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RESEARCH ARTICLE

Weight Reduction in Aluminum Metal Matrix Composite by Adding Copper Slag as A Reinforcement

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ABSTRACT

The aim of this paper is to fabricate aluminum metal matrix composite which should have less weight than aluminum and better mechanical property. Copper slag (waste from copper extraction) is taken as a reinforcement and the metal matrix composite of aluminum 95% and copper slag 5% was fabricated using the stir casting method. The particle distribution is verified by an optical microscope. Mechanical properties of the composite were calculated by conducting the tensile test, impact test, and hardness test, and the calculated values are compared with the theoretical value and aluminum. The chemical composition of the copper slag is tested and checked with literature values. The tensile strength, hardness, and impact strength of the composite is increased when compared with base metal aluminum but the weight of the composite is less.

Keywords: AMMC, Stir casting, Rule of mixture, XRF PMI

1 Introduction

Composite is a tailor-made material, using composites any needed property can be obtained by combining two (or) more materials. Aluminum is one of the preferable materials in the aerospace industry due to its low density, good castability, corrosion resistance, but its strength is less. Composites of aluminum were fabricated by adding high-strength material as a reinforcement to improve the strength of aluminum[1]. Aluminum silicon carbide metal matrix composite was used for additive manufacturing [2]. Copper is one of the most usable metals of human beings in various fields like construction, electric field and transportation equipment. During the extraction of copper from copper ore, the waste product obtained is called copper slag[3]. Copper slag can be used as a good replacement for concrete, the density will increase by nearly 5% but the workability increased rapidly [4]. It is used as filler material in jute fiber composite to increase the erosion resistance [5]. Due to the high content of iron, copper, and zinc, copper slag can be used in value-added products such as abrasive tools, roofing granules, road-base construction, railroad ballast, fine aggregate in concrete, etc.[6]. The impact strength, tensile strength, and hardness of the aluminum were increased by adding copper slag [7]. Stir casting is one of the cost-effective and efficient methods of making AMMC (Aluminum metal matrix composites)[8]. Mechanical characterization of composites means, finding the mechanical properties (Tensile strength, impact strength, hardness) of the composite by conducting various tests (Tensile test, impact test and hardness test) [9].

The aim of the paper is to fabricate a metal matrix composite of an aluminum ingot as the matrix material (95%) and copper slag (5%) as a reinforcement. The stir casting method is used to fabricate composite. Mechanical characterization of the composite is done by conducting the tensile test, hardness test and impact test.

2 Composite Fabrication

The stir casting method is used to fabricate the composite. Since copper slag is an industrial waste, the chemical composition of the copper slag was tested and tabulated in the table 1. The chemical composition of the copper slag was found out using Portable XRF (X-ray fluorescence) PMI (Positive material identification) machine as per the standard ASTM E 1916 - 11.

Table 1: *Chemical composition of copper slag*

S. No	Material	Quantity in %
1	Copper	4.30
2	Sulphur	3.0
3	Manganese	0.07
4	Chromium	0.049
5	Molybdenum	0.90
6	Lead	0.16
7	Titanium	0.32
8	Antimony	0.350
9	Zinc	2.01
10	Iron	88.60

2.1 Methodology of Composite Fabrication

Aluminum plate of 950 grams (Fig-1(a)) were taken in a graphite crucible and heated to 680^0 C using electrical furnace (Fig 2(a)) when the temperature reaches 640^0 C, the aluminum plate starts melt. At 680^0 C, it reaches the liquid state. Now the preheated copper slag of 50 grams (Fig-1(b)) was added slowly and stir by the stirrer at a speed of 300 rpm at about 5 minutes. The copper slag is preheated using muffle furnace (Fig- 2(b)) at 180^0 C of about 20 minutes [10]. 10 gm of magnesium was added to increase the wettability[11] of the aluminum before add copper slag powder . After stirring, the molten mixer is poured in to the metallic mold and allowed to solidify. The solidified composite (Fig-3(b)) was separated from the mould.

