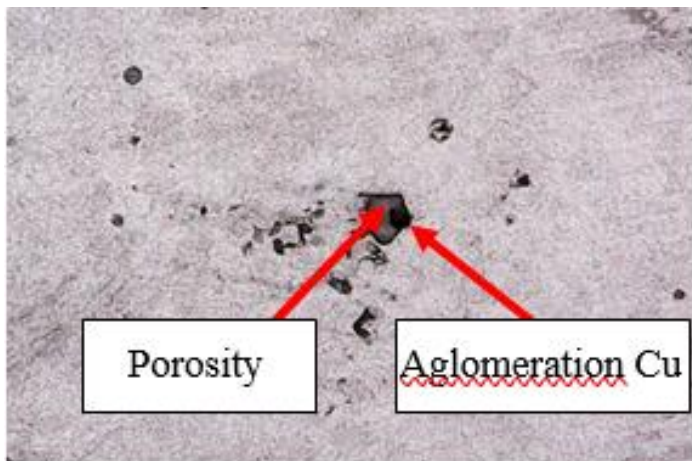


Fig. 9. Macro photo of Al-Cu 7.5%

### 3.2 Microstructure

In the microstructure observation of the raw material, aluminum shows the structure of aluminum matrix and silicon matrix with grains of various sizes. In recycled aluminum, there may be inclusions or segregation of impurities that can form hard and brittle intermetallic phases, as shown in Fig. 10.

At a concentration of 2.5%, the amount of copper powder added to the aluminum matrix is very small. This small amount makes the copper particles difficult to detect or clearly observe in macro or microstructure observations. At low concentrations, copper particles may not be evenly dispersed in the aluminum matrix. Copper particles tend to gather or disperse in small amounts in some areas, making it difficult to observe as a whole in the sample. As seen in Fig. 11.

