Mechanical Characterization of Ni/Cu hybrid reinforced 6061 Aluminum alloy composites

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Abstract: Metal Matrix Composites (MMCs) with particulate reinforced in the form of hybrid composites are commonly used in many applications where the component deals with wear and breakage. These types of components can have unbalanced faults or corrupted faults. Therefore, it is necessary to analyze the different mechanical properties like fracture toughness behavior and wear behavior of the metal matrix composite. It has been reported that various types of metal particulate fillers have been used as reinforcing fillers in metal matrices, but the use of metal powders for this purpose has not been thoroughly studied. In this study, a new class hybrid reinforced aluminum alloy composite material was developed using nickel / copper metal powder filler. Further the effect of weight percentage of copper and nickel particulates on different mechanical properties of Al 6061 / Cu / Ni / matrix composite have been analyzed. The results show that among all the MMCs produced, MMC with 2 wt% Ni and 2 wt% Cu hardness and 2 wt% Ni and 2 wt% Cu has the highest tensile strength and flexural strength. It can be concluded that because of their higher tensile strength these MMCs are widely used in a variety of industrial and engineering aerospace, new and wear applications.

Keywords: Aluminum, Metal Matrix Composites, Copper, Nikel

1. INTRODUCTION

In recent years, there has been a growing interest in the development of advanced materials with enhanced mechanical properties to meet the increasing demand for lightweight, high-strength materials in various industrial applications. Aluminum alloys, renowned for their excellent strength-to-weight ratio, are extensively utilized in aerospace, automotive, and structural engineering. To further improve their mechanical performance, researchers have been exploring the incorporation of reinforcing phases, such as metallic particles, into these alloys.

This study focuses on the experimental investigation of the mechanical properties of 6061 aluminum alloy composites reinforced with a hybrid combination of nickel (Ni) and copper (Cu) particles. The rationale behind incorporating a hybrid reinforcement lies in the potential synergistic effects that may arise from the combination of these two distinct metallic elements. Nickel is known for its excellent strength and resistance to corrosion, while copper is valued for its high conductivity and enhanced ductility.

2. MATERIAL & METHODS

This section highlights the materials, manufacturing techniques and methods used to achieve the proposed research results. In the current study, aluminum 6061 alloy was used as the base material and nickel and copper were used as the reinforcing material.

For the production of hybrid reinforced aluminum alloy composites, liquid agitation casting technique was used. The experiment includes details of physical properties (density, porosity), mechanical properties (hardness, flexural strength) of hybrid reinforced aluminum alloy composites.

2.1 Matrix Material

Aluminum 6061 is known for its excellent performance in extreme environments. Aluminum 6061 is highly resistant to both seawater and industrial chemistry environments. Aluminum 6061 maintains excellent strength even after welding. It has the highest strength of non-heat treated alloy, but it is not recommended to use at temperatures above 65 ° C. Copper and nickel with different filler percentage is used as reinforcement materials[8].

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Table-1: Chemical composition of alloy Al7075 in % wt.

Element	Wt %
Si	0.5
Fe	0.5
Cu	3.8-4.9
Mn	0.3-.09
Mg	1.2-1.8
Zn	0.25
Ti	0.15
Al	0.1
	Remaining

2.2Density and Void Contents

The theoretical density (ρ_{ct}) of the reinforcing filler composite samples is determined using formula given by Agarwal and Broutman[12].

$$\rho ct = 1/((wf/\rho f) + (wm/\rho m))$$

Where ρ and w are the density and the weight fraction. The suffixes ct, p and m are used for composites, particulate and matrices, respectively. The actual density (ρ_{ce}) of the unfilled aramid fiber reinforced composite material is experimentally determined using a water immersion technique. The volume fraction of the voids (V_v) in the composite material can be determined using the following formula:

$$Vv = (\rho ct - \rho ce)/\rho ct$$

2.3Hardness

The hardness is measured with a Rockwell hardness tester. A diamond cone indenter having an angle of 120 ° between the opposed surfaces is pushed into the test material under a light load of usually 10 kgf and an additional large load of 150 kgf is applied to the lever and the dial showing the Rockwell hardness number as "B" scale indicator.

