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# Investigation of Tribological properties of Micro-Titanium and CNT Reinforced Copper Based MMC

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## ABSTRACT

Copper based composites plays a vital role in the field of marine, aerospace, automobile and power sector for making of components like electrical sliding contacts, gears, bearings, bushes, brakes and clutches etc. CNT is one of the effective reinforcement used in the metal matrix composites by various researches because of its excellent properties. The present work is focused on the preparation of copper/CNTs/Micro-Titanium composite through stir casting technique performance studies of the composite are made on the wear and corrosion behavior. The composite prepared with reinforcement such as CNTs and Micro-Titanium of 0.5, 1, 1.5 % and 1, 3 & 5wt. % were studied. Wear studies were carried out using pin on disc setup as per ASTM G992010. The wear test was carried out in the load range of 10-30N for the sliding speed of 100-500 rpm. Wear rate increased with the increase in speed and load for every combination of the composite. However, with CNT being the main reinforcement with addition of CNT wear rate has reduced marginally. Addition of micro titanium also to some extent decreased the wear rate but CNT plays a major role in reducing the wear rate. At room temperature, the CNT and micro titanium reinforced Copper composites exhibited better corrosion resistance than the pure Copper matrix in NaCl and HCl aqueous solution. Increasing the composition of the CNT and micro titanium particulates increased the corrosion resistance of the CNT and micro titanium reinforced Copper composites. The corrosion resistance increases with increase in duration of time. The improvement in corrosion resistance is due to this factor is attributed to a protective layer formed on the surface of the material which gradually builds up and reaches a steady state with time.

**Keywords:** Micro Titanium, CNT, Wear Rate, Corrosion Rate, MMC.

# I. INTRODUCTION

Generally, a composite material is composed of reinforcement (fibers, particles, flakes, and/or fillers) embedded in a matrix (polymers, metals, or ceramics). The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than would each individual material.

Composites are multifunctional material systems that provide characteristics not obtainable from any discrete material. They are cohesive structures made by physically combining two or more compatible materials, different in composition and characteristics and sometimes in form.

Or

Composite materials are heterogeneous materials consisting of two or more solid phases, which are in intimate contact with each other on a microscopic scale. They can also be considered as homogeneous materials on a microscopic scale in the sense that any portion of it will have the same physical property.

## 1.1 USES

The composites industry has begun to recognize that the commercial applications of composites promise to offer much larger business opportunities than the aerospace sector due to the sheer size of transportation industry. Thus the shift of composite applications from aircraft to other commercial uses has become prominent in recent years. The various reasons for the use of composites are due to:

- To increase stiffness, strength and dimensional stability and to increase toughness and impact strength.
- To increase mechanical damping.
- To reduce permeability to gases and liquids.
- To modify electrical properties. .
- To decrease thermal expansion
- To increase secondary uses and recyclability, and to reduce negative impact on the environment.

## 1.2 Characteristics of composites

Properties of composites are strongly dependent on the properties of their constituent materials, their distribution and the interaction among them. The composite properties may be the volume fraction sum of the properties of the constituents or the constituents may interact in a synergistic way resulting in improved or better properties.

Apart from the nature of the constituent materials, the geometry of the reinforcement (shape, size and size distribution) influences the properties of the composite to a great extent. The concentration distribution and orientation of the reinforcement also affect the properties. The shape of the discontinuous phase (which may by spherical, cylindrical, or rectangular cross sectioned prisms or platelets), the size and size distribution (which controls the texture of the material, and volume fraction determine the interfacial area, which plays an important role in determining the extent of the interaction between the reinforcement and the matrix.

## 1.3 Constituents of composites

In its most basic form a composite material is one, which is composed of at least two elements working together to produce material properties that are different to the properties of those elements on their own. In practice, most composites consist of a bulk material (the "matrix”), and a reinforcement of some kind, added primarily to increase the strength and stiffness of the matrix shown in figure 1.1.

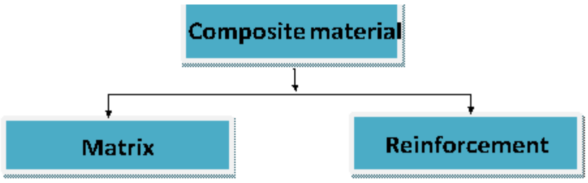

Figure 1.1 constituents of composites.