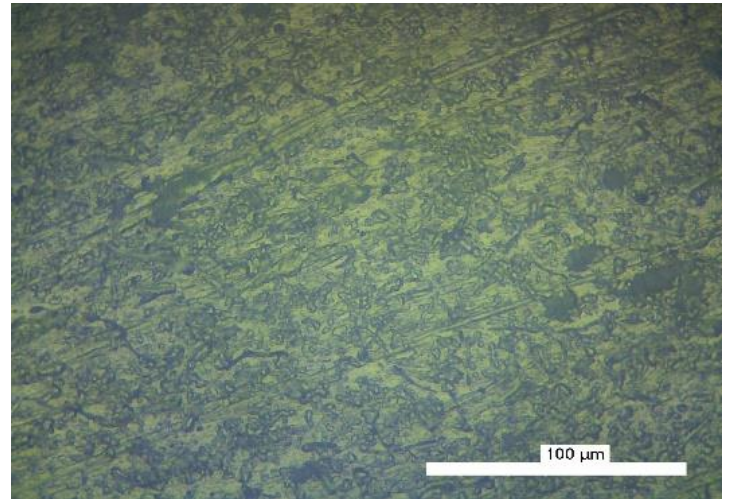


Fig. 10. microstructure of Raw material

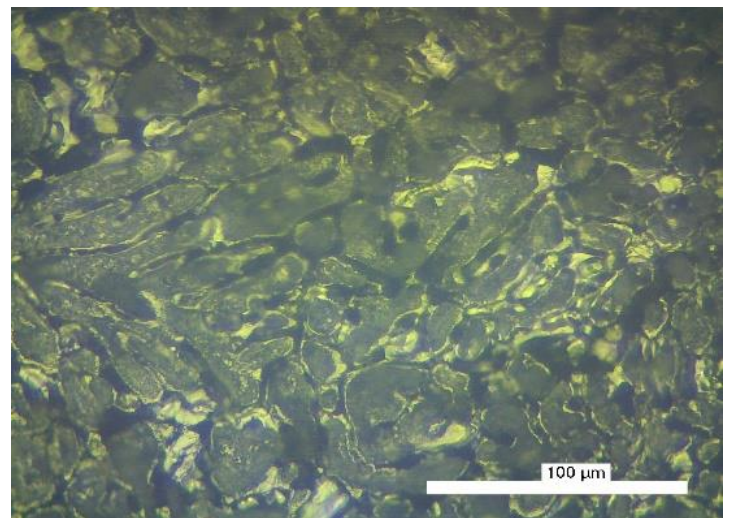


Fig. 11. microstructure of Al-Cu 2.5%

At a percentage of 5%, there is some agglomeration of copper particles. Particle distribution is still quite good, but there are some areas with higher particle concentrations. This may be due to the increased viscosity of the mixture which makes the particle distribution less homogeneous (Fig. 12).

At a powder addition concentration of 7.5%, the agglomeration of copper particles becomes more pronounced. The particle distribution becomes uneven with copper clumps in some areas. The stirring speed of 500 Rpm may not be effective enough to achieve homogeneous distribution at this high reinforcement concentration (Fig. 13).

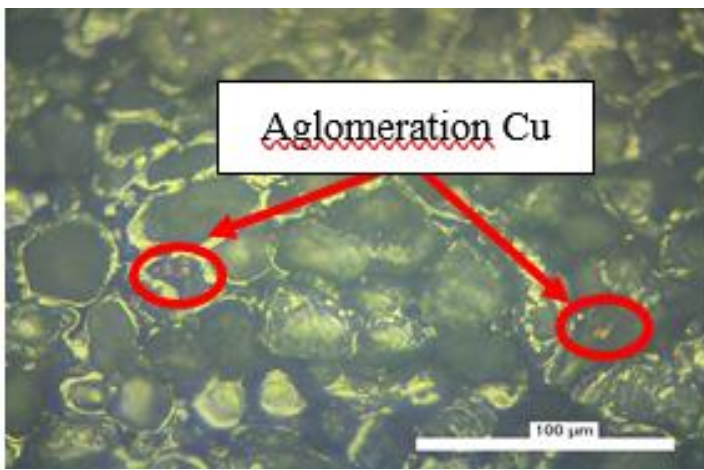


Fig. 12. microstructure of 5% Al-Cu

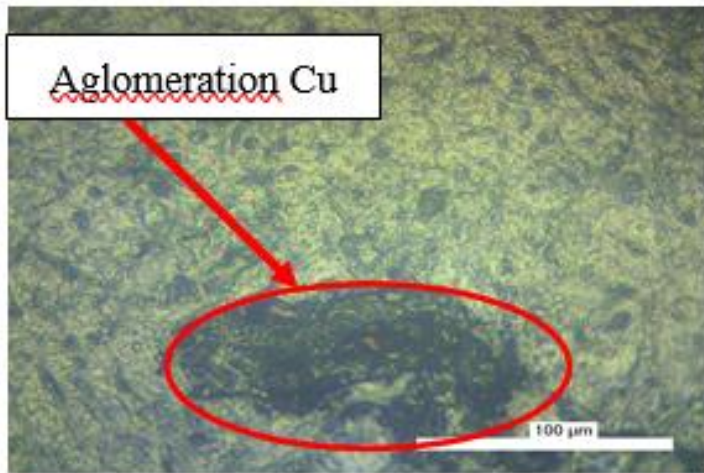


Fig. 13. Microstructure of Al-Cu 7.5%

### 3.3 Hardness value

The hardness value of aluminum composites reinforced with copper powder with variations from 2.5% to 7.5% has decreased (Fig. 14). The raw material has a hardness value of 43.77 BHN and the lowest value occurs at a percentage of 7.5% Cu with a value of 39.5 BHN. The decrease is caused by several factors. The following is an analysis of some of the main reasons why the hardness value can decrease with the addition of powders including that with the addition of larger amounts of copper powder (5% and 7.5%), the copper particles tend to agglomerate or agglomerate as seen in Fig. 13.

