iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 7 Issue: VIII Month of publication: August 2019

DOI: http://doi.org/10.22214/ijraset.2019.8038

Evaluation of Wear Properties of Micro titanium and Carbon Nanotubes Reinforced Copper Based Metal Matrix Composites

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Abstract: Over the year's manufacturers and researchers have paid attention and showed interest on metal matrix composites. These MMC's composites by the virtue of properties like high strength to weight ratio. High temperature strength and excellent creep, fatigue and wear resistance have a demand in the current market. The current work focusses on the influence and contribution of single or multi walled carbon nanotube and micro titanium to the wear properties of copper matrix composites. The metal matrix composites were subjected to stir casting by varying different weight fractions of micro titanium and carbon nanotubes after casting the composites were subjected to wear test and wear test were conducted as per ASTM standards G99-95a.The results of experiments conducted and results obtained are successfully highlighted and the use of experimental reinforcing limits of micro titanium on wear characteristics of copper composites were successfully studied on this paper.
Keywords: Stir casting, copper matrix, micro titanium, carbon nanotubes, ASTM standards.

I. INTRODUCTION

Metal matrix composites are composed of a metallic matrix (aluminium, manganese, iron, cobalt, copper) and a dispersed ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) phase. Metal matrix composites are generating a wide interest in research fraternity are due to properties like these metal matrix composite can withstand elevated temperatures in corrosive environment than polymer composites and hence they are preferred. Traditional materials do not always provide the necessary properties under all service conditions. Metal matrix composites are advanced materials resulting from a combination of two or more materials in which tailored made properties are the requirements. In the recent years there has been a considerable interest in the use of metal matrix composites due to their superior properties. Though many desirable properties are obtained through finer reinforcement these composites exhibit isotropic behavior and are not easily producible by the conventional techniques. The properties like high strength to weight ratio, high stiffness to weight ratio makes the metal matrix composites for the suitable application. If metallic matrix materials have to offer high strength, they require high modulus reinforcements.

Hybrid composites are the most advanced composites as compared to conventional composites. Hybrid composites can have more than one reinforcing phase and a single matrix phase or single reinforcing phase with multiple phases or multiple reinforcing and multiple matrix phases. These hybrid composites have a better flexibility as compared to other reinforced composites. Normally these hybrid composites provide a better stiffness and load bearing qualities and these are advantages in development of a metal matrix composites. The concept of hybrid composites is to extend the tailored made properties in order to suit for the particular design requirements and to offset the disadvantages of one component by the addition of another.

Metal matrix composites have found application in many areas of daily life for quite some time. These innovative materials open up unlimited possibilities for modern material science and development; the characteristics of MMCs can be designed into the material, custom-made, dependent on the application. These metal matrix composites are innovative materials open up to unlimited possibilities for modern science and development the characteristics of MMC's can be designed into material, custom made dependent on the applications.

The processing of metal matrix composites plays a prominent role and the different processing techniques like solid state processing, liquid metal processing, in-situ process is the currently used techniques for metal matrix composites. In this project basically metal stirring process is implement for the processing of the composite materials. The reinforcing and matrix materials such as carbon nanotubes, micro titanium and copper billets are subjected for thorough mixing in a metal stirrer which uses the liquid state processing technique for the processing of metal matrix composites.

In this project work the main materials used to develop metal matrix composites are carbon nanotubes, micro titanium and copper alloys. The carbon nanotubes are the interesting nanostructures with the large potential in any application and hence they are known as carbon nanotubes. These nanotubes are members of the fullerene structural family the main advantages with the carbon nanotubes is that a carbon nanotube as a sheet of graphite rolled into tube at the end of the sheet forming the bonds that close the tube. Micro titanium has low density and corrosion resistant properties and also these micro titanium is considered because of its high strength to weight ratio and their mechanical properties and high melting point. The copper alloys offer high resistance against corrosion and hence these material are considered in our project work.

The main objective of the present research work development of copper based carbon nanotubes and micro titanium reinforced hybrid composites and the main objective of this metal matrix composite is to improve wear properties of the developed metal matrix composites. The literature study plays a prominent role in any projects in this project the literature related to copper composites and carbon nanotubes are mentioned below:

Kyung Tae Kim et al. [1], prepared Cu-CNT composite by Molecular- Level-Mixing method. They studied the thermal expansion behaviour of prepared composite. The results of 5% and 10% CNT volume were 14 ppm K^{-1} and 12.1 ppm K^{-1} respectively which were lower when compared to unreinforced Cu sample with CTE value 17 ppm K^{-1}. This reveals addition of CNT increases the stiffness of composite.