### 1.3.1 Matrix

Many materials when they are in a fibrous form exhibit very good strength but to achieve these properties the reinforcement should be bonded by a suitable matrix. The matrix isolates the reinforcement from one another in order to prevent abrasion and formation of new surface flaws and acts as a bridge to hold the reinforcement in place. A good matrix should possess ability to deform easily under applied load, transfer the load onto the fibers and evenly distributive stress concentration.

### 1.3.2 Reinforcement

Reinforcement is the minor constituent in the composite material which is actually responsible for improving the properties of the matrix material. This is strong and stiffer than the matrix material.

## 1.4 Classification of composites

Classification of composite is done based on both geometry of reinforcing material and the type of matrix material. Classification scheme for the composite is as illustrated in figure 1.2 shown below.

### 1.4.1 Classification of composites based on Matrix Materials

a) Polymer Matrix Materials
b) Carbon Matrices
c) Metal Matrix Materials
d) Ceramic Matrix Materials

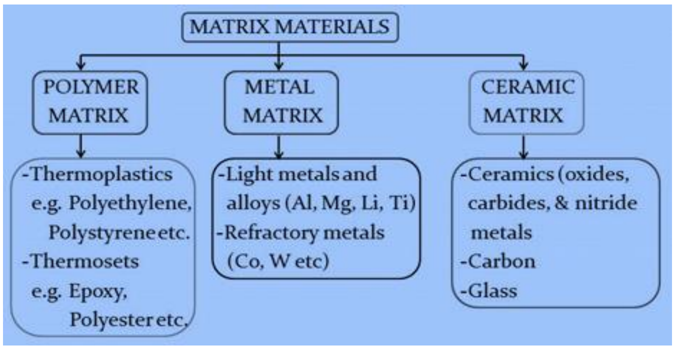

Figure 1.2 Classification of composites based on matrix.

### 1.4.2 Classification of composites based on Reinforcement

a) Fiber Reinforcement
b) Particulate Reinforced Composites
c) Structural Composites (Laminar Composites)

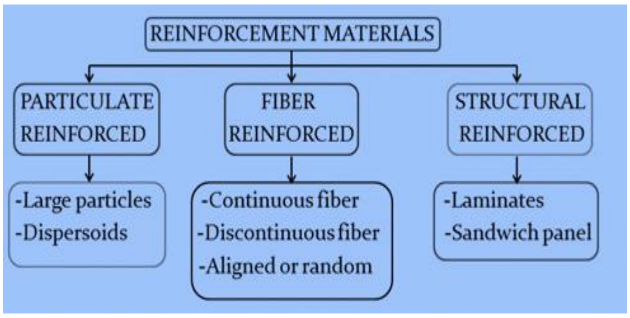

Figure 1.3 Classification of composites based on reinforcements

### 1.1.5 METAL MATRIX COMPOSITES

Metal matrix composite (MMC's) is engineered combination of the metal (matrix) and hard particle or ceramic (reinforcement) to get the tailored properties. Metal composite materials have found application in many areas of daily life for quite some time. Often it is not realized that the application makes use of composite materials. These materials are produced in situ from the conventional production and processing of metals. Here, the Dalmatian sword with its meander structure, which results from welding two types of steel by repeated forging, can be mentioned. Materials like cast iron with graphite or steel with high carbide content, as well as tungsten carbides, consisting of carbides and metallic binders, also belong to this group of composite materials. For many researchers the term metal matrix composites are often equated with the term light metal matrix composites (MMCs).

Substantial progress in the development of light metal matrix composites has been achieved in recent decades, so that they could be introduced into the most important applications. In traffic engineering, especially in the automotive industry, MMCs have been used commercially in fiber reinforced pistons and copper crank cases with strengthened cylinder surfaces as well as particle-strengthened brake disks.

MMC's are used for the space shuttle, commercial airliners, electronic substrates, bicycles automobiles, golf clubs and a variety of other applications. Like all composites, copper matrix composites are not a single material but a family of material whose stiffness, strength, density, thermal and electrical properties can be tailored. The matrix alloy, reinforcement material, volume and shape of the reinforcement, location of the reinforcement and fabrication method can be varied to achieve desired properties. The aim involved in designing MMC's is to combine the desirable attributes of metals and ceramic materials. Metals have useful combination of properties such as medium strength, ductility and high temperature resistance but sometimes have low stiffness, whereas ceramic material is stiff and strong. Though brittle, the addition of high strength, a high modulus refractory particle to a ductile metal matrix produces a material whose mechanical properties are intermediate between the matrix alloy and the ceramic reinforcement.

