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Investigation of Wear Properties of Microtitanium and CNT Particulates Reinforced Copper Hybrid Metal Matrix Composite

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***Abstract:** Current engineering applications require materials that are stronger, lighter, and less expensive. Substituting composite structures for conventional metallic structures has many advantages because of higher specific stiffness and strength of composite materials. In the recent days, there is a huge demand for a lightweight material such as composites seems to be a promising solution to this arising demand. These materials have gained attention due to their applications in the field of automotive, aerospace, sports goods, medicines, and household appliances. This study represents the work done by various researchers and their methodologies. In contrast with most metallic materials, copper alloy has many remarkable properties, such as its excellent electrical and thermal conductivities, good strength, and formability, having outstanding resistance to corrosion and fatigue, and others. Due to their excellent properties, copper alloy is widely used in electrical, automotive, architecture, petrochemicals, transportation, and marine industry. In this work the different percentages of CNT and Micro-Titanium are reinforced with pure Copper and are studied. The current work investigated the influence of the CNT and Micro-Titanium on the wear behavior (tribological behavior) of developed hybrid metal matrix composite.*

The conventional liquid stir casting technique will be used for the fabrication of the composite materials. The composite was produced considering combination of0.5, 1, 1.5 percentages of CNT and 1, 3, 5 percentages of Micro-Titanium. The specimens were prepared as per ASTM standard size by turning and facing operations to conduct wear test. The specimens for investigation of wear were tested using pin on disk apparatus. Through the results, it is concluded that the hybrid MMC obtained has got better reduction in wear rate. The inclusion of CNT has played a major role in reducing the wear rate and addition of micro titanium has decreased the wear rate to some extent

Keywords: Wear, Copper, Micro titanium, CNT, MMC

I. INTRODUCTION

A composite material consists of two or more distinct materials which have been mechanically or metallurgically bonded to a non-uniform solid. Each of the various composites preserves its identity in the composite, maintaining its particular properties such as rigidity, weight, high temperature, resistance to corrosion, hardness and conductivity that cannot be achieved by individual components alone. Examples of classic composites are brick that consists of clay mixed with grass and concrete, consisting of cement and sand. In this example, clay and cement are matrix components, whereas grass and sand are components that strengthen them. Many modern engineering systems have in-service performance requirements that necessitate materials with a wide range of qualities, which are challenging to achieve using monolithic material systems. In a number of technological applications, Metal matrix composites (MMCs) were discovered to offer the customised property combinations required. These combinations are only a few of these characteristics: high specific strength, low thermal coefficient and high thermal resistance, good damping, excellent wear resistance, high special stiffness and adequate corrosion resistance. Metal matrix composites (MMCs) are a specialised combination of metal (matrix) and hard particle or ceramic (reinforcement) that are engineered to achieve the desired qualities. In order to create better characteristics of the metal matrix composite, the distribution of reinforcing material in the matrix should be consistent and the linkage or wettability must be assured. According to the literature, the main challenge was to achieve homogeneous ceramic particle dispersion utilising low-cost conventional equipment for commercial applications.

Copper and its alloys, among the different matrix materials available, are frequently used in the construction of MMCs and have reached industrial production level. Because of the anticipated possibilities of these combinations in generating highly desirable composites, the focus has been on building inexpensive Cu-based MMCs with various hard ceramic reinforcements such as Al2O3, SiC, TiB, B, C, and others. Micro titanium is an interesting reinforcement for copper and its alloys because it has many of the mechanical and physical properties that an effective reinforcement should have, including high stiffness and hardness.

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Stir cast copper micro titanium particulate MMCs constitute a type of low-cost tailor-made materials for a larger range of engineering applications, involving cylinder blocks, piston and piston insert rings, and braking disk/drums. Because of their exceptional technological qualities, for instance low low wear rate and co-efficient of friction, their applications are being investigated. This has inspired a surge in study into the effects of reinforcing type and weight fraction, as well as the manufacturing technique for MMCs. In the present investigation, the effect of CNT and Micro-Titanium in different percentages with Copper is studied. Thus this aided in reaching an optimum weight of percentage reinforcement the specific objective & scope of the present investigation.