2.4. Flexural Strength

Inter-laminar shear strength (ILSS) of the composite is short beam shear (SBS) test. The SBS test is a three-point bending test carried out using the same UTM as ASTM Standard D 2344 – 84. The size of the sample is 65 mm × 10 mm × 10 mm It was measured at a crosshead speed of 10 mm / min. MMC of reinforced metal matrix 0 wt%, 1 wt%, 2 wt% and 3 wt%, so that the thickness of the sample varies from 1 to 4 mm respectively. The length and width of the particulate filling composite It is the same as the unfilled composite, but the thickness is constant 2 mm in total Particulate filling composite material. The ILSS value is evaluated using the following equation

$$F.S = 3PL/〖2bt〗^2$$

Where P is the maximum load, b is the width of the specimen; t is the thickness of the test Sample. Evaluate using the same three point bending test with the same bending strength. The flexural strength of the composite is evaluated using the following formula.

Where, L is the length of the span of the sample specimen.

Test parameters

- Size of composite samples = 100 mm*10 mm*(1.3 to 2.4 mm)
- Crosshead speed = 10 mm/min
- Span length = 60 mm

3. RESULT AND DISCUSSION

3.1 Physical, mechanical and fracture toughness analysis of nickel metal powder particulate filled 6061 aluminum alloy composites

Effect of Voids content on nickel metal powder filled 6061 aluminum alloy composites

The theoretical density of the alloyed composite is calculated using the rule of mixture according to equation 1 and the experimental density is evaluated using a water immersion method based on the

Archimedes principle. The void content is then calculated according to equation .[9]

$$\rho_{th} = \frac{1}{\frac{W_m}{\rho_m} + \frac{W_{Ni}}{\rho_{Ni}} + \frac{W_{Co}}{\rho_{Co}} + \frac{W_{Ti}}{\rho_{Ti}} + \frac{W_{cr}}{\rho_{cr}}}$$

$$= \frac{\text{Theoretical density}_{(\rho_{th})} - \text{Experimental density } (\rho_{ex})}{\text{theoretical density }_{(\rho_{th})}}$$

Table 2 Comparison of Experimental Density and Theoretical Density

Sl. No.	Composition	Theoretical density (gm/cc^3)	Experimental density (gm/cc^3)	Void Content (%)
1	0 wt.-% Ni Al6061	2.7173	2.805	3.23
2	1.0 wt.-% Ni Al6061	2.7369	2.847	3.85
3	2.0 wt.-% Ni Al6061	2.7571	2.916	5.73
4	3.0 wt.-% Ni Al6061	2.7657	3.0736	11.13

Table 2 shows when variation in void content in the alloy composite may be due to the presence of air bubbles during mechanical mixing of the filler in the alloy composite during manufacture. Voids can adversely affect the wear and mechanical properties of alloy composites. The decrease in void content was due to an increase in wettability or due to a reduction in the threshold pressure or applied load on infiltration process by addition of nickel particulates in Al 6061 alloy composites.

Effect of hardness on nickel metal powder filled 6061 aluminum alloy composites

Figure 1 shows the Rockwell hardness values of aluminum alloy composites filled with various weight percent nickel metal powders. It can be seen that the hardness gradually increases with the addition of the nickel powder and decreases after a certain time point.

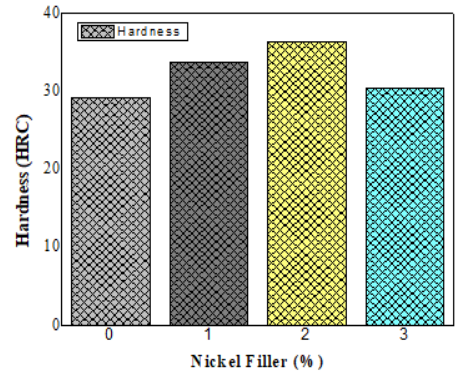

Fig. 1 Effect of Hardness on Nickel Metal Powder Filled Al 6061 Alloy Composites

Hardness (Rockwell hardness on ‘C’ scale (HRC) of the specimen samples are evaluated on Rockwell hardness machine as per ASTM E-92 at applied load of 150 KN. It can be seen that the alloy shows 29.2 HRC on addition of 0 wt. % and when adding the filler content the hardness increased in gradually. Again increase in filler content of 1 wt. % over neat alloy composite hardness increased by 34 HRC. Again increase in filler content of 1.0 wt. % to 2.0 wt. % hardness increased by 37 HRC. Again increase in filler content of 2.0 wt. % to 3.0 wt. % hardness decreased by 31 HRC. In the alloyed composite when adding the hard nickel metal reinforcement particles may increases the micro hardness of the composite by the increase of dislocation density of the alloyed composite. As the number of dislocations in the base matrix increases, by the addition of nickel powder particles and their interaction in between dislocation and reinforcement. It can be seen that strength of the alloyed composite increased by the dispersion of hard metal particulate of reinforcement in soft and ductile matrix. By the addition of reinforcement in the composite load carrying capacities and bonding strength of matrix has to be increased[13].