In fabrication of MMC's by stir casting routs, there are several factors that need considerable attention, including the difficulty of achieving a uniform distribution of the reinforcement material, wettability between the two main substance, porosity in the cast and chemical reactions between the reinforcement and matrix material. In order to achieve the optimum properties of the metal matrix composite, the distribution of the reinforcement material in the matrix must be uniform and the wettability or bonding between these substances should be promised. The literature reveals that the major problem was to get homogenous dispersion of ceramic particle by using low cost conventional equipment for commercial applications. Among various matrix material available, copper and its alloy are widely used in fabrication of MMC's and has reached industrial production stage. The emphasis has been given on developing affordable Cu-based MMC's with various hard ceramic reinforcements such as Al2O), SiC, TiB), B,C etc because of the likely possibilities of these combination in forming highly desirable composites. Micro titanium is an attractive reinforcement for copper and its alloys showing many of the mechanical and physical properties required of an effective reinforcement, in particular high stiffness and hardness. Copper micro titanium particulate MMC's produced by stir casting represents a class of inexpensive tailor made materials for variety of engineering application such as cylinder blocks, piston and piston insert rings, brakes disk/drum. Their uses are being explored in the view of their superior technological properties such as low co-efficient of friction and low wear rate. This has led to increase in research interest on evaluating the effect of type and weight fraction of reinforcement and procedure used to produce MMC's.

Generally, there are two phases, e.g., a fibrous or particulate phase, distributed in a metallic matrix. Examples include continuous Al, fiber reinforced AI matrix composites used in power transmission line Nb-Ti filaments in a copper matrix for superconducting magnets Tungsten Carbide particulate reinforced Al matrix composites used in industrial processes like rotating paddles or impellers, aerospace, automotive, marine industries and thermal management applications.

## 1.6 Processing of Metal Matrix Composites

Metal-matrix composites can be processed by several techniques. Some of these important techniques are described below.

- Solid state processing
- Liquid metal processing
- In situ processing
- Vapor state processing
- Plasma/spray deposition

### 1.6.1 Liquid state processing (Stir casting)

Many times it is better to have the matrix in liquid form so as to facilitate the flow of filling the interstices and to cover completely the fibers, whatever form they may be. That's the reason because the foundry is one of the techniques more used and less expensive to produce metal matrix composites. In such a situation, using a molten bath, production can be increased considerably, it is not coincidence that it is widely used by industry to produce semi-finished products and for this there are several solutions.

Generally, in this case technologies are divided between those that provide for the incorporation of ceramic reinforcement into the liquid metal, and that where the cast is infiltrated into pre-forms of the same reinforcement.

The most common method is explained below.
Both the terms compo-casting and melt stirring are used for stirring particles into a light alloy melt. The particles often tend to form agglomerates, which can be only dissolved by intense stimming. However, here gas access into the melt must be absolutely avoided, since this could lead to unwanted porosities or reactions.

Careful attention must be paid to the dispersion of the reinforcement components, so that the reactivity of the components used is coordinated with the temperature of the melt and the duration of stirring, since reactions with the melt can lead to the dissolution of the reinforcement components. Because of the lower surface to volume ratio of spherical particles, reactivity is usually less critical with stirred particle reinforcement than with copper.