II. MATERIALS AND SPECIMEN PREPARATION

A. Copper

Copper and copper alloys are widely used in a variety of products that enable and enhance our everyday lives. They have excellent electrical and thermal conductivities, exhibit good strength and formability, have outstanding resistance to corrosion and fatigue, and are generally nonmagnetic. They can be readily soldered and brazed, and many can be welded by various gas, arc and resistance methods.

Figure: Copper

B. CNT

Carbon nanotubes (CNTs) are allotropes of carbon with a cylindrical nanostructure. CNTs are cylindrical large molecules consisting of a hexagonal arrangement of hybridized carbon atoms, which may by formed by rolling up a single sheet or multiple sheets of graphene. In particular, owing to their extraordinary thermal conductivity and mechanical and electrical properties, carbon nanotubes find applications as additives to various structural materials

Figure: CNT

C. Micro-titanium

Titanium is a lustrous transition metal with a silver color, low density, and high strength. Titanium can be alloyed with iron, copper, aluminum, vanadium, and molybdenum, among other elements, to produce strong, lightweight alloys for variuos applications. The processing of titanium metal occurs in four major steps: reduction of titanium ore into "sponge", a porous form; melting of sponge, or sponge plus a master alloy to form an ingot; primary fabrication, where an ingot is converted into general mill products such as billet.

Figure: Micro-titanium

D. Manufacturing Process

1) *Stir Casting:* The microstructure of any material is a complex function of the casting process, subsequent cooling rates. Therefore, composites fabrication is one the most challenging and difficult task. Stir casting technique of liquid metallurgy was used to prepare CNT and Micro-Titanium reinforced Copper Metal Matrix Composite.
2) *Procedure*

a) Required amount of Carbon nanotube, Micro-Titanium and pure copper weighed and Kept aside.
b) To reduce moisture content, carbon nanotube powder and Micro-Titanium are preheated to 300° C-350°C and kept at that temperature for about 15 minutes.
c) The copper was then melted in a crucible at above 1085°C in a weighed quantity.
d) Slag is removed using scum powder.
e) Solid dry hexachloroethane tablets are used to degas the molten metal at a temperature of 1000°C.
f) Later the molten metal is stirred to form a vortex and the measured quantity of pre heated carbon nanotubes, Micro-Titanium and Copper are slowly added to the molten metal maintained at a temperature >1000°C with continuous stirring at a speed of 350- 500rpm to a time of 7-10 minutes.
g) The melt containing the reinforced particles was then poured into warmed moulds at a temperature of 1000°C.
h) The castings are taken once the solidification of molten metal takes place

Figure: Casting Set up

Figure: Die

Figure: Pouring Molten metal into die

E. Specimen Preparation

The casted specimens are withdrawn from the mould and machined to required dimension according to ASTM for conducting tensile, compression, corrosion, and hardness tests. For the preparation of specimens the lathe is used.

Figure: Lathe Machine

Figure: Machined Specimens

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III. EXPERIMENTATION

A. Testing

Using a pin-on-disk equipment, this test technique specifies an experimental approach for evaluating the materials wear due to friction while sliding. The wear test was performed considering the ASTM standards G99-95 utilising a pin-on-disc computerised wear testing system, as illustrated in the figure

The pin specimen is usually a ball that is swiftly grasped. The disc or pin specimens are rotated above the disc centre by the test machine. In both the cases, sliding path in the disk surface is a circular path. The plane of the disk may be connected either vertically or horizontally.

Figure: Pin on Disc Wear testing machine

IV. RESULTS AND DISCUSSION

The copper reinforced with CNT and Micro-Titanium (µ-Ti) composites are cast, machined according to ASTM standard and tested to explore its hidden Tribological properties. The obtained values are tabulated and plotted. Results are justified with theoretical backgrounds.