H. Yang et al. [2], studied the effect of the ratio of graphite/pitch coke on the mechanical and tribological properties of copper–carbon composites. Addition of pitch coke in the matrix can much improve the interfacial bonding strength between carbon particles and phenolic resin (binder). The bending strength and micro -hardness of the copper–carbon composites increased with increase in the content of pitch coke and reached a maximum. The friction coefficient of copper–carbon composites increased significantly with increasing the content of pitch coke. The wear rate of composites initially decreased as the content of pitch coke increased and obtained a minimum and then ascended.

Manchang et.al [3] observed that increased in the test/sample temperature resulted in increased wear rate. The increase in test temperature led to increase in coefficient of friction between the contacting surfaces which led to increase in the wear rate. Also the matrix started to lose its ability to hold reinforcing particles with the increase in temperature leading to increased probability of particle pull-out phenomenon.

Summary of literature review: There were major problems and challenges faced in the synthesis of Cu-CNT composites are very common in literature namely, the surface wettability issue was prominent throughout for few metal matrix composites and for this reason the result showed a poor load transfer and this is being the main disadvantage and also non uniform dispersion of carbon nanotubes in copper matrix was a main disadvantage. In order to minimize these defects and disadvantages the addition of micro titanium was crucial in this project and hence this micro titanium provided a better wear properties and hence the wear test was conducted by using a pin on disc apparatus the reading of wear with respect to the RPM is studied in this papers and the results and discussion with respect to wear rate and for different RPM is successfully compared and the conclusion are derived based on the graphical variation of wear rate.

II. MATERIALS AND METHODOLOGY

A. Materials Used

1) *Copper:* Copper was procured in the form of billets. The copper billets used in our project has high thermal conductivity and wear resistance. Copper is considered because of its properties like it has a good ductility and by cold deformation it is possible to reach the strength values close to the strength values of soft steel. Copper is heavily utilized by the electrical and, mechanical industries the main reason is because of its high thermal conductivity and the strength. The figure shows the copper billets used in the experiments to prepare samples.

Fig 1 Copper Billets

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.177
Volume 7 Issue VIII, Aug 2019- Available at www.ijraset.com

2) *Micro Titanium:* Micro titanium is a lustrous transition metal which possesses silver colour, low density and high strength. The characteristics of micro titanium like excellent in corrosion resistance, light weight equivalent to 60% of stainless steel and from strength perspective the tensile strength of 275-735 Mpa and hence due to these properties micro titanium is considered in the powder form and is shown in the below figure.

Fig 2 Micro titanium

3) *Carbon Nanotubes:* Carbon nanotubes are the allotropes of carbon with a cylindrical nanostructure. These cylindrical carbon molecules have unusual properties which are valuable for nanotechnology, electronics, optics and other field s of materials science and technology. Due to its high tensile strength, high electrical conductivity and low thermal expansion coefficient the carbon nanotubes are considered in a power form in this project. The figure shows the carbon nanotubes in project work,

Fig 3. Carbon nanotubes

B. *Methodology Used in Project*

The methodology can be discussed by using the following

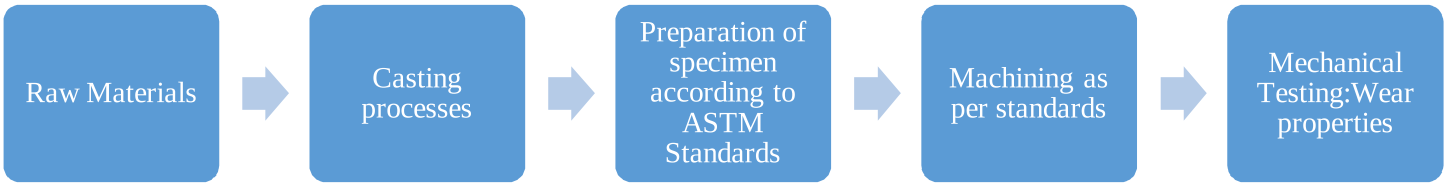

Fig 4 Methodology of project work

The objective of this study is to determine wear properties according to ASTM standards G99-95a.

III. EXPERIMENTATION

In this section the experimentation of the composites is discussed based on the following steps namely:

A. Casting

The casting is a manufacturing process by which a liquid metal is poured into mould which contains hallow cavity of desired shape and then allowed to solidify the solidified part is known as casting. The specimens when subjected to casting involves microstructure which is function of casting process. The fabrication of the composites plays a prominent role in any of the manufacturing process in our project the stir casting is a processing technique and this technique is used in the preparation of the copper alloy composites.