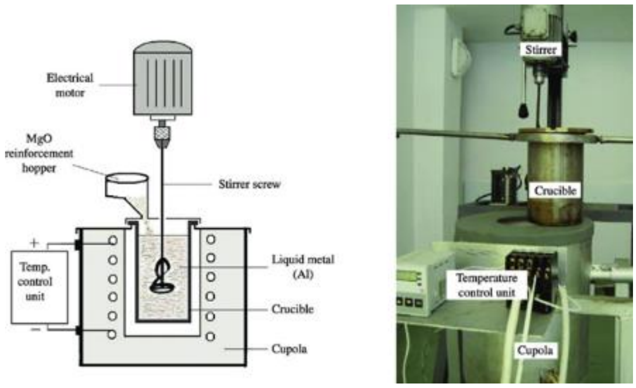

Figure 1.4 melt stirring

## II. METHODS AND MATERIAL

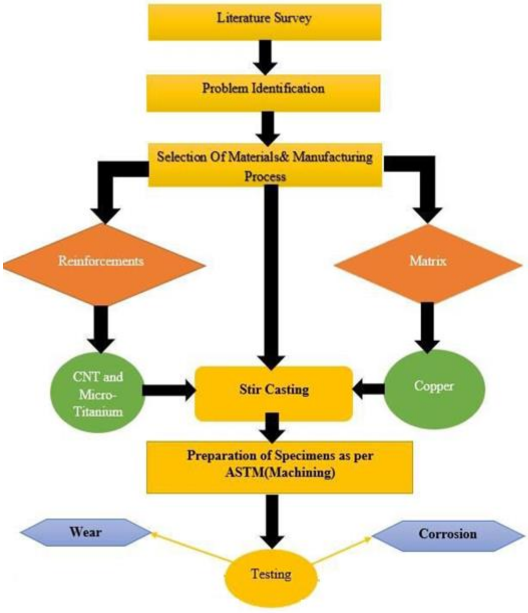

Figure:2.1 Experimental methodology

### 2.1 Material Selection:

In selection of matrix material such as metals or alloys the matrix should be chosen only after giving careful consideration to its chemical compatibility with the reinforcement, its ability to wet the reinforcement and to its own characteristics properties and processing behaviour. One of the very crucial issues to be considered in selection of the matrix alloy composition involves the natural dichotomy between wettability of the reinforcement and excessive reactivity with it. Good load transfer from the matrix to the reinforcement depends on the existence of a strongly adherent interface. In turn, a strong wetting and aggressive reactivity are both favored by strong chemical bonding between the matrix and reinforcement. Adjusting the chemical compositions to execute this is difficult as many substitutes are involved.

As a rule of alloying element addition, the added element should not form inter metallic compounds with the matrix elements and should not form highly stable compounds with the reinforcing metals. The good properties can be obtained in a composite material when the reinforcement particulates and matrix are as physically and chemically compatible as possible.

Reinforcements: CNT and Micro-Titanium

Matrix: Copper

### 4.1.1 Copper (Cu)

The word copper comes from the Latin word 'cuprum', which means 'ore of Cyprus'. This is why the chemical symbol for copper is Cu. 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. They can be polished and buffed to almost any desired texture and luster. Pure copper is used extensively for electrical wire and cable, electrical contacts and various other parts that are required to pass electrical current. Coppers and certain brasses, bronzes and copper nickels are used extensively for automotive radiators, heat exchangers, home heating systems, solar collectors, and various other applications requiring rapid conduction of heat across or along a metal section. Because of their outstanding ability to withstand corrosion, coppers, brasses, bronzes and copper nickels are also used for pipes, valves and fittings in systems carrying potable water, process water or other aqueous fluids, and industrial gases. Copper alloys are also ideally suited where it is important to minimize bacterial* levels on touch surfaces.

Figure 2.2. Copper

### 4.1.2 Carbon Nanotubes (CNT)

Carbon nanotubes (CNTs) are allotropes of carbon with a cylindrical nanostructure. Nanotubes have been constructed with length-to-diameter ratio of up to 132,000,000:1, significantly larger than for any other material. These cylindrical carbon molecules have unusual properties, which are valuable for nanotechnology, electronics, optics and other fields of materials science and technology. In particular, owing to their extraordinary thermal conductivity and mechanical and electrical properties, carbon nanotubes find applications as additives to various structural materials. For instance, nanotubes form a tiny portion of the material(s) in some (primarily carbon fiber) baseball bats, golf clubs, car parts or Damascus steel.

Nanotubes are members of the fullerene structural family. Their name is derived from their long, hollow structure with the walls formed by one-atom-thick sheets of carbon, called graphene. These sheets are rolled at specific and discrete ("chiral") angles, and the combination of the rolling angle and radius decides the nanotube properties; for example, whether the individual nanotube shell is a metal or semiconductor. Nanotubes are categorized as single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTS).