A. Considering 10N load

1) 200 RPM speed

Table 5.1 Wear rate of copper hybrid metal matrix composites at 10N & 200 RPM

	Wear rate in µm		
Reinforcements	0.5% CNT	1% CNT	1.5% CNT
1 % µ-Ti	480	360	267
3 % µ-Ti	357	230	195
5 % µ-Ti	289	140	120

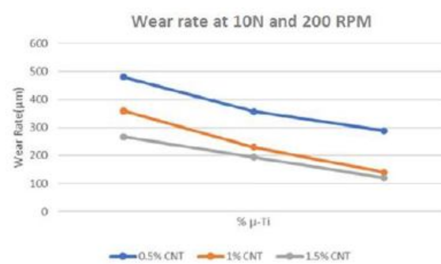

Figure 5.1 Wear rate of copper hybrid metal matrix composites at 10N & 200 RPM

2) 300 RPM speed

Table 5.2 Wear rate of copper hybrid metal matrix composites, at 10N & 300 RPM

	Wear rate in µm		
Reinforcements	0.5% CNT	1% CNT	1.5% CNT
1 % µ-Ti	560	460	415
3 % µ-Ti	450	347	256
5 % µ-Ti	325	237	180

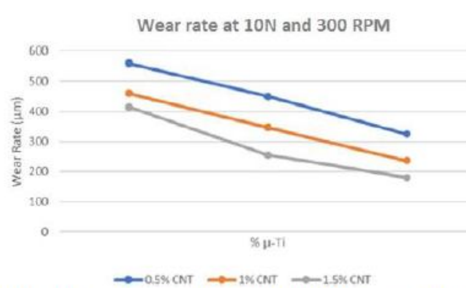

Figure 5.2 Wear rate of copper hybrid metal matrix composites, at 10N & 300 RPM

3) 400 RPM speed

Table 5.3 Wear rate of copper hybrid metal matrix composites, at 10N & 400 RPM

	Wear rate in µm		
Reinforcements	0.5% CNT	1% CNT	1.5% CNT
1 % µ-Ti	875	675	650
3 % µ-Ti	468	375	295
5 % µ-Ti	365	318	210

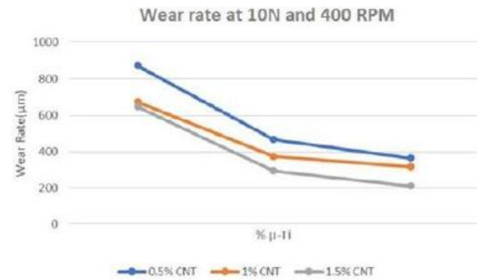

Figure 5.3 Wear rate of copper hybrid metal matrix composites, at 10N & 400 RPM

4) 500 RPM speed

Table 5.4 Wear rate of copper hybrid metal matrix composites at 10N & 500 RPM

	Wear rate in µm		
Reinforcements	0.5% CNT	1% CNT	1.5% CNT
1 % µ-Ti	1110	850	772
3 % µ-Ti	655	460	356
5 % µ-Ti	467	358	280

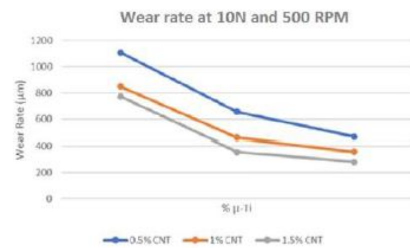

Figure 5.4 Wear rate of copper hybrid metal matrix composites at 10N & 500 RPM

The wear resistance enhances with increasing the percentage of micro titanium(1%, 3%, and 5%) and CNTs(0.5%,1.0%,1.5% CNT) in CNT in Copper based MMC. The content micro-titanium has a vital role on wear resistance of developed composite that is found clearly in the wear rate of Copper reinforced with 0.5 % CNTs and 1 %, 5 % of micro-titanium.ie 29.91 % reduction in wear rate.

B. Considering 20N load

1) 200 RPM speed

Table 5.5 Wear rate of copper hybrid metal matrix composites, at 20N & 200 RPM

	Wear rate in µm		
Reinforcements	0.5% CNT	1% CNT	1.5% CNT
1 % µ-Ti	753	476	220
3 % µ-Ti	625	368	178
5 % µ-Ti	530	296	150