The copper billets were loaded to graphite crucible and placed in the coke fired furnace and melted at a temperature above 1500^{o}C.The stirrer was introduced into molten metal to create a vortex and rotated to a speed of 200-300RPM.The Micro titanium and CNT were preheated in graphite crucible and was introduced into vortex of molten metal and was stirred well. The below figure shows the stir casting setup of coke fired furnace.

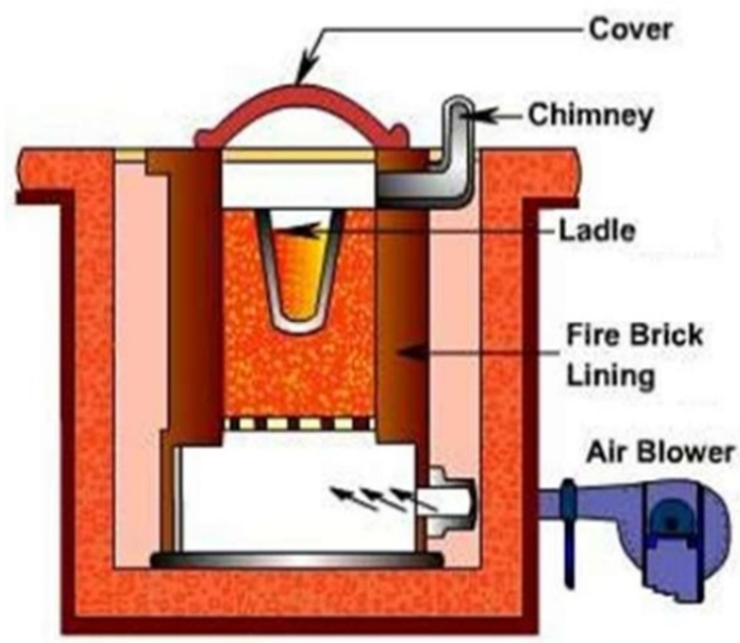

Fig 3 Coke fired furnace

After the discussion of the coke fired furnace it is important to note the composition of the copper composite which is shown in the below table:

Table 1 Compositions of copper composites

Compositions	Percentage of Carbon nanotubes %	Percentage of Micro titanium %	Percentage of Copper %
C	0	0	100
C1	0.5	1	98.5
C2	0.5	3	96.5
C3	0.5	5	94.5
C4	1	1	98.5
C5	1	3	96.5
C6	1	5	96.5
C7	1.5	1	98.5
C8	1.5	3	96.5
C9	1.5	5	94.5

B. Machining

In this section after casting the specimen were subjected to machining as per standards on the lathe machine. The specimen is fabricated as for the ASTM standards with a diameter of 6mm and a length of 30mm as shown in the below figure;

Fig 5 Casted specimens

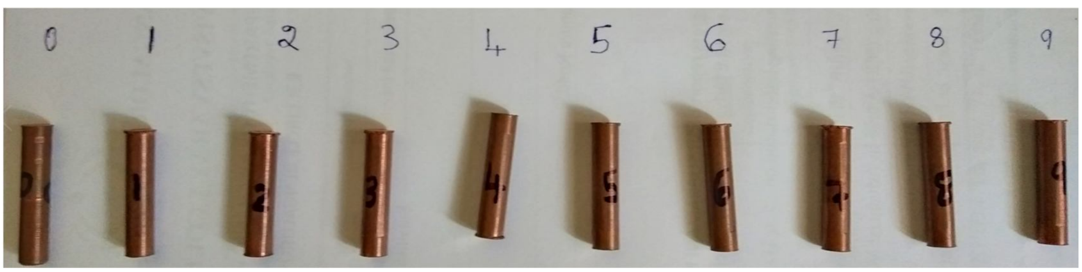

Fig 6 Wear test specimen

C. Testing

After casting and machining of the copper composites the specimens are subjected to wear test which was conducted using a pin on disc computerized wear testing machine according to ASTM standard G99-95. The test uses the specimen of diameter of 6mm and length of 30mm machined specimens. The line diagram of pin on disc wear machine is shown in the below figure;