(a) (b)

Figure 1: *(a) Aluminum plate (matrix) (b) Copper slag (reinforcement)*

(a) (b)

Figure 2: *(a) 18 KW Electrical Furnace coil type for melting (c) 3KW box type muffle furnace for preheating*

(a) (b)

Figure 3: *(a) Stirring machine (b) Fabricated composites*

3 Characterization of Composite

The property of the composite is calculated both theoretically and experimentally. For theoretical calculation rule of mixture is used [12].

Property of Composite = (Volume fraction of First material x Property of first Material) + (Volume fraction of Second material x Property of Second Material).

3.1 Rule of Mixture

$E_C = (E_m \times V_m) + (E_r \times V_r)$

Where, E_C – Property of composite

E_m, E_r - Property of matrix and reinforcement material

V_m, V_r - Volume fraction of matrix and reinforcement material

Table 2: *Property values of Aluminum (matrix) Copper slag (reinforcement)*

S. No	Property Name	Unit	Aluminum	Copper slag
1	Young s Modulus	N/mm^2	0.68 x 10^5	1.17 x 10^5
2	Tensile Strength	N/mm^2	90	220
3	Hardness	HRB	33	54
4	Melting point	^{0} C	660	1320
5	Density	kg $/cm^3$	2.69	2.31

The property values (Table -2) of Aluminum (matrix) and copper slag (reinforcement) were collected from the literature, volume fraction of aluminum is 0.95(V_m) and copper slag is 0.05 (V_r) was substituted in the equation and the theoretical property value of the composite is calculated. The calculated property values of composite are listed (Table -3).

Table 3: *Property of composite as per the rule of mixture*

S.No	Property Name	Unit	Theoretical (Rule of Mixture)
1	Young s Modulus	N/mm^2	0.7 x 10^5
2	Tensile Strength	N/mm^2	96
3	Hardness	HRB	34.05
4	Density	kg $/cm^3$	2.594

Property of the composite calculated theoretically in Table 3 (using formula):
Example: As per the rule of mixture

Tensile strength of composite = (Tensile strength of Matrix x Volume fraction of matrix) + (Tensile strength of reinforcement x Volume fraction of matrix)

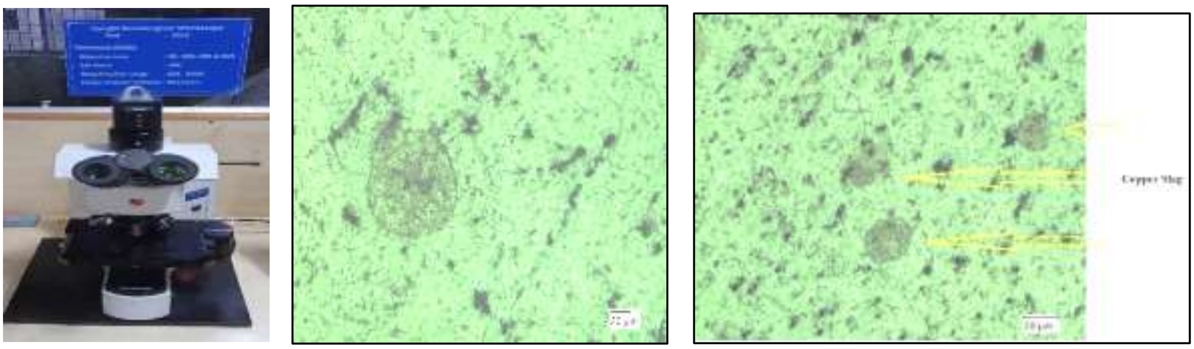
Our composite – matrix aluminum (95%), reinforcement copper slag (5%)
Tensile strength of composite = (90 x 0.95) + (220 x 0.05) = 85 + 11 = 96 N/mm^2.
All the properties are calculated and listed in table 3.

3.2 Microstructure

Microstructure of the composite was analyzed using optical microscope of magnification (Fig-4(a)) range 50X to 500X, BX41M model, software used is metal plus [13].