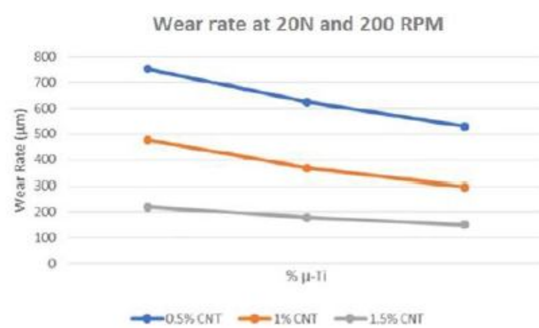

Figure 5.5 Wear rate of copper hybrid metal matrix composites, at 20N & 200 RPM

2) 300 RPM speed

Table 5.6 Wear rate of copper hybrid metal matrix composites at 20N & 300 RPM

	Wear rate in µm		
Reinforcements	0.5% CNT	1% CNT	1.5% CNT
1 % µ-Ti	780	598	420
3 % µ-Ti	650	456	270
5 % µ-Ti	600	364	210

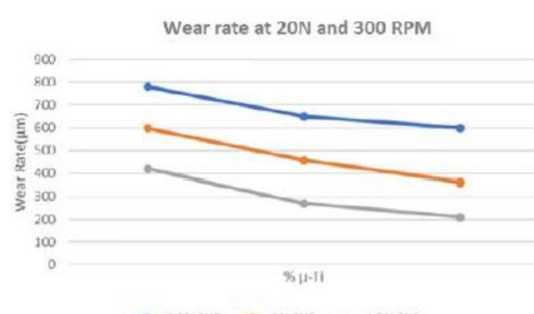

Figure 5.6 Wear rate of copper hybrid metal matrix composites at 20N & 300 RPM

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3) 400 RPM speed

Table 5.7 Wear rate of copper hybrid metal matrix composites at 20N & 400 RPM

	Wear rate in µm		
Reinforcements	0.5% CNT	1% CNT	1.5% CNT
1 % µ-Ti	965	864	584
3 % µ-Ti	740	526	344
5 % µ-Ti	695	436	295

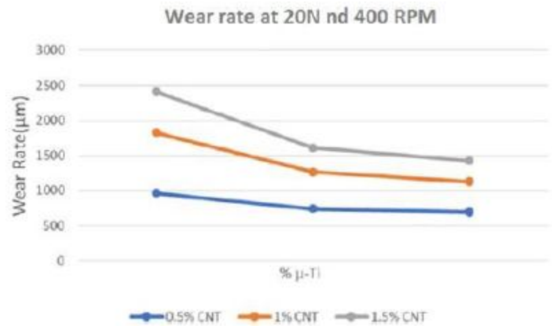

Figure 5.7 Wear rate of copper hybrid metal matrix composites at 20N & 400 RPM

4) 500 RPM speed

Table 5.8 Wear rate of copper hybrid metal matrix composites at 20N & 500 RPM

	Wear rate in µm		
Reinforcements	0.5% CNT	1% CNT	1.5% CNT
1 % µ-Ti	1170	953	670
3 % µ-Ti	875	582	393
5 % µ-Ti	795	470	325

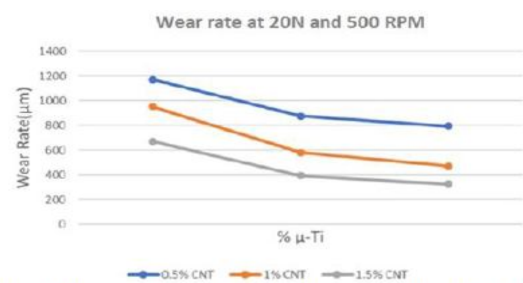

Figure 5.8 Wear rate of copper hybrid metal matrix composites at 20N & 500 RPM

From figures,, the wear rate reduces as the percentage of micro titanium increases from 1%, 3%, and 5% and 0.5%,1.0% and 1.5% CNT in CNT and micro titanium hybrid reinforced Copper based MMC. At 20N load and 200,300,400 &500rpm, the wear rate of developed copper composite found to be decreased due to reduction in pull out of CNTs.

