Experimental Investigation of Mechanical Properties of Metal Matrix Composite

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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 5083 / 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.
Key words: Aluminum, Metal Matrix Composites, Copper

I. INTRODUCTION

Composite materials are mixtures of two or more constituent materials. They have different physical and chemical prosperity, by combining these materials the properties of composite material get different from the single component. When the composite material is analyzed at macroscopic level, it has two or more phases, one phase is a matrix and the other phase is reinforced. The reinforcing material may be a continuous type or a discontinuous type. Reinforcement is more difficult and powerful than other phases called matrices. The load bearing component is reinforcement and is the strength and rigidity provided by the matrix material [1].

Reinforcing material is used in the form of fine particles and metal is used in the form of base material, the composite material is called a metal matrix composite (MMC). On the basis of mixing when the base material and reinforcement material maintain their physical as well as mechanical properties, these materials increase the mechanical characteristics of the composite. On the basis of reinforcement particulate distribution in the matrix the behavior of strain-stress has to be changed. These MMCs has many disadvantages when compared to other material in the single form because their higher manufacturing cost and mixing with reinforcement material their toughness and ductility has to be reduced. Some of the important materials are Co, Be, Al, Mg, Ni, Ti, Fe are some of the materials used as the base materials [2].

In today's world, the composite is widely using the material of the current scenario for its excellent properties and various industrial applications. Because of light weight, the aluminum composite materials are mainly used in the automobile industry. When composites are used, the net weight loss should be 20 - 50%. The composite material has excellent weather ability and can sustain chemical attack in a wide range of applications. It is also used for the manufacture of chemical storage pipes, chimneys, ducts, tanks, car bodies, hull composites [3] [4].

II. LITERATURE SURVEY

The literature review provides the aware of various aspects of hybrid metal matrix composites and specifically refers to erosion and abrasion characteristics and fracture analysis of hybrid metal matrix materials. Various studies have been conducted by different researchers on different conditions of composite materials.

A. Physical & Mechanical Characterization of Metal Alloys/Composites

Cheng et al. [5] investigated the mechanical behavior of SiCP / 6066Al composite materials and fabricated samples by powder metallurgy method. They found that the load transfer between the matrix and the reinforcement, the grain refinement of the metal matrix, and the dislocation enhancement are the main reinforcement structures of SiCP / Al composites.

Kubota et al. [6] Reported that Al - 15 at. % MgB_2 composite material was investigated and mechanically ground (MMed) using a vibrating ball mill and spark plasma sintering (SPS) to produce a composite material to prepare a sample. They examined the following properties such as hardness, compressive strength, etc. They found that the highest compressive strength is obtained by increasing the hardness of the composite material.

Nguyen et al. [7] investigated the mechanical behavior of the oxidation behavior of the magnesium alloy AZ 31 B and weave the sample by a solidification process. They found that the presence of nano-sized alumina (Al 2 O 3) fine particles increased and the oxidation resistance of the AZ 31 B alloy gradually increased. The presence of nano-Al 2 O 3 particulates tended to retard the transient phase of oxidation.

Sardar et al. [8] Did not prepare samples using ultrasonic cavitations assisted agitation casting method, but examined the mechanical behavior of the magnesium matrix composite material. They examined the following properties such as mechanical properties and microstructure of composites. They found that Mg - micro / nano composites developed by UASC show much better tensile properties and wear resistance compared to base alloys or composites made by mechanical stirring only.

Velmurugan et al. [9] investigated the mechanical properties of SiC and graphite particles in Al 6061 hybrid composites and produced them by stir casting process method. They used the Rockwell hardness test for the mechanical properties, hardness and hardness values of the hybrid reinforced composites and found that increasing the graphite content for the same amount of SiC reduces the hardness of the composite. In addition, the composite also shows lower weight loss.

B. Fracture Characterization of MMCs

Srivatsani [10] investigate the fracture analysis and find the result that fracture on the microscope scale initiated by decomposition of individual or agglomerates of Al_2O_3 micro particles in the metal matrix and disaggregation at the matrix-particle interface. Faults due to cracks and disaggregation at the interface increased with the amount of reinforcement in the matrix.

It has been shown that the micro mechanism of fractures is significantly affected by the details of the matrix microstructure, the interface properties, and the degree of clustering in the material. The Fracture of SiC is dominant in the untreated material, with damage in the matrix and those in the vicinity of the interface in the overrated material prevailed. Metallographic and fractography analysis showed that in both aging conditions tested, the clustered region is the preferred site of damage initiation, Preliminary results further indicate that the accumulation of damage preceding the propagating crack also tends to occur in the clustered region.

III. MATERIALS & METHODS

This section highlights the materials, manufacturing techniques and methods used to achieve the proposed research results. In the current study, aluminum 5083 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.

A. Matrix Material

Aluminum 5083 is known for its excellent performance in extreme environments. Aluminum 5083 is highly resistant to both seawater and industrial chemistry environments. Aluminum 5083 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 [11].

Element	Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
%	0.4	0.4	0.1	0.4-1.0	4.0-4.9	0.25	0.15	0.05-0.25	Balance

Table 1: Chemical Composition for Aluminum Alloy 5083

B. Density & Void Contents

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

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

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:

$$Vv = \frac{\rho ct - \rho ce}{\rho ct}$$

C. Hardness

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.

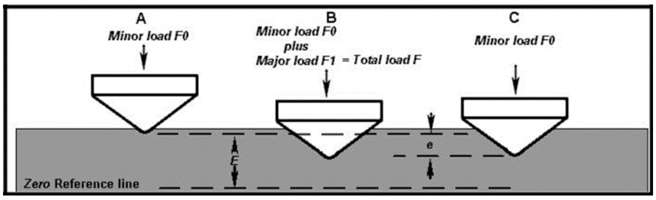

Fig. 1: Steps in Rockwell Hardness Tester

Figure 1 shows the principle of Rockwell. Repeat the test on all metal matrix reinforced composite samples
Following are the test parameters:

- Minor load = 10 kgf
- Major load = 150 kgf
- Indenter = 120 degree diamond cone indenter
- Size of test samples (EA-1 to EA-4) = 25 mm*25 mm*(1.3 to 2.4 mm)

D. 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

$$F.S = \frac{3PL}{2bt^2}$$

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.

1) 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

IV. RESULT & DISCUSSION

Physical, mechanical and fracture toughness analysis of nickel metal powder particulate filled 5083 aluminum alloy composites

A. Effect of Voids Content on Nickel Metal Powder Filled 5083 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 [12].

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

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

Sl. No.	Composition	Theoretical density (gm/cc^3)	Experimental density (gm/cc^3)	Void Content (%)
1	0 wt.-% Ni Al5083	2.7173	2.805	3.23
2	1.0 wt.-% Ni Al5083	2.7369	2.847	3.85
3	2.0 wt.-% Ni Al5083	2.7571	2.916	5.73
4	3.0 wt.-% Ni Al5083	2.7657	3.0736	11.13

Table 2: Comparison of Experimental Density and Theoretical Density

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 5083 alloy composites.

B. Effect of Hardness on Nickel Metal Powder Filled 5083 Aluminum Alloy Composites

Figure 2 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.

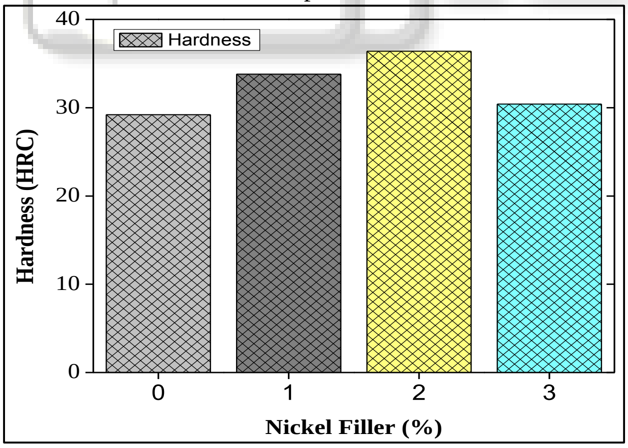

Fig. 2: Effect of Hardness on Nickel Metal Powder Filled Al 5083 Alloy Composites

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].

C. Effect of Flexural Strength on Nickel Powder Filled Al 5083 Alloy Composites

The flexural strength variations with nickel metal powder reinforced Al5083 alloy composites are shown in Figure 4.1.5. 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. 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[13].

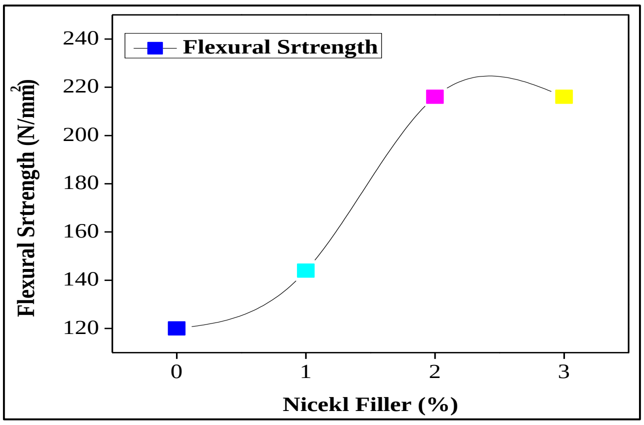

Fig. 3: Effect of flexural strength on nickel powder filled 5083 aluminum alloy composites

D. Physical, mechanical and fracture toughness analysis of copper metal powder particulate filled 5083 aluminum alloy composites

1) Effect of Voids content on copper metal powder filled 5083 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].

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

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

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 5083 alloy composite by the apply load on infiltration process or increase in wet ability or diminishing threshold pressure void content can be reduced [14][13].

Sl. No.	Composition	Theoretical density (gm/cc^3)	Experimental density (gm/cc^3)	Void Content (%)
1	0 wt.-% Cu Al5083	2.7176	2.796	2.88
2	1.0 wt.-% Cu Al5083	2.7368	2.832	3.48
3	2.0 wt.-% Cu Al5083	2.7571	2.926	6.12
4	3.0 wt.-% Cu Al5083	2.7657	3.0736	11.13

Table 2: Comparison of Experimental Density and Theoretical Density

2) Effect of Hardness on Copper Metal Powder Filled 5083 Aluminum Alloy Composites

Figure 4 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.

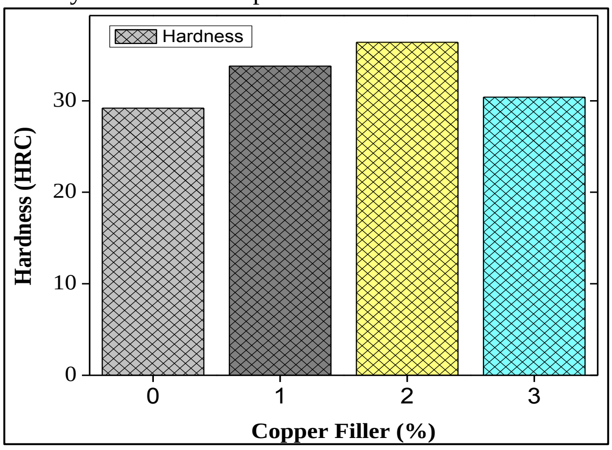

Fig. 4: Effect of Hardness on Copper Metal Powder Filled Al 5083 Alloy Composites

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 increased [14] [13].

3) Effect of Flexural Strength on Copper Powder Filled Al 5083 Alloy Composites

The flexural strength variations with copper metal powder reinforced Al 5083 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. 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% [14][13].

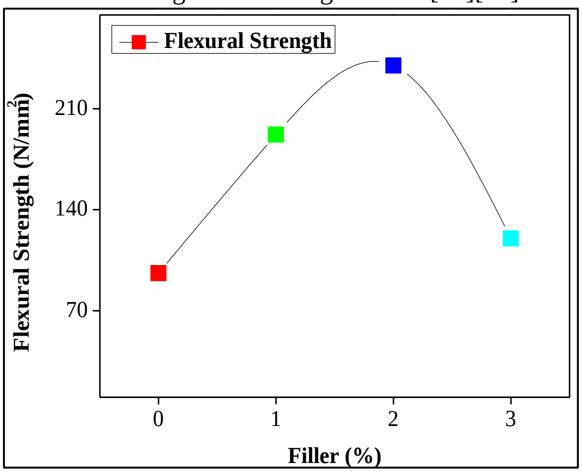

Fig. 5: Effect of Flexural Strength on Nickel Powder Filled 5083 Aluminum Alloy Composites

V. CONCLUSION

The following conclusion have been drawn from present research work

- For copper and nickel reinforcement the voids content in Cu-Ni metal powder filled 5083 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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