3.2.1 Specimen Preparation

The surface of the specimen is first smoothened by fine emery sheet after that the surface is etched by Keller Reagent (Combination of reagent is 92ml deionized water, 6ml HNO_3, 2ml HF). Etching time 15 to 20 sec [11].



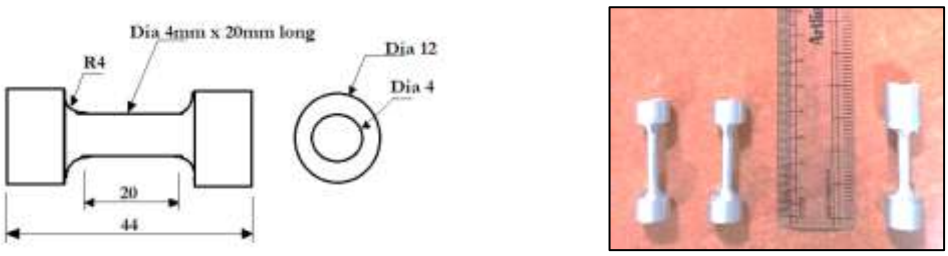
(a) (b) (c)

Figure 4: *(a) Optical microscope (b) Image of 200 X without etch (c) Image 200X with etch*

The microstructure was analyzed using optical microscope without etching (Fig-4 (b)) with etching (Fig-4(c)), both shows that the particle is distributed uniformly.

3.3 Tensile Test

Tensile test is carried out in tenso meter (Micro tensile testing machine). Testing specimen was made as per ASTM standard A370 – E8 (Fig-5 (a), (b)) and the test was performed 20kN load cell tenso meter (Fig- 6(a)). Three specimens are made average value was taken. stress and stress diagram were plot by ER3 software [14].



(a) (b)

Figure 5: *(a) ASTM standard A370-E8 (b) Tensile test specimen*

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(a) (b) (c)

Figure 6: *(a) Tensometer for tensile testing (b, c) tested specimens*

The visual inspection of fractured specimen (Fig-6 (b),(c)) indicates that there is no formation of cub and cone [15] so material behavior is changed from ductile to brittle nature also the material did not fail in the middle, both specimens failed at one end that shows failure occur at the weaker section (Fig-6(c)).

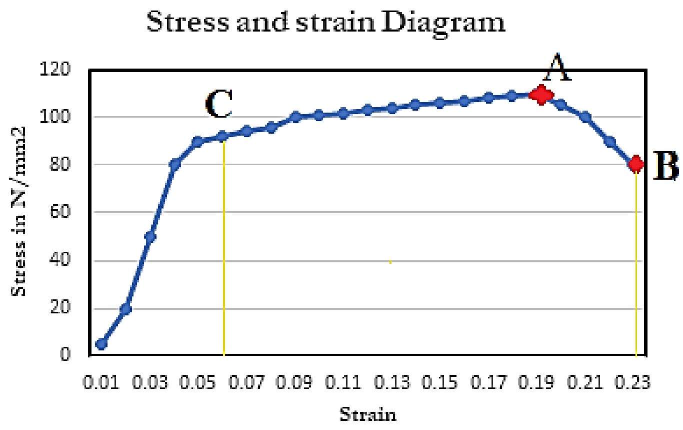

Figure 7: *Graph between stress and strain*

From the graph (Fig 7) between stress and strain, the observation is (i) there is no upper and lower yield point (ii) the graph is not same with ductile material, it is near to brittle material (iii) normally for brittle material the plastic zone area is small but here we get considerable plastic zone. So, the composite neither behave as pure ductile nor brittle material.

3.4 Hardness Test

The hardness of the composite material is tested in digital Rockwell hardness testing machine with 1/16-inch steel ball with minimum load 100 kg and dwell time 15 sec [16]. Three specimens were tested and average value is taken as hardness of composite.

(a) (b) (c)

Figure 8 *(a) Digital Rockwell hardness testing machine (b) with specimen (c) tested specimen*

The experimental hardness value is match with theoretical value (Table -3). The hardness of the composite is nearer to the aluminum matrix this indicates the percentage of copper slag is less.