C. Considering 30N load

1) 200 RPM speed

Table 5.9 Wear rate of copper hybrid metal matrix composites at 30N & 200 RPM

	Wear rate in µm		
Reinforcements	0.5% CNT	1% CNT	1.5% CNT
1 % µ-Ti	910	540	425
3 % µ-Ti	660	411	230
5 % µ-Ti	456	375	188

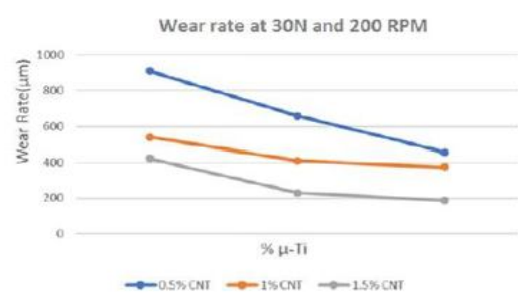

Figure 5.9 Wear rate of copper hybrid metal matrix composites at 30N & 200 RPM

2) 300 RPM speed

Table 5.10 Wear rate of copper hybrid metal matrix composites at 30N & 300 RPM

	Wear rate in µm		
Reinforcements	0.5% CNT	1% CNT	1.5% CNT
1 % µ-Ti	965	595	495
3 % µ-Ti	695	445	286
5 % µ-Ti	509	387	215

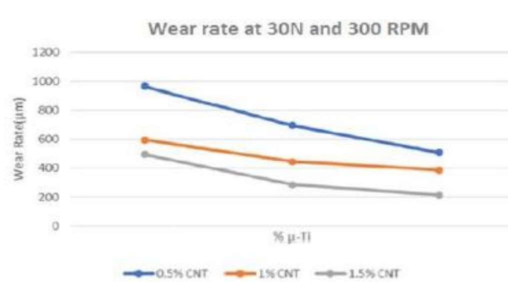

Figure 5.10 Wear rate of copper hybrid metal matrix composites at 30N & 300 RPM.

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3) 400 RPM speed

Table 5.11 Wear rate of copper hybrid metal matrix composites at 30N & 400 RPM

Reinforcements	Wear rate in µm		
	0.5% CNT	1% CNT	1.5% CNT
1 % µ-Ti	1115	630	535
3 % µ-Ti	730	470	310
5 % µ-Ti	520	440	245

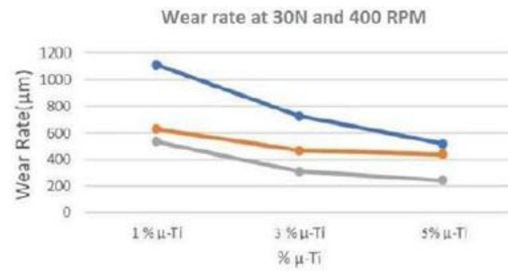

Figure 5.11 Wear rate of copper hybrid metal matrix composites at 30N & 400 RPM

4) 500 RPM speed

Table 5.12 Wear rate of copper hybrid metal matrix composites at 30N & 500 RPM

Reinforcements	Wear rate in µm		
	0.5% CNT	1% CNT	1.5% CNT
1 % µ-Ti	1148	680	625
3 % µ-Ti	786	496	325
5 % µ-Ti	547	480	258

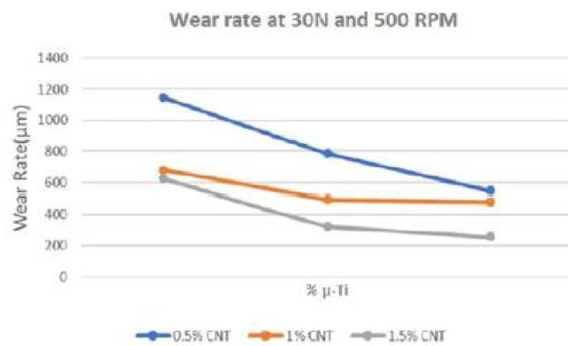

Figure 5.12 Wear rate of copper hybrid metal matrix composites at 30N & 500 RPM

The wear rate decreases as the percentage of micro titanium increases from 1%, 3%, and 5% and 0.5%, 1.0% and 1.5% CNT in CNT and micro titanium hybrid reinforced Copper based MMC. At 30N load and 200, 300, 400 & 500 rpm, the wear test results in reduction of wear rate due to high interfacial bonding of CNTs and Micro-titanium particles with copper that prevents the pull out of micro-titanium parties. This is the main reason of improved wear resistance.