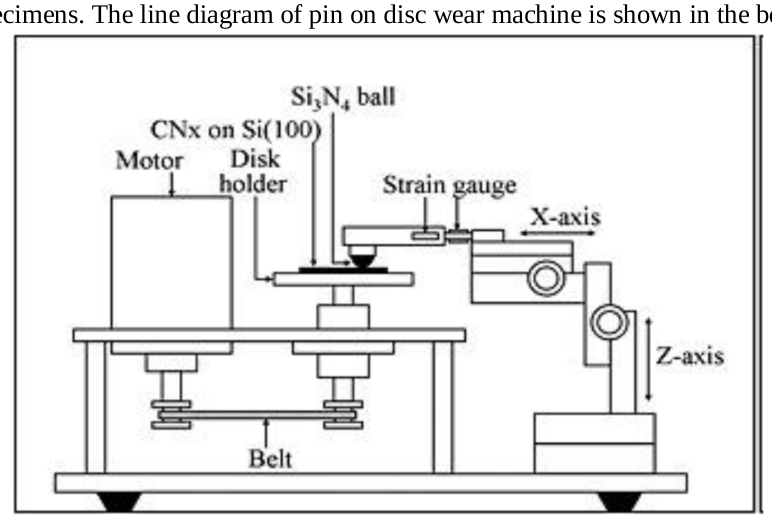

Fig 7 Line diagram of Pin on disc wear test machine

During the pin on disc wear test the following steps are followed:

Prior to the testing and measuring the wear rate, clean and dry the specimen to remove dirt and foreign substances from the specimen. After cleaning insert, the disc securely in the holding device so that the disc is fixed perpendicular at 61^{o} to the axis of resolution in order to meet the contact conditions. Add a proper mass to the system lever to develop selected force pressing the pin against the disc. Start the motor set the revolution counter to desired number of revolution. Begin the test with the specimens in the contact of load. The test is stopped when the desired number of revolution is achieved. Remove the specimen and clean off any wear debris. The reading of wear rate with varying RPM is noted and the graph is plotted for the same from the computerised machine.

IV. RESULTS AND DISCUSSION

The wear property of copper composites developed by varying the percentage of micro titanium and CNT by pin on disc wear testing method the following effect of wear rate is discussed below with graphical representation;

A. Effect Of Carbon Nanotube And Micro Titanium On Wear Rate

The study of wear is an important phenomenon in for a metal matrix composites and these wear properties are considered as tribological properties and hence plays a prominent role in any of the metal matrix composites. The presence of the reinforcement has been reported decrease the wear rate with the variation in higher loads. In this case the loads at which transition occurred were found to be much higher and this is considered as an important factor. The below table gives an idea of wear rate at different RPM and load and the graphical representation are shown based on the wear rate of composites with the increase in reinforcement content. The improvement in wear resistance was based on low loads due to presence of reinforcements and the reduction in the wear rate by 30-35% was noted as the content of CNT (1-1.5%) and micro titanium (1-5%) was varied. Wear rate for the copper composites with different composition and different loads are shown in the below table;

Table 2 wear rate at load 1N

MODELS WEAR RATE	LOAD 1N			
	SPEED RPM			
	200RPM	300RPM	400RPM	500RPM
C1	480	560	875	1110
C2	357	450	468	655
C3	289	325	365	467
C4	360	460	675	850
C5	230	347	375	460
C6	140	237	318	358
C7	267	415	650	772
C8	195	256	295	356
C9	120	180	210	280

Table 3wear rate at load 2N

MODELS WEAR RATE	LOAD 2N			
	SPEED RPM			
	200RPM	300RPM	400RPM	500RPM
C1	753	780	965	1170
C2	625	650	740	875
C3	530	600	695	795
C4	476	598	864	953
C5	368	456	526	582
C6	296	364	436	470
C7	220	420	584	670
C8	178	270	344	393
C9	150	210	295	325

Table 4 wear rate at load 3N

MODELS WEAR RATE	LOAD 3N			
	SPEED RPM			
	200RPM	300RPM	400RPM	500RPM
C1	910	965	1115	1148
C2	660	695	730	786
C3	456	509	520	547
C4	540	595	630	680
C5	411	445	470	496
C6	375	387	440	480
C7	425	495	535	625
C8	330	286	310	325
C9	188	215	245	258

The graphical representation of the above tabulate reading of wear rate and varying reinforcement is discussed below:

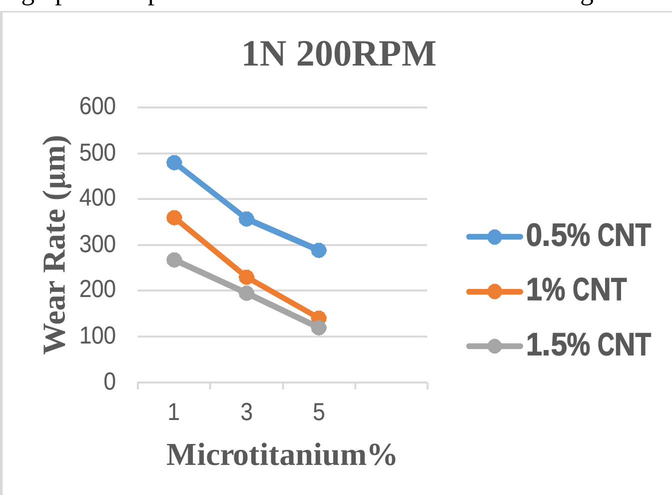

Fig Wear rate decrease as the percentage of CNT and Micro titanium increases at load1N and 200 RPM

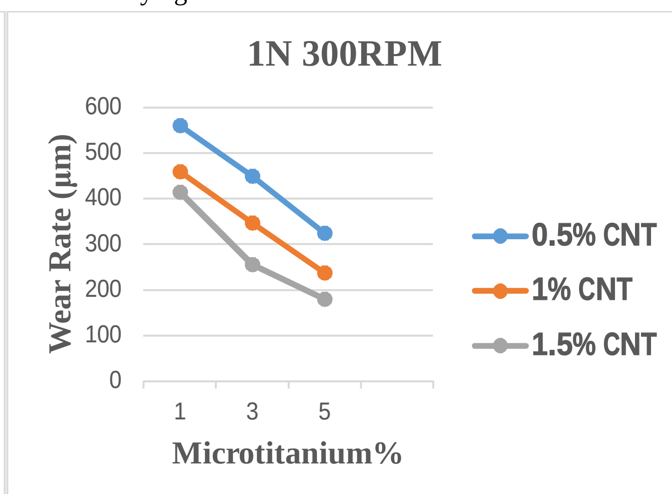

Fig Wear rate decrease as the percentage of CNT and Micro titanium increases at load1N and 300 RPM

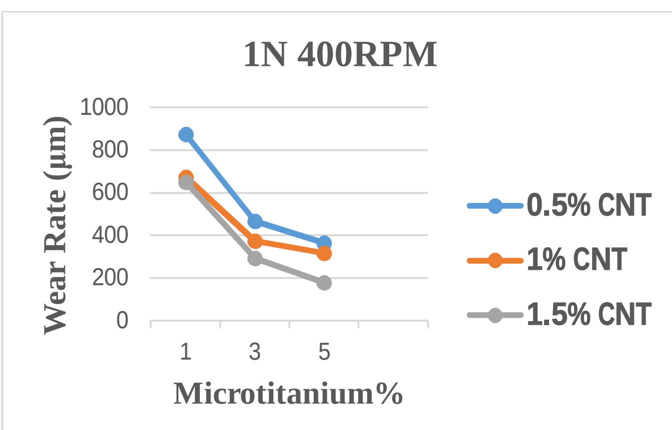

Fig Wear rate decrease as the percentage of CNT and Micro titanium increases at load1N and 400 RPM

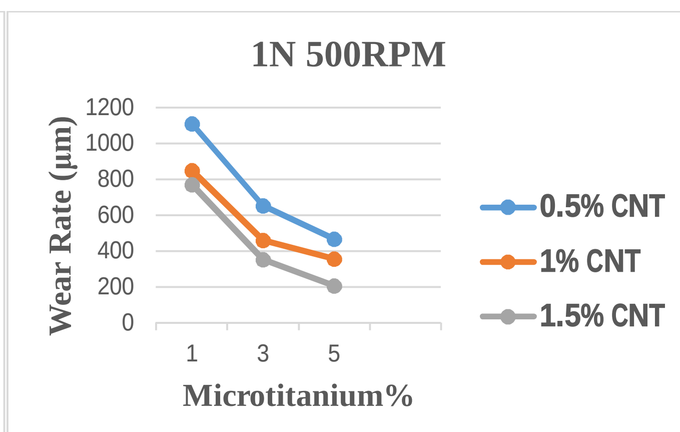

Fig Wear rate decrease as the percentage of CNT and Micro titanium increases at load 1N and 500 RPM