3.5 Impact Test

The charpy test was conducted to find the impact strength of the composite. Testing specimen made as per ASTM standard A370 (Fig –(9(b))[17] The test was carried out in the impact testing machine in Charpy position (Fig- 9(a)).

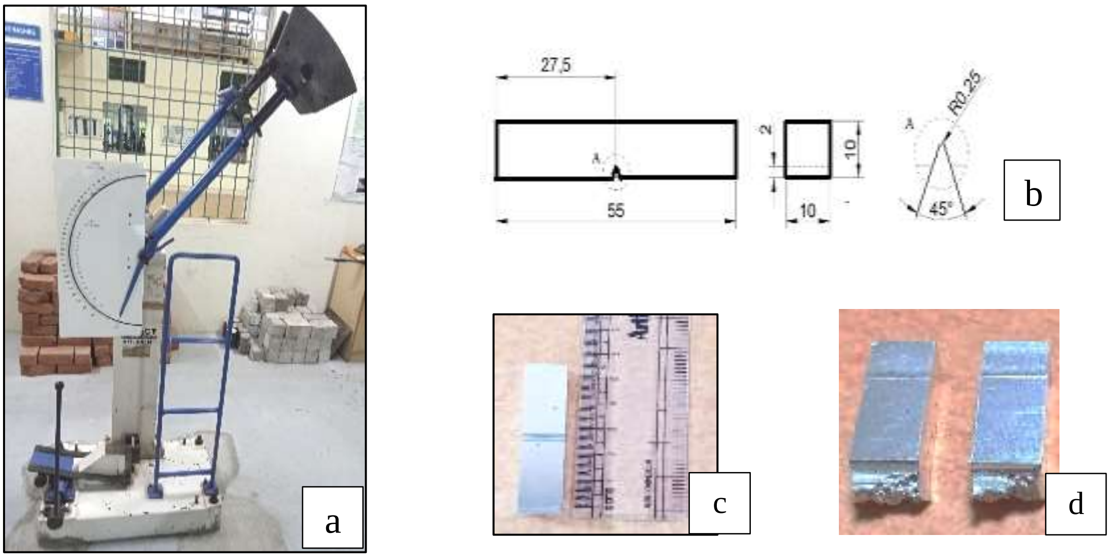

Figure 9: *(a) Impact testing machine (b) Specimen size as per ASTM Standard A 370 (c) Before testing (d) After testing*

4 Results & Discussion

Aim of this work is to fabricate and characterize the composite of aluminum, which have higher strength, hardness and young's modulus than aluminum but the weight of the composite is less than aluminum. For this reason copper slag is taken as a reinforcement. Composite was fabricated using stir casting. The fabricated composite was tested in tensile testing machine, Digital Rockwell hardness testing machine and in Charpy and their property were fond, the results are listed.

Table 4: *Comparison of composite property with base materials*

S.NO	Property Name	Unit	Base Material (Aluminum)	Theoretical (Rule of Mixture)	Experimental Value
1	Young s Modulus	N/mm^2	0.68×10^5	0.7×10^5	1.33×10^5
2	Tensile Strength	N/mm^2	90	96	110
3	Hardness	HRB	33	34	35
4	Density	kg/cm^3	2.69	2.594	2.6

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Stir casting is the one of the cheapest and best method for metal matrix composite fabrication. In this stir casting is successfully used to fabricate the composites

All the properties of the composite were initially calculated theoretically using rule of mixture and listed in the table No-4, column number -5. The experimental value of the composite was found out by conducting tensile test in tensiometer, hardness in Vickers harness machine and impact in Charpy. Distribution of the particle was found using optical microscope. The theorical value and experimental value of the composites are listed in table No-4 and compared with aluminium.

Normally MMC are fabricated to increase the properties (e.g.) strength, hardness and wear resistance of metals. For that high property materials are added named as reinforcements, but addition of reinforcement will increase the weight of the composite compared to base material. From table-2, the tensile strength, hardness of the reinforcement (copper slag) is higher than the matrix (Aluminium) but the density of the copper slag is less than aluminium which makes the reduction in weight of the composite and increase the strength of composites.