D. Comparative Analysis

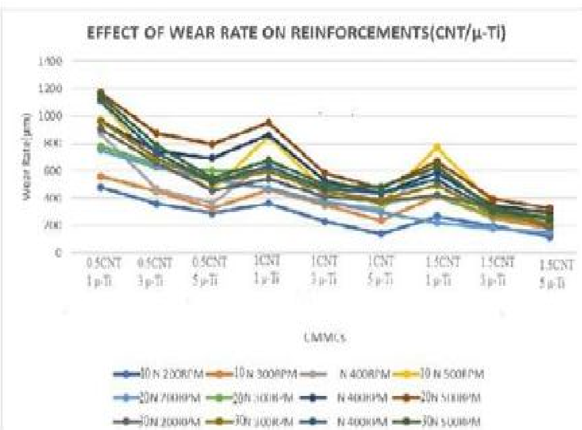

Figure 5.13 Effect of wear rate on reinforcements at different speeds and loads

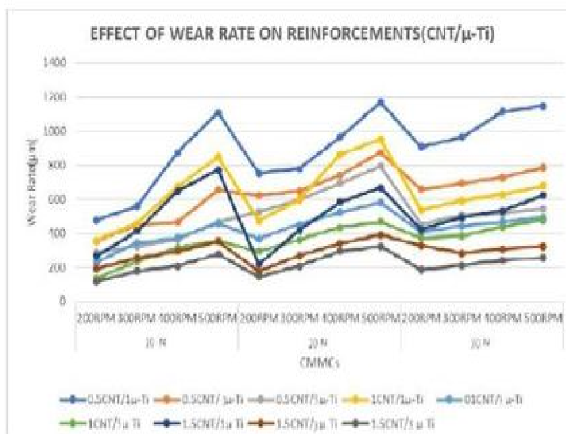

Figure 5.15 Comparative analysis of wear rate of copper hybrid composites.

The wear rate of the composites with 1.5 wt. % CNTs/ 3 % µ-Ti is reduced by 75% when compared to the 0.5 wt. percent CNT 1 wt. percent -Ti specimen, demonstrating that CNTs/- Ti has a high wear rate reduction impact. The wear rate of CNT/-Ti specimens is lower than that of pure Cu specimens under dry sliding wear conditions. This suggests that when compared to pure Cu specimens, the CNTs/-Ti/Cu combination has a greater wear resistance

E. Effect of Wear Rate on Sliding Speed

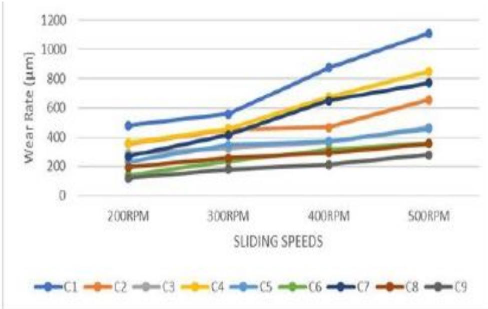

Figure 5.16 Effect of wear rate on different sliding speeds and sliding load of 10N

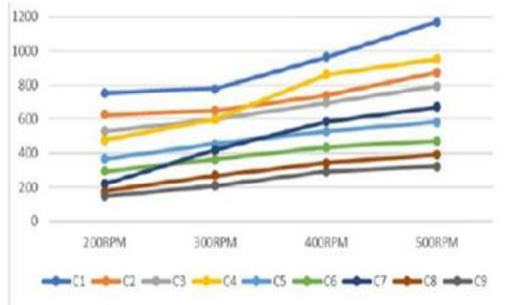

Figure 5.17 Effect of wear rate on different sliding speeds and sliding load of 20 N

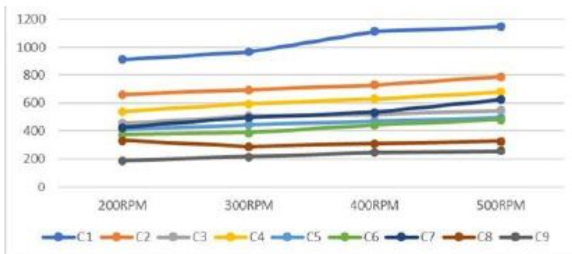

Figure 5.18 Effect of wear rate on different sliding speeds and sliding load of 30 N

With increasing CNT/-Ti content, the wear rate of each CNT/-Ti reinforced copper composite specimen decreased. Wear rate increases as load increases up to 20 N. The wear rate quickly increases at greater loads, where the transition from mild to severe wear occurs. The friction and wear rose noticeably as a result of the high loads used.