Effect of Flexural Strength on Nickel Powder Filled Al 6061 Alloy Composites

The flexural strength variations with nickel metal powder reinforced Al6061 alloy composites are shown in Figure 2. it’s found that flexural strength Increase linearly then fix for the last two samples with the addition of nickel metal reinforcement. The composite shows 120MPa. When adding the 0 wt. % filler content and it has to be increase up to 144MPa with the addition of wt. % of 1.0.

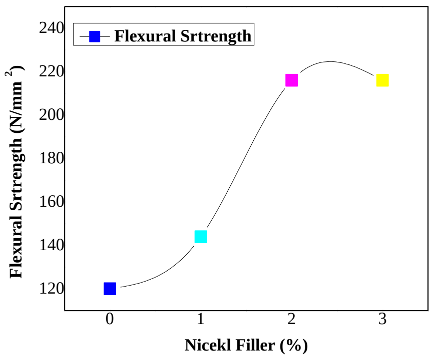

Fig. 2 Effect of flexural strength on nickel powder filled 6061 aluminum alloy composites

Now increase the wt. % of nickel metal powder in the composite the flexural strength of the composite has to be increased 216MPa with the wt. % of 2.0. After that it has to be shown that when increasing further the nickel metal powder in the alloyed composite the its didn't show any change in the value and it has to be 216MPa for the wt. % of 3.0[10].

3.2 Physical, mechanical and fracture toughness analysis of copper metal powder particulate filled 6061 aluminum alloy composites

3.2.1 Effect of Voids content on copper metal powder filled 6061 aluminum alloy composites

By the rule of mixture via equation 1, we can find the theoretical density of the alloyed composites. Experimental density can be finding by the water immersion technique on the basis of Archimedes principle and void content find out by the equation[12].

$$\rho_{th} = \frac{1}{\frac{W_m}{\rho_m} + \frac{W_{Ni}}{\rho_{Ni}} + \frac{W_{Co}}{\rho_{Co}} + \frac{W_{Ti}}{\rho_{Ti}} + \frac{W_{cr}}{\rho_{cr}}}$$

$$Voidcontents = \frac{Theoreticaldensity_{(\rho_{th})} - Experimentaldensity\ (\rho_{ex})}{theoreticaldensity_{(\rho_{th})}}$$

Table 3 Comparison of Experimental Density and Theoretical Density

Sl. No.	Composition	Theoretical density (gm/cc^3)	Experimental density (gm/cc^3)	Void Content (%)
1	0 wt.-% Cu Al6061	2.7176	2.796	2.88
2	1.0 wt.-% Cu Al6061	2.7368	2.832	3.48
3	2.0 wt.-% Cu Al6061	2.7571	2.926	6.12
4	3.0 wt.-% Cu Al6061	2.7657	3.0736	11.13

When the fabrication of alloy composites with the mechanical mixture of filler materials the effect of variation of void content in the presence of air bubbles in the alloy composites and the presence of void content could be greatly affect the wear and mechanical properties of alloy composites. Adding of nickel and copper particulates in Al 6061 alloy composite by the apply load on infiltration process or increase in wet ability or diminishing threshold pressure void content can be reduced[10].

3.2.2 Effect of hardness on copper metal powder filled 6061 aluminum alloy composites

Figure 3 indicates the Rockwell Brinell hardness values of the aluminum alloy composites filled with various weight percentage of copper metal powder. It can be seen that by the addition of Copper powder hardness will be increased gradually and after some point it will reduce.