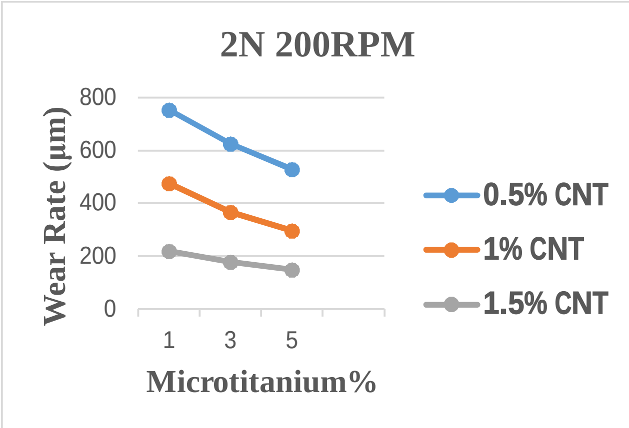

Fig wear rate decrease as the percentage of CNT and Micro titanium increases at load 2N 200RPM

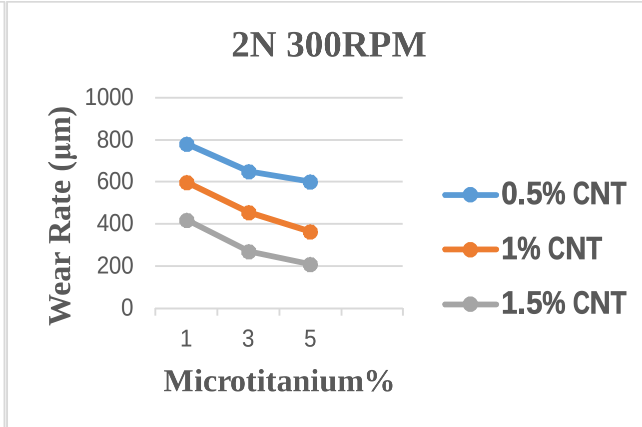

Fig Wear rate decrease as the percentage of CNT and Micro titanium increases at load 2N 300RPM

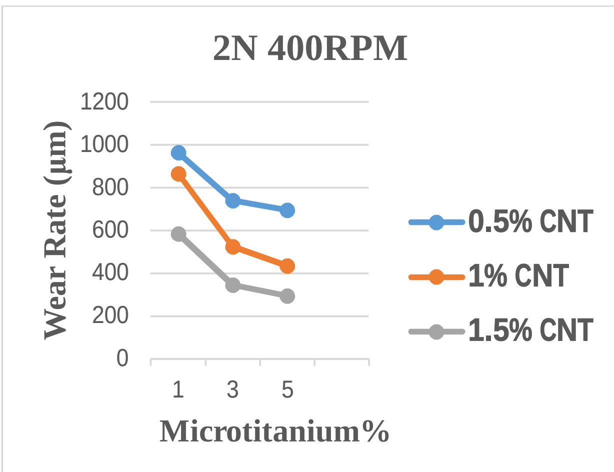

Fig wear rate decreases as the percentage of CNT and micro titanium increases at load 2N 400RPM

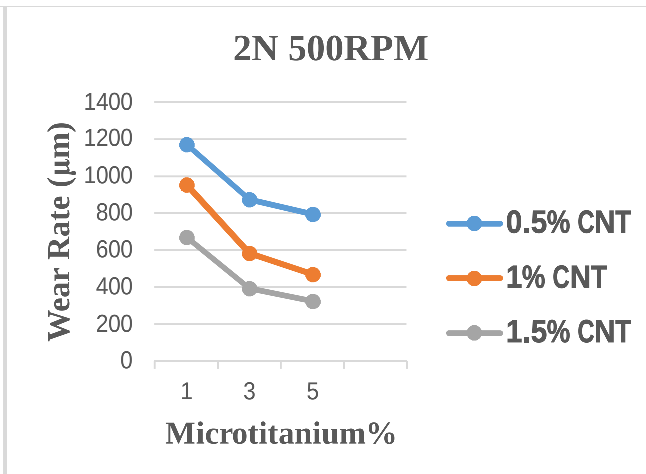

Fig wear rate decreases as the percentage of CNT and micro titanium increases at load 2N 500RPM

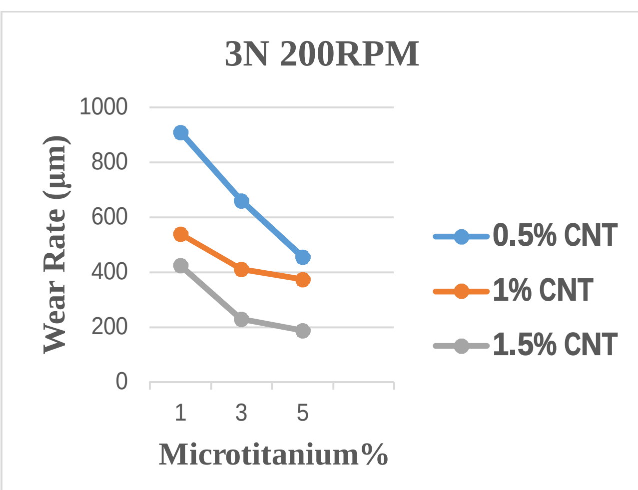

Fig wear rate decreases as the percentage of CNT and Micro titanium increases at load 3N 200RPM