F. Effect Of Wear Rate On Sliding Load

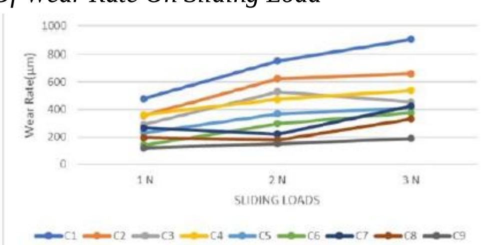

Figure 5.19 Effect of wear rate on different sliding loads and sliding speed of 200 RPM

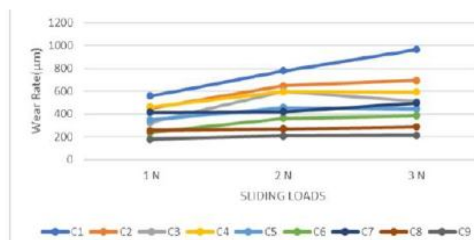

Figure 5.20 Effect of wear rate on different sliding loads and sliding speed of 300 RPM

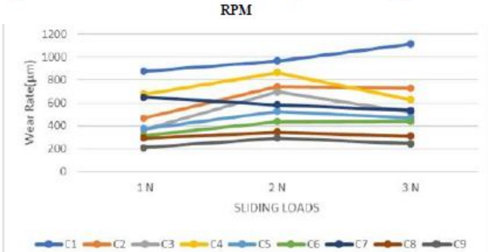

Figure 5.21 Effect of wear rate on different sliding loads and sliding speed of 400 RPM

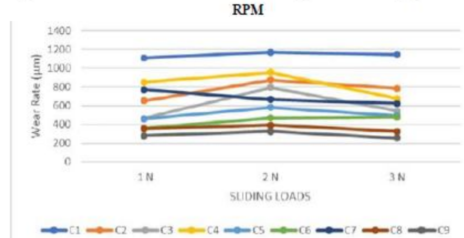

Figure 5.23 Effect of wear rate on different sliding loads and sliding speed of 500 RPM

From above figures, it is concluded that the wear rate of copper metal matrix composites increases with increase in sliding speed of 200,300,400 & 500 rpm at load of 10 N,20 N & 30 N. With an increase in speed, the weight loss volume increases slightly. It can be observed from the Figures that as sliding speed increases from 200 to 500 RPM the wear rate increases for copper metal matrix composites. The reason behind this is that when the sliding speed increases, the amount of frictional heat energy increases. The heat energy dissipated softens and weakens the matrix interface, allowing particles to be pulled out more easily.

V. CONCLUSION

The Copper reinforced with CNT and Micro-Titanium is manufactured and their inherent properties are found out via different tests. The major contribution of the research work is concluded below.

A. The effect of CNT and micro titanium particles on the sliding wear resistance in Copper alloys varies with the depending load and speed.
B. For every composite combination, the wear rate rose as the speed and load increased. However, because CNT is the major reinforcement, the wear rate has been reduced marginally. The addition of micro titanium reduced the wear rate to some extent; however CNT plays a crucial role in reducing the wear rate.
C. In unreinforced matrix alloys, transition to severe wear occurs above the critical load. On the other hand, the reinforced MMC's have a higher wear resistance. With increment in the % of CNT, the decrease in the wear rate has been observed and it is proven from the test results that as the percentage of micro titanium increased in the composite, the wear rate decrease which is a good sign for production of low cost material.
D. The best combination for better wear resistant is at 5% of micro titanium and 1% &1.5%of CNT as consideration.

The wear resistance of metal-metal and metal-particle wear in material increased with increasing distance from the center of the specimen. During a metal wear test, the material's worn surface revealed the creation of an iron-rich transfer layer. The grooving action of the abrasion grains accelerated abrasive wear. Abrasion resistance of the composite was decreased with the size of particle. For higher speeds and weights, composites exhibited a significant increase in abrasion rate.