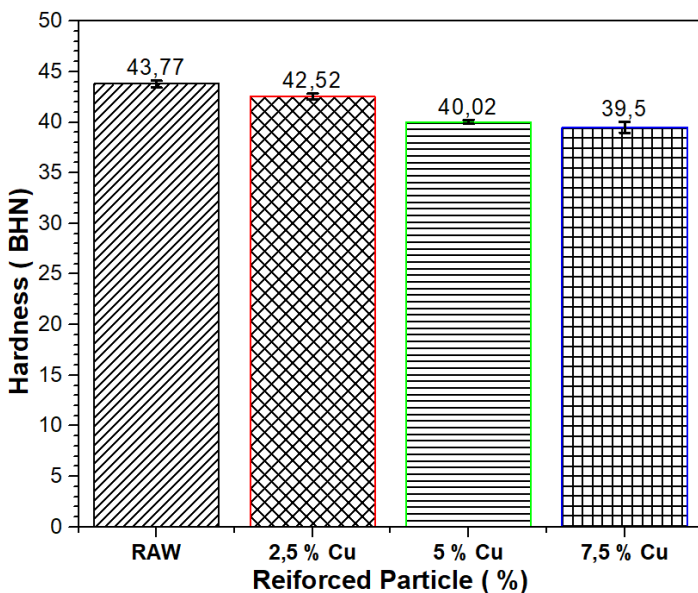


Fig. 14. Hardness

This agglomeration can create weak areas in the composite structure, reducing the effectiveness of reinforcement and even load distribution, thus decreasing the hardness of the material. At higher copper powder concentrations, the distribution of reinforcement particles in the aluminum matrix becomes less homogeneous. This uneven distribution results in some areas not getting enough reinforcement from the copper particles, which can lower the overall hardness of the composite. The addition of copper powders in higher concentrations often leads to increased porosity in the composite [29]. Porosity is a cavity or small hole in the material that can reduce the effective cross-sectional area and result in a decrease in mechanical properties, including hardness. The results of the hardness values are shown in Fig. 14.

### 3.4 Tensile Strength

The results of the tensile strength seen in Fig. 15 show that the highest tensile strength results are still in the raw material of 100.8 Mpa at yield stress and 111.7 Mpa at ultimate stress, while the lowest value is located at the percentage of Cu addition of 7.5%, namely at yield stress 49.8 Mpa and at ultimate stress 55.2 Mpa. Showing a decrease in tensile strength values in aluminum composites reinforced with copper powder at a percentage of 2.5% to 7.5% can be caused by several factors. Here are some of the main reasons that could explain this phenomenon: At higher percentages, copper particles tend to agglomerate or gather into lumps. This agglomeration reduces the homogeneity of the mixture and creates regions of high copper concentration, leading to non-uniformity in particle distribution. This non-uniformity reduces the effectiveness of the reinforcement, as not all copper particles are evenly distributed to provide optimal reinforcement throughout the aluminum matrix. Agglomeration of copper particles can also lead to increased porosity in the composite. Porosity is the presence of voids or small holes in a material that reduces its mechanical strength. These porosities act as weak points that can cause cracks or breaks in the material under tensile load, thus lowering the overall tensile strength value [30]. Stir casting at a stirring speed of 500 rpm may not be sufficient to ensure a homogeneous distribution of copper particles at high concentrations. Stirring speed that is not high enough may cause copper particles to be unevenly dispersed in the aluminum matrix.