From fig -6(b), (c) the reduction in diameter and increase in length is very less and fig-7, the shape of the stress strain diagram is similar to brittle material but plastic zone is large (C-B) like ductile materials. This makes the conclusion that our composite moves from ductile nature to brittle nature.

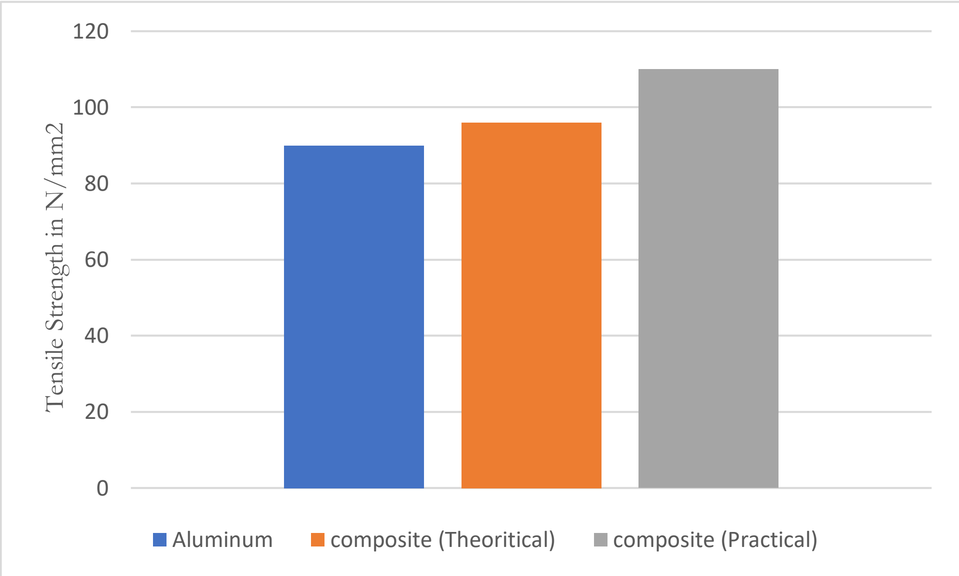

Figure 10: *Tensile strength comparison*

From fig -10 the matrix material (Aluminium) has the tensile strength of 90 N/mm^2. Theoretical tensile strength of the composite calculated by rule of mixture is 96 N/mm^2. Practical tensile strength of the composite from tensile test is 110 N/mm^2. The deviation is considerable value. Reason is copper slag is waste from copper extraction. So based on the copper ore and quality of the equipment, the composition differs from copper slag to copper slag. In this research the copper slag used have high percentage of FeO and absence of Al_2O_3 and SiO_2. This high content of FeO makes the difference in property. It will reflect in other property also.