### Types of carbon nanotubes and related structures

There is no consensus on some terms describing carbon nanotubes in scientific Literature : both "-wall" and "-walled" are being used in combination with "single", "double", “triple" or "multi", and the letter C is often omitted in the abbreviation; for example, Multiwalled carbon nanotube (MWNT)

- Single-walled carbon nanotubes (SWNTS)
- Multi-walled nanotubes (MWNTS)
- Double-walled carbon nanotubes (DWNTS)

Figure 2.3 CNT

### 4.1.3 Micro-Titanium (µ-Ti):

Titanium is a chemical element with symbol Ti and atomic number 22. It is a lustrous transition metal with a silver color, low density, and high strength. Titanium is resistant to corrosion in sea water, aqua regia, and chlorine. Titanium was discovered in Cornwall, Great Britain, by William Gregor in 1791, and was named by Martin Heinrich Klaproth after the Titans of Greek mythology. The element occurs within a number of mineral deposits, principally rutile and ilmenite, which are widely distributed in the Earth's crust and lithosphere, and it is found in almost all living things, water bodies, rocks, and soils. The metal is extracted from its principal mineral ores by the Kroll and Hunter processes. The most common compound, titanium dioxide, is a popular photo catalyst and is used in the manufacture of white pigments. Other compounds include titanium tetrachloride ($TiCl4$), a component of smoke screens and catalysts; and titanium trichloride ($TiCl3$), which is used as a catalyst in the production of polypropylene.

Titanium can be alloyed with iron, copper, aluminum, vanadium, and molybdenum, among other elements, to produce strong, lightweight alloys for aerospace (jet engines, missiles, and spacecraft), military, industrial processes (chemicals and petrochemicals, desalination plants, pulp, and paper), automotive, agri-food, medical prostheses, orthopedic implants, dental and endodontic instruments and files, dental implants, sporting goods, jewelry, mobile phones, and other applications. The two most useful properties of the metal are corrosion resistance and strength-to-density ratio, the highest of any metallic element. In its unalloyed condition, titanium is as strong as some steels, but less dense. There are two allotropic forms and five naturally occurring isotopes of this element, 46Ti through 50Ti, with 48Ti being the most abundant (73.8%).Although they have the same number of valence electrons and are in the same group in the periodic table, titanium and zirconium differ in many chemical and physical properties.

For example, cuprotitanium (rutile with copper added is reduced), Ferrocarbon titanium (ilmenite reduced with coke in an electric furnace), and manganotitanium (rutile with manganese or manganese oxides) are reduced. 2

$$FeTiO_3 + 7\ Cl_2 + 6\ C \rightarrow 2\ TiCl_4 + 2\ FeCl_3 + 6\ CO\ (900\ °C)$$

$$TiCl_4 + 2\ Mg \rightarrow 2\ MgCl_2 + Ti\ (1{,}100\ °C)$$

Figure: 2.4. Micro-Titanium

## Characteristics of Micro-Titanium

- High Strength-to-Weight Ratio
- Low Density
- Quite Ductile
- Low Electrical and Thermal Conductivity
- Excellent Resistance to corrosion
- High Melting Point
- Non Toxic

## Applications

Titanium is used in steel as an alloying element (ferro-titanium) to reduce grain size and as a deoxidizer, and in stainless steel to reduce carbon content Titanium is often alloyed with aluminum (to refine grain size), vanadium, copper (harden), iron, manganese, molybdenum, and other metals. Titanium mill products (sheet, plate, bar, wire, forgings, castings) find application in industrial, aerospace, recreational, and emerging markets. Powdered titanium is used in pyrotechnics as a source of bright-burning particles.

## 4.2 Manufacturing Process.

One of the most important issues to prepare CNT metal matrix composite is the CNTs dispersion in composites, the main purpose of many research and experiments is to improve it. Another issue need to be considered is the reinforcement of CNTs, which depend on the interfacial wettability between CNTs and metal matrix. Also chemical reaction should be avoided during composites manufacture process.

### 4.2.1 Stir casting

Stir casting set-up mainly consists a furnace and a stirring assembly as shown in Figure 4.6. In general, the solidification synthesis of metal matrix composites involves a melt of the selected matrix material followed by the introduction of a reinforcement material into the melt, obtaining a suitable dispersion. The next step is the solidification of the melt containing suspended dispersoids under selected conditions to obtain the desired distribution of the dispersed phase in the cast matrix. In preparing metal matrix composites by the stir casting method, there are several factors that need considerable attention, including The difficulty in achieving a uniform distribution of the reinforcement material.

Wet ability between the two main substances.
Porosity in the cast metal matrix composites.
Chemical reactions between the reinforcement material and the matrix alloy.