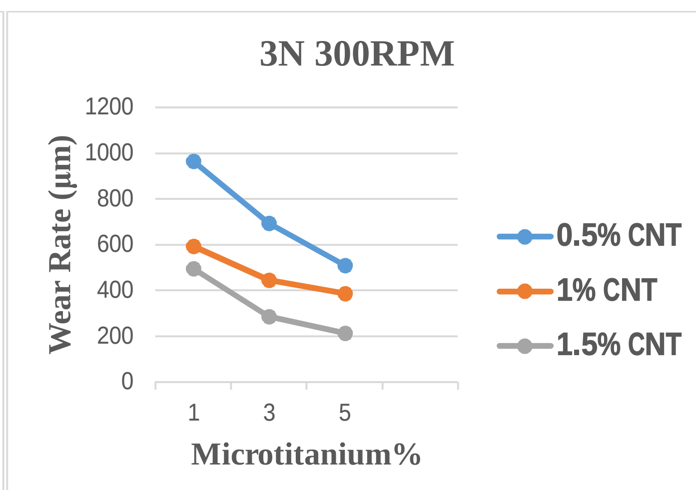

Fig wear rate decreases as the percentage of CNT and Micro titanium increases at load 3N 300RPM

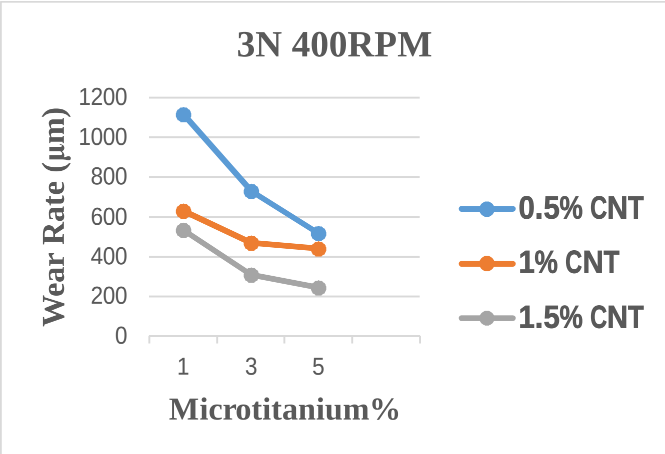

Fig wear rate decreases as the percentage of CNT and Micro titanium increases at load 3N 400RPM

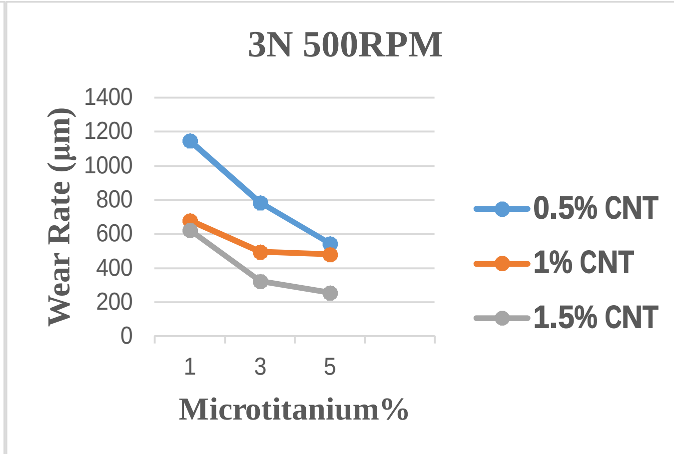

Fig wear rate decreases as the percentage of CNT and Micro titanium increases at load 3N 500RPM

From the above results and discussion, it is cleared that wear rate showed a good behaviour with respect to percentage of micro titanium at different loading at 1N,2N, 3N with respect to different speed at 200RPM,300RPM,400RPM,500RPM respectively, these behaviour is due to variation in percentage of micro titanium and percentage of CNT as reinforcement in the copper matrix.

V. CONCLUSIONS

The developed copper composites can be considered as the effective material for the application of the metal matrix composites in any of the field of application. These MMC feature in an enhancing the various properties like thermal conductivity in many applications.