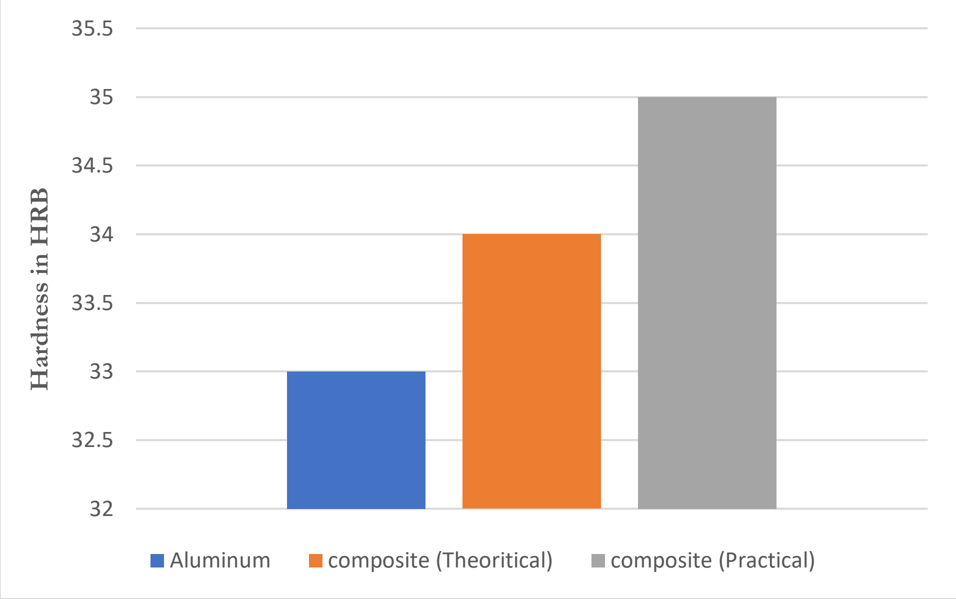

Figure 11: *Hardness comparison*

From fig-11, the high content of Fe will not make any difference in hardness value

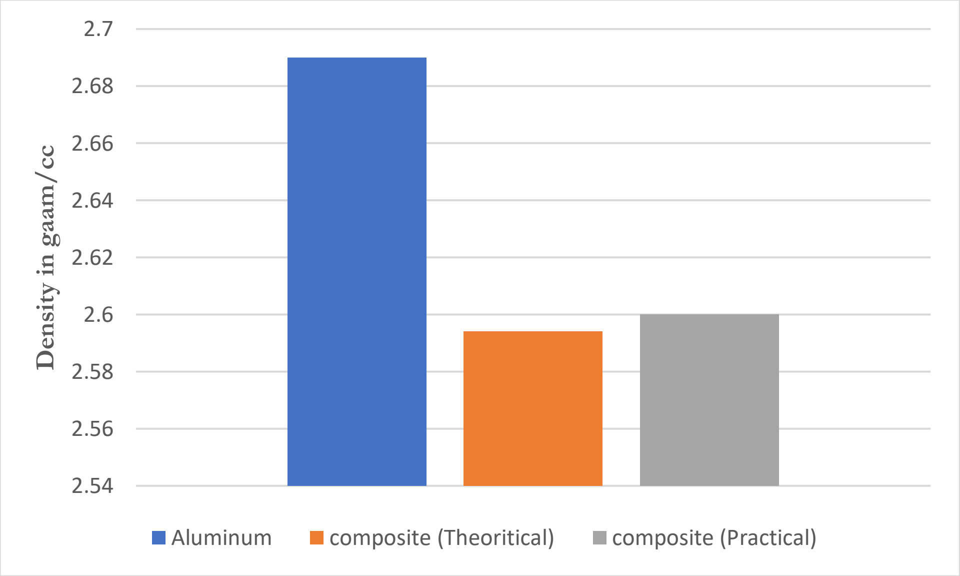

Figure 12: *Density comparison*

From fig-12, the density of aluminium (matrix material) is 2.69 gram/cc. But the composite density is 2.6 gram/cc which is less than the density of aluminium, the reason is the copper slag have very low density 2.31 gram/cc. This indicates that the weight of the composite is less than the matrix (Aluminium), but from fig-10 and fig-11 the strength and hardness value of composite is higher than aluminium.

5 Conclusion

Composite was fabricated by using stir casting method. Stir casting is one of the cheapest methods to fabricate metal matrix composite fabrication. The microscopic images shows that the particles are distributed uniformly. Various test result shows that the mechanical property such as ultimate tensile strength, hardness and impact strength increase by the addition of copper slag like other reinforcement but the important thing is the density of the composite decrease that shows the weight of the composite is less than the aluminium. So by adding copper slag as a reinforcement the strength of the aluminium can be increased without increase the weight.

6 Declarations

6.1 Study Limitations

Copper slag (Waste from copper extraction) it contains large number of oxides like FeO, SiO_2, Al_2O_3, CaO etc. So high percentage addition will affect the strength of the composite. Copper slag don't have uniform composition, it differs from copper slag to copper slag based on the copper ore and quality of copper extraction technique. Hence we will not get the same property for the composite of same matrix and same percentage of copper slag.

6.2 Competing Interests

The author declares no conflict of interest

6.3 Publisher's Note

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