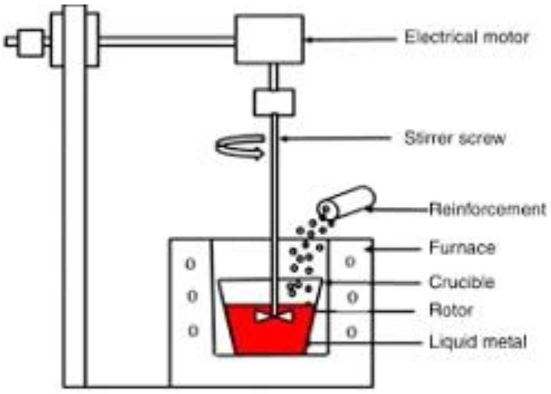

Figure 2.5:- Stir Casting

In order to achieve the optimum properties of the metal matrix composite, the distribution of the reinforcement material in the matrix alloy must be uniform, and the wettability or bonding between these substances should be optimized. The porosity levels need to be minimized.

Figure 2.6. Casting Set up

**Stir Casting Procedure:**

1. Required amount of Carbon nanotube, Micro-Titanium and pure copper weighed and Kept aside.
2. Carbon nanotube powder and Micro-Titanium is preheated to 300° C-350°C and maintained at that Temperature for about 15 minutes to remove moisture content.
3. Then weighed quantity of copper was melted in a crucible at more than 1085°C.
4. Slag is removed using scum powder.
5. The molten metal is degassed at a temperature of 1000°C using solid dry hexachloroethane tablets.
6. Then the molten metal is stirred to create a vortex and the weighed 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.
7. Then the melt with the reinforced particles were poured into preheated moulds the poring temperature is maintained at 1000°C.
8. The castings are taken once the solidification of molten metal takes place.

### 4.3 Testing

### 4.3.1Wear Test

This test method describes a laboratory procedure for determining the wear of materials during sliding using a pin – on – disk apparatus. Materials are tested in pairs under nominal non-abrasive conditions. The principle areas of experimental attention in using this type of apparatus to measure wear are described. The coefficient of friction may also be determined. The values stated in SI units are to be regarded as standard.

This standard does not purport to address all of the safety concerns, if any, associated with it use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. The wear characteristics are determined by using pin on disc wear system.

Figure 2.7 Pin on Disc Wear testing machine

Figure 2.8 Machined specimen of wear test.

### 4.3.2 Corrosion test

The corrosion test was carried out using static immersion weight loss method as per Standards. The test specimens were machined into standards discs of 20 mm diameter and 20mm thick. Before testing the specimen, the surfaces was ground with silicon carbide paper of 1000 grit size. After subsequent rinsing with water and acetone the specimens were weighed accurately to a hundredth of milligram accuracy before starting the test by the weight loss method.

Procedure for corrosion test

The following procedure is followed for the corrosion experimentation in this project work:

1. Preparation of the acidic solutions containing sodium chloride of different normalities.
2. Immersion of the corrosion specimens in the solution for the required time.
3. Removal and cleaning of the corroded specimens.

The method used for preparing the different normal NaCl or HCl solutions was by volumetric analysis. Volumetric analysis is a method of quantitative analysis involving measurement of volumes of the reacting solutions. The volume of a standard solution required to react completely with a known volume of another solution is determined experimentally. From this normality of the other solution may be calculated.

Figure 2.9 Corrosion test specimen

Figure 2.10 Corrosion test specimen before testing

## III. 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 Tribological properties. The obtained values are tabulated and plotted.