The current study of copper composites with respect to wear characteristics are discussed in this project work can be the following conclusions can be derived from this work:

A. The best wear resistant combination is at 5% of micro titanium and 1% and 1.5% of carbon nanotube as considered.
B. The effect of CNT and micro titanium on sliding wear resistance copper alloys varies with applied load and speed.
C. Wear rate increased from every combination with the increase in speed and load with every combination of copper combinations.
D. With the increase in carbon nanotube, wear rate has increased and is clear from the result that as the percentage of micro titanium increased in the composite, the wear rate decreased which is a good sign and hence the objective is fulfilled.
E. Above critical loading the transition to severe wear occurs in the unreinforced matrix and hence from this project wok the reinforced composite material had a superior wear resistance.

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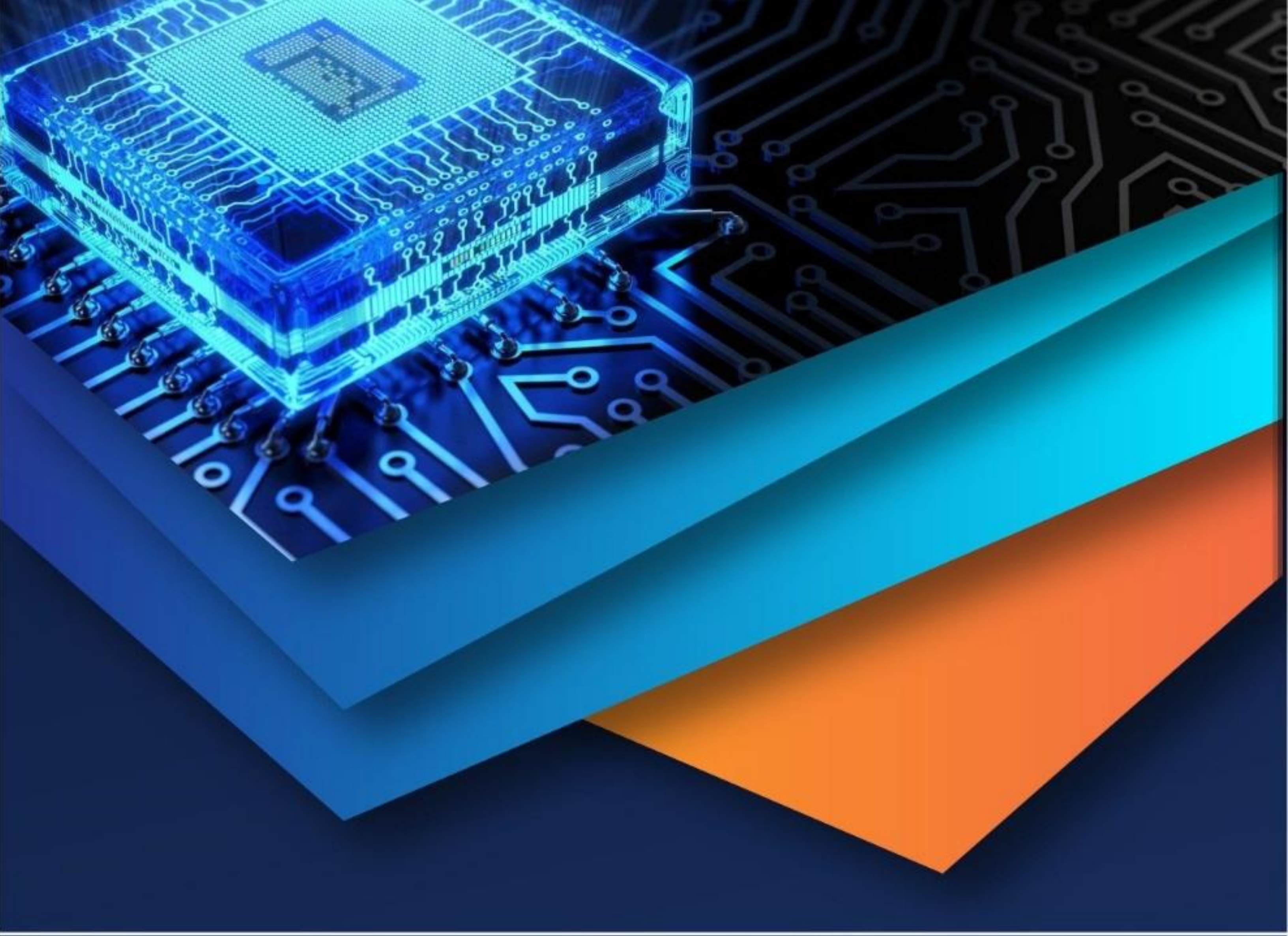

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