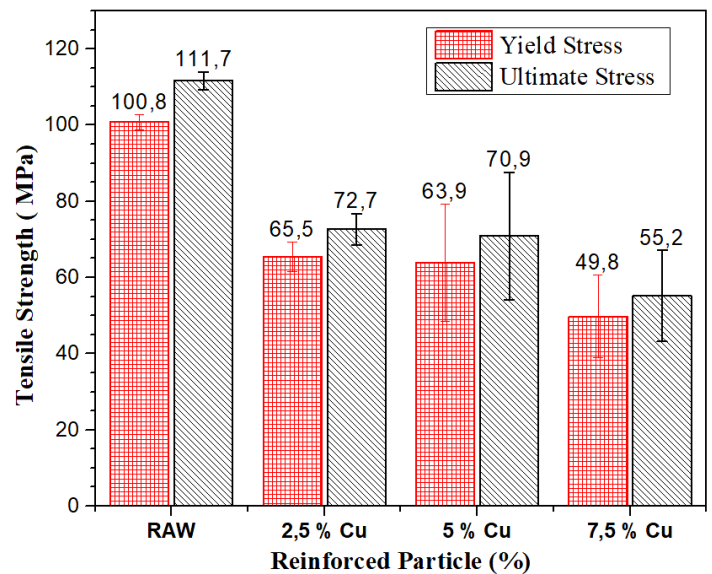


Fig. 15. Tensile strength

### 3.5 Elongation

The decrease in elongation value in aluminum composites reinforced with copper powder at a percentage of 2.5% to 7.5% is due to the addition of large amounts of copper powder which tends to make the material more brittle (Fig. 16). The hard and brittle copper particles can inhibit the plastic deformation of the aluminum

matrix, thus reducing the ability of the material to stretch before fracture. At higher percentages, the copper particles tend to aggregate into agglomerates or lumps. This agglomeration creates regions of high copper concentration and non-uniformity in particle distribution. The addition of large amounts of copper powder can increase the porosity of the composite. Porosity is the presence of small cavities in the material that can act as crack initiation points and the hard and brittle copper particles can interfere with the plastic deformation of the aluminum matrix. When the composite is deformed, these copper particles cannot conform to the plastic deformation of the matrix, thereby reducing the ability of the material to stretch.

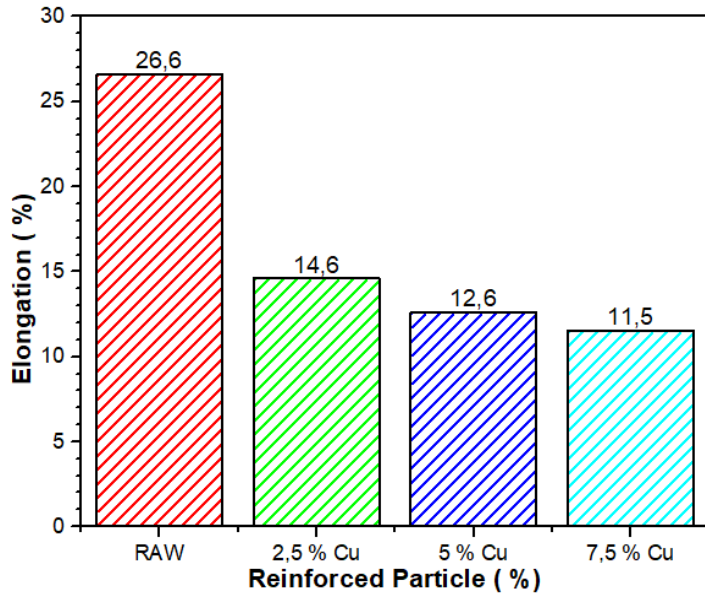


Fig. 16. Elongation

#### 4 Conclusion

The study on aluminum matrix composites reinforced with copper powder using the stir casting method revealed that the optimal reinforcement distribution was achieved at a 5% Cu volume fraction. Higher Cu concentrations (7.5%) resulted in particle agglomeration and increased porosity, negatively affecting material properties. The highest hardness value (42.52 BHN) was recorded at 2.5% Cu, while the maximum tensile strength (111.7 MPa) was obtained at 5% Cu. Beyond this concentration, mechanical properties deteriorated due to excessive porosity and uneven dispersion of Cu particles. These findings underscore the significance of carefully controlling reinforcement levels in aluminum matrix composites to enhance performance while minimizing defects. Future research should explore advanced stirring techniques or secondary processing methods to further improve the homogeneity and mechanical properties of copper-reinforced aluminum composites.

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