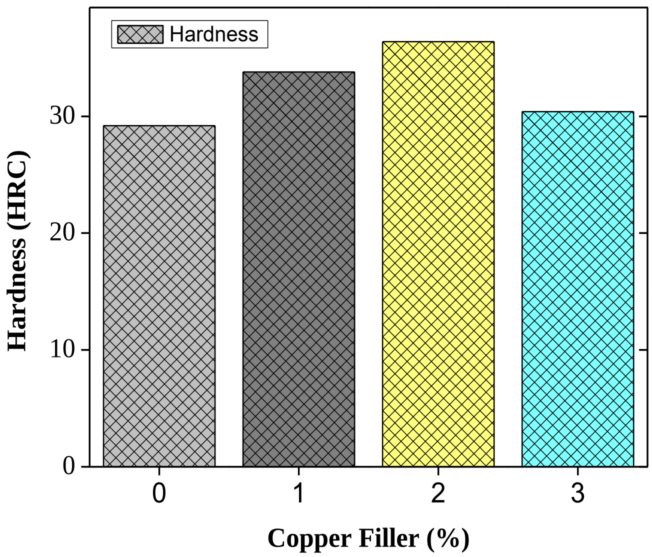

Fig.3 Effect of Hardness on Copper Metal Powder Filled Al 6061 Alloy Composites

Hardness (Rockwell Brinell hardness at sample "C" scale (HRC)) is evaluated according to ASTM E-92 with a Rockwell Brinell hardness tester with an applied load of 150 kN. It can be seen that the alloy shows 39 HRC with addition of 0% by weight. As the filler content was added, the hardness gradually increased. An increase in the filler content of 1% by weight occurs again, the alloy composite hardness increased by 33 HRC. Again increase in filler content of 1.0 wt. % to 2.0 wt. % hardness increased by 43 HRC. Again increase in filler content of 2.0 wt. % to 3.0 wt. % hardness decreased by 30 HRC. In the alloying composite when adding hard copper metal reinforcing particles, the micro hardness of the composite can be increased by increasing the dislocation density of the alloyed composite. As the number of dislocations in the base matrix increases, due to the addition of nickel powder particles and their interaction with dislocations and reinforcement. It can be seen that the dispersion of the hard metal particulate in the soft and ductile matrix increases the strength of the alloyed composite. By adding a reinforcing material to the composite material, the capacity and bond strength of the matrix must be increase.[7][8].

3.2.3 Effect of Flexural Strength on Copper Powder Filled Al 6061 Alloy Composites

The flexural strength variations with copper metal powder reinforced Al 6061 alloy composites are shown in Figure 5. It's found that flexural strength Increase linearly then decrease for the last samples with the addition of copper metal reinforcement. The composite shows 96 MPa. When adding the 0 wt. % Filler content and it has increased to 192 MPa with the addition of wt.% of 1.0.

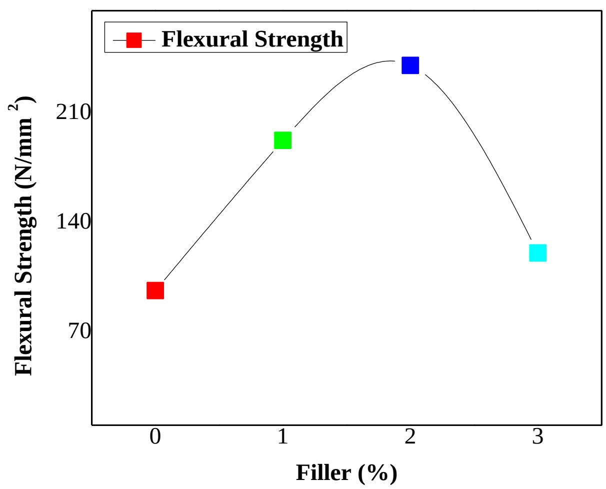

Fig.4 Effect of flexural strength on nickel powder filled 6061 aluminum alloy composites

Now increase the wt. % of copper metal powder in the composite the flexural strength of the composite has to be increased 240 MPa with the wt. % of 2.0. Thereafter, when further increasing the copper metal powder in the alloyed composite material, no change in its value is observed and it must be shown that it must be 120 MPa against the weight. 3.0%[8].

4. CONCLUSION

The following conclusion have been drawn from present research work

- For copper and nickel reinforcement thevoids content in Cu-Ni metal powder filled 6061 aluminum alloy composites maximum shown by matrix on 11.13 %.
- For the weight wt. % of Cu-Ni in aluminum matrix the hardness of the MMC is increase with the increasing of the Cu-Ni reinforcement maximum at 2 wt. % and then decreasing when increasing the Cu-Ni content.

- For the weight wt. % of Cu-Ni in aluminum matrix the flexural Strength of the MMC is increase with the increasing of the Cu-Ni reinforcement maximum at 2 wt. % and then decreasing when increasing the Cu-Ni content.
- Finally it can be concluded that increasing the copper reinforcement in MMC, affect the hardness as well as flexural strength first it will increase and then decrease.

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