VI. ACKNOWLEDGMENT

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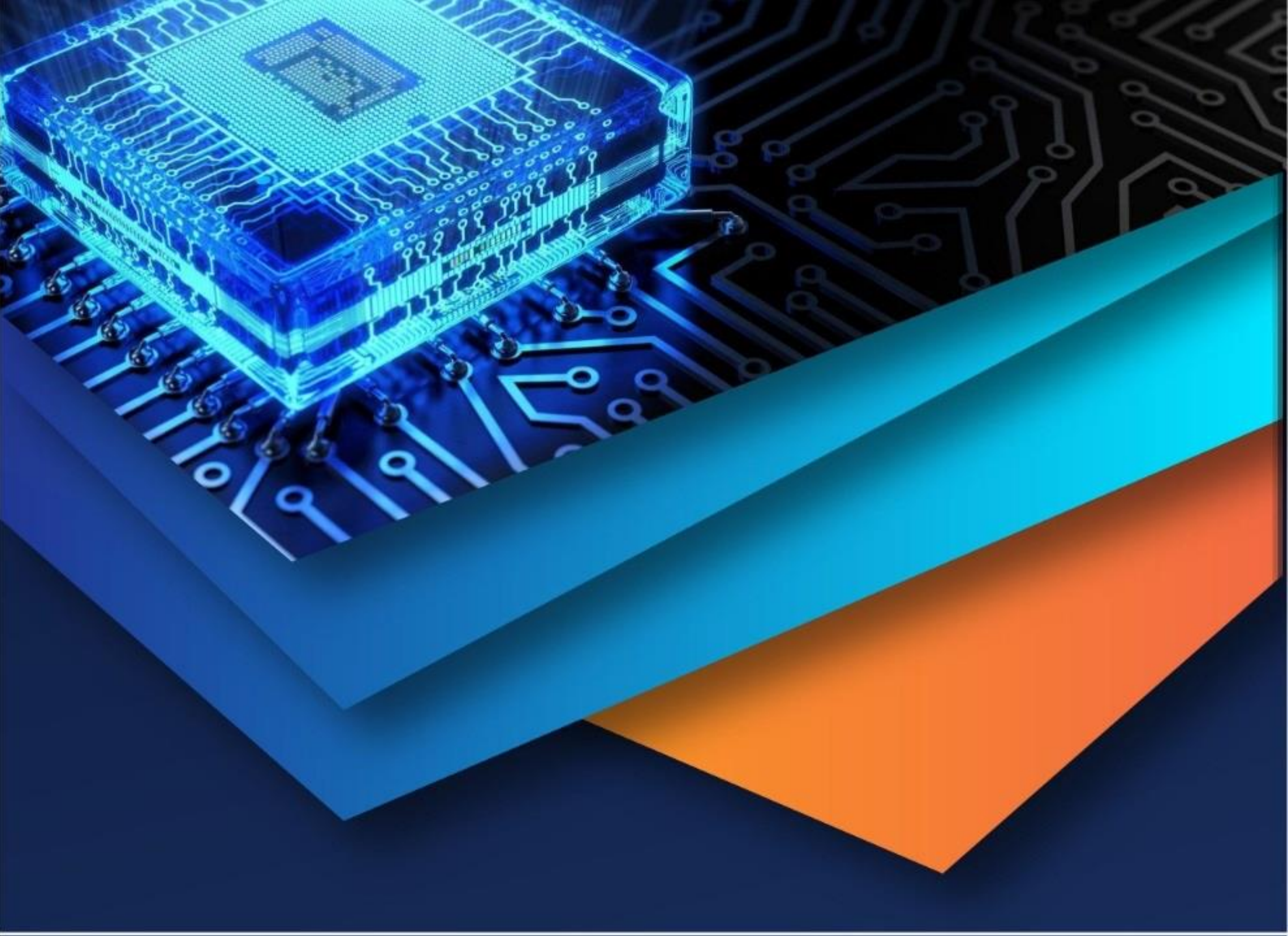

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