### 1. Wear test Results

Table 3.1. Wear Rate of Copper hybrid metal matrix composites at 10N & 200 RPM

| **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 |

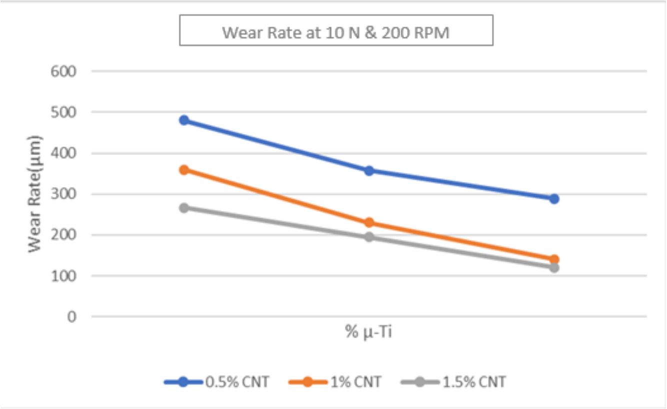

Figure 3.1: Wear Rate at 10 N & 200 RPM

Figure 3.1. Wear Rate of Copper hybrid metal matrix composites at 10N & 200 RPM As observed in above figure,the wear rate declines 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 10N load and 200rpm at track diameter of 100mm in pin on disc experiment, we can see the wear resistance of the developed composite increases with increase in Micro-titanium which acts as a barrier for wear process.

Table 3.2. Wear Rate of Copper hybrid metal matrix composites, at 10N & 300 RPM

| 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 |

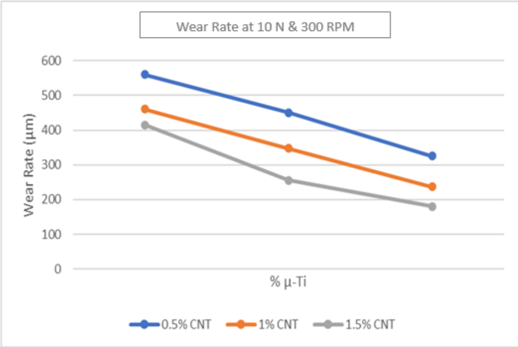

Figure 3.2: Wear Rate at 10 N & 300 RPM

Figure 3.2. Wear Rate of Copper hybrid metal matrix composites, at 10N & 300 RPM

As observed in above figure,, 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. The combined effect of reinforcement as well as its bonding with copper prevents wear phenomena.

Table 3.3.Wear Rate of Copper hybrid metal matrix composites, at 10N & 400 RPM

| 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 |

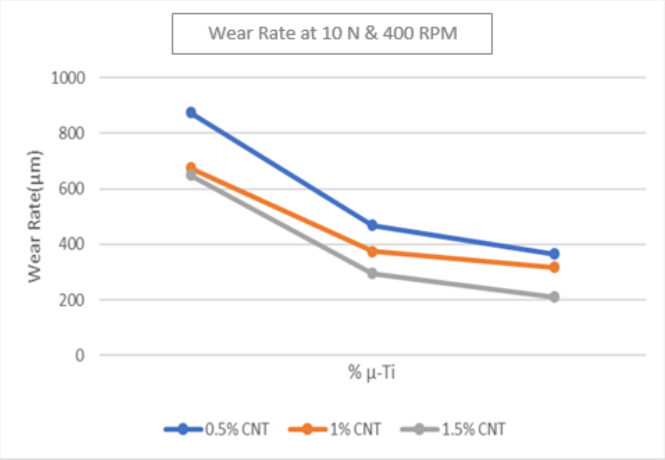

Figure 3.3: Wear Rate at 10 N & 400 RPM

Figure 3.3. Wear Rate of Copper hybrid metal matrix composites, at 10N & 400 RPM.

As observed in above figure,, the wear rate declines 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. The combined effect of reinforcement as well as its bonding with copper prevents wear phenomena.

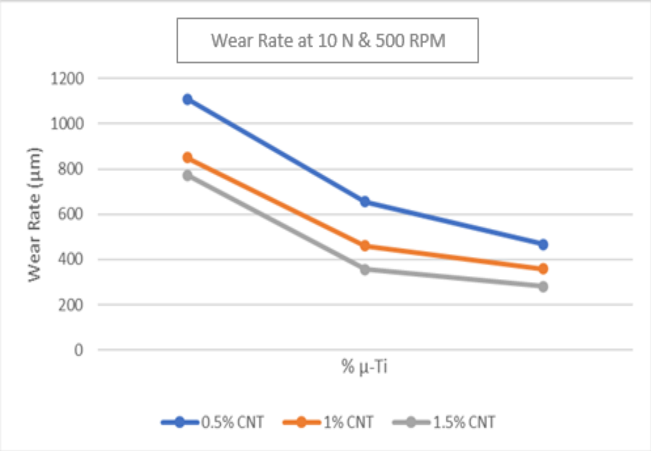

Figure 3.3. Wear Rate of Copper hybrid metal matrix composites, at 10N & 500 RPM

Table 3.3. