Investigation of Mechanical Properties of Al 5083 Metal Matrix Composites Reinforced with Cu and Ni Particulates: A Study of Flexural and Tensile Behavior

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Abstract- Metal matrix composites (MMCs) are increasingly recognized as advanced engineering materials across various industries, such as aerospace, automotive, electronics, thermal management, and wear-resistant applications, due to their exceptional properties, including high tensile strength, hardness, Young's modulus, and enhanced wear resistance. The mechanical performance of metal matrix composites (MMCs) is depending on the various factors, such as the type, shape, size, volume fraction, and orientation of the reinforcements embedded in the matrix. Al 5083 alloy, characterized by its high magnesium content, is widely used in marine and automotive applications, Automotive Trailers and Caravans, cryogenic vessels, armored vehicles, and wind turbine components. However, it has low wear resistance. Incorporating copper and nickel particulates into MMCs can improve their hardness and, consequently, their wear resistance.

This study investigates how varying weight percentages of copper and nickel particulates affect the mechanical properties of Al 5083/Cu/Ni matrix composites. The results indicate that the composite containing 0% nickel and 3% copper exhibits the highest ultimate tensile strength, flexural strength, and tensile strength among all tested samples. Furthermore, while ultimate tensile and flexural strengths increase with higher copper content, they decrease with the addition of nickel.

Keywords: **Aluminium, Copper, Nickel, Metal Matrix Composites**.

1. INTRODUCTION

Metal matrix composites (MMCs) are commonly used in industries such as aerospace, automotive, defence, marine, and sports because of their enhanced mechanical properties [1]. MMCs are made from a base matrix alloy and reinforcements, and their final properties depend on the characteristics of these components [2]. Compared to unreinforced alloys, MMCs have better tensile strength, hardness, and thermal conductivity [3][4]. The performance of MMCs is affected by factors like the type of reinforcement, its volume, size, shape, and orientation in the matrix. By carefully selecting these elements, the desired properties of MMCs can be achieved for different applications [5]. Common metals used in MMCs include aluminum (Al), magnesium (Mg), titanium (Ti), zinc (Zn), copper (Cu), and stainless steel, with aluminum being the most widely used matrix material due to its strength, low weight, and resistance to corrosion [6][7][1].

Various reinforcements, such as silicon carbide (SiC), alumina (Al_2O_3), boron carbide, and carbon nanotubes, are added to improve properties like strength and stiffness, though these materials may reduce ductility [8][9][1][10][7]. The demand for MMCs has increased in applications that require strong wear resistance, such as automotive and aerospace parts. Wear affects the lifespan of components, making it essential to study wear behavior in MMCs used in high-stress environments [11][12]. Kumar et al. experimentally studied the physical, mechanical and tribological behavior of nickel powder-filled aluminum MMCs [13]. Vannana et al. used liquid metallurgy technique for the fabrications of Al7075/basalt short fiber Metal Matrix Composites to study the coefficient of thermal expansion of develop MMC as a function of temperature and reinforcement [27]. Zhanwei et al. employed powder metallurgy for the fabrication of SiC reinforced aluminum based MMCs. The micro-hardness and Young's modulus of MMCs have been investigated using instrumental micro-indentation technique [28]. Salimia et al. fabricated aluminium based MMCs reinforced with ZrO_2 nano-particles in different % weight [29]. Yuvraj et al. used friction stir processing (FSP) for the production of 5083 aluminum alloy with reinforced layers of boron carbide (B_4C). Micro and nano sized B_4C particles have been used as reinforcements [30]. Kandpal et al. fabricated Al_2O_3 reinforce aluminium metal matrix composites to study the impact of wt. % of Al_2O_3 on mechanical properties and microstructure of fabricated composites [31]. The main goal of this research is to see how changing the amount of copper and nickel particles as reinforcement affects the bending and stretching behavior of Al 5083 alloy-based metal matrix composites (MMCs).

2. RAW MATERIALS USED FOR THE FABRICATION OF MMCs

Different aluminum 5083-based metal matrix composites (MMCs) reinforced with copper and nickel in various weight percentages have been fabricated using the manual stir casting method. A muffle furnace and an induction furnace were used for preheating and melting the aluminum alloy for fabricate various metal matrix composites (MMCs), aluminum 5083 alloy was used as the matrix material in different weight percentages. This alloy, part of the 5000 series, is favored for marine and aviation applications due to its superior corrosion resistance and formability [14][15]. However, it has low wear resistance, limiting its applications. To enhance wear resistance and mechanical properties, nickel and copper particulates were added. Copper powder (99.9% purity, 80-100 microns) improves hardness, while nickel powder (20-50 microns) enhances tribological properties [16][13]. Additionally, 1% magnesium was included to improve wetting between the reinforcements and the matrix [17].

3. FABRICATION OF MMCS

First, Al 5083 alloy ingots were soaked in a 10% sodium hydroxide solution for 15-20 minutes to clean the surface. To maintain the chemical integrity of Al 5083 in an NaOH bath, use a dilute solution (2-5%) and control soaking duration and temperature (below 40°C). Add inhibitors like sodium silicate to minimize corrosion. Then, they were dipped in a mixture of nitric acid and water to remove any leftover residue and washed with methanol. After air-drying at room temperature, the ingots were weighed and placed in a graphite crucible, which was heated to 800°C in a furnace [23]. Hexachloroethane tablets were added to the melted aluminum to remove gas bubbles, and the mixture was stirred for 10-15 minutes. At the same time, copper, nickel, and magnesium particles were heated to 400°C for 2-3 hours to remove moisture, with manual stirring to ensure they heated evenly. Once the aluminum was at the right temperature, it was stirred with an alumina-coated stainless-steel impeller to create a whirlpool. Preheated copper and nickel particles were slowly added into this whirlpool, followed by magnesium. Stirring continued for another 10-15 minutes to mix everything well. The liquid metal mixture was then poured into preheated molds to create the desired shapes. After cooling for 30-35 minutes, the metal matrix composites (MMCs) were taken out of the mold, and this process was repeated for all samples [24].

4. TESTING EQUIPMENT FOR TENSILE AND FLEXURAL TEST

A universal testing machine from Engineering Models and Equipment, Roorkee, was used for tensile and flexural tests on the fabricated MMCs, meeting the standards of IS 1828-1975. The maximum capacity of the UTM machine is 400 kN, and the least count of the machine is 0.8 kN. Flat specimens sized 140 mm x 10 mm x 10 mm for tensile tests and 65 mm x 10 mm x 10 mm for flexural tests were prepared. The tests were carried out at a constant speed of 1 mm/min. During the flexural tests, the load applied and the movement of the crosshead were recorded, and the flexural strength was calculated using the relevant formula [25][26].

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

where
P is the maximum load,
b is the specimen width,
t is the specimen thickness,
and L is the span length of the sample.

Table 1: Fabricated MMCs nomenclature for the current research work

Composite Designation	Al5083(% by Weiwei)	Copper (Cu) (% by Weiwei)	Nickel (Ni) (% by Weiwei)	Magnesium (Mg) (% by Weiwei)	Particulate Matter
(3Ni Al0Cu)	96	0	3	1	Ni particulates
(3Ni Al1Cu)	95	1	3	1	Cu, Ni particulates
(3Ni Al2Cu)	94	2	3	1	Cu, Ni particulates
(3Ni Al3Cu)	93	3	3	1	Cu, Ni particulate
(0Ni Al3Cu)	96	3	0	1	Cu particulates
(1Ni Al3Cu)	95	3	1	1	Cu, Ni particulates
(2Ni Al3Cu)	94	3	2	1	Cu, Ni particulates

Figure 1 and 2: Al5083 ingots used for the fabrication of MMCs manufacturer by Bharat Aerospace Metals (Courtesy: MNIT, Jaipur)

Figure 3 and 4: Melting and Pouring Molten Metal and fabricated MMCs (Courtesy: MNIT, Jaipur)

Figure 5 and.6: Shows the specimen used for tensile and flexural test after test.

5. ULTIMATE TENSILE STRENGTH

The strength of a material refers to its capacity to resist external forces without fracturing. Tensile strength measures how well a material resists being pulled apart [18]. In metal matrix composites (MMCs), tensile strength is influenced by the type of reinforcement, its amount, and the bond between the reinforcement and matrix. Failure under tensile loading usually happens when cracks form at different sections [19]. In this study, two samples of each MMC were tested for tensile strength, and the average of the two results was taken. Table 1.2 shows the tensile strength of both samples and the average for all MMCs.

6. FLEXURAL STRENGTH

Flexural strength, also called modulus of rupture or bend strength, refers to a material's ability to resist deformation under bending or flexural loading. In this study, flexural tests were conducted on two specimens for each composition. The average of the two values was taken as the final flexural strength for the respective MMC. All tests were done using a universal testing machine with the three-point bending method, which is easy to set up and requires simple specimen preparation. Table 1.3 shows the flexural strength of all fabricated MMCs, and Figure 1.6 illustrates how flexural strength varies with the percentage weight of reinforcements.

From Table 1.3 and Figure 1.5, it is evident that flexural strength increases as the percentage of copper particulates in the MMCs increases, while it decreases with a higher percentage of nickel particulates. This is due to greater alloy formation with the increasing copper content in the MMC [17].

Table 2: Ultimate tensile strength for all fabricated MMCs

Composite Designation	Sample 1 UTS (MPa)	Sample 2 UTS (MPa)	Mean of UTS (MPa)
Al/Cu/Ni MMC (3NiAl0Cu)	247	259	253
Al/Cu/Ni MMC MMC (3NiAl1Cu)	271	251	261
Al/Cu/Ni MMC MMC (3NiAl2Cu)	266	278	272
Al/Cu/Ni MMC MMC (3NiAl3Cu)	279	299	289
Al/Cu/Ni MMC MMC (0NiAl3Cu)	338	316	327
Al/Cu/Ni MMC MMC (1NiAl3Cu)	313	319	316
Al/Cu/Ni MMC MMC (2NiAl3Cu)	247	259	253

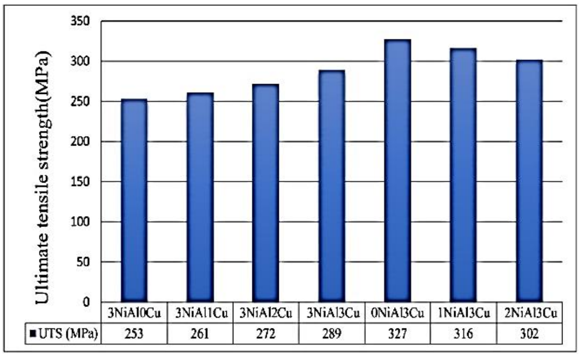

Figure 7: Presents a bar chart displaying the average tensile strength values for all the fabricated MMCs.

Moreover, the copper particles displayed good wettability with the aluminum matrix at the interface, this resulted in strong bonding between the matrix and Cu particles in the MMC, which improved the flexural strength [20]. As a result, an increase in the percentage weight of Cu correlates with an increase in flexural strength. Conversely, the formation of voids escalates with a higher percentage of nickel particles in the MMC due to the incompatibility among the matrix, interface, and reinforcement. The presence of these voids weakens the flexural strength because of reduced interfacial strength within the MMCs [21][13]. Additionally, the brittle particulates in the

MMC, and its quantity increases with a higher percentage of nickel particles [22], further reducing the flexural strength. The highest flexural strength is achieved in the $0NiAl_3Cu$ MMC, which contains 0% weight of Ni and 3% weight of Cu.

Table 3: Flexural strength of the fabricated MMCs

Composite Designation	Sample 1 (MPa)	Sample 2 (MPa)	Average Flexural strength (MPa)
Al/Cu/Ni MMC (3NiAl0Cu)	95	101	98
Al/Cu/Ni MMC MMC (3NiAl1Cu)	128	116	122
Al/Cu/Ni MMC MMC (3NiAl2Cu)	143	149	146
Al/Cu/Ni MMC MMC (3NiAl3Cu)	158	166	162
Al/Cu/Ni MMC MMC (0NiAl3Cu)	244	236	240
Al/Cu/Ni MMC MMC (1NiAl3Cu)	213	203	208
Al/Cu/Ni MMC MMC (2NiAl3Cu)	192	182	187

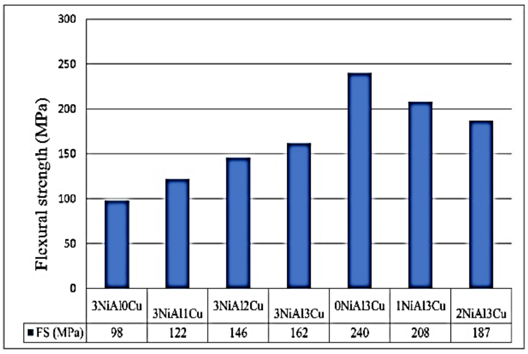

Figure 8: Variations in flexural strength for all MMC

7. CONCLUSION

- The $0NiAl_3Cu$ MMC, which has 0% Ni and 3% Cu, showed the highest ultimate tensile strength and flexural strength within all the MMCs made.
- Additionally, both ultimate tensile strength and flexural strength rise with increased copper content but fall with the addition of nickel.
- Copper (Cu) and Nickel (Ni) particles are harder than aluminum, so when they are mixed into the aluminum, they make the material stronger. These hard particles help the aluminum resist stretching or pulling forces (tensile forces) better than pure aluminum alone.
- While tensile strength increases, the matrix becomes less ductile due to the incorporation of hard particles, which reduces its ability to withstand flexural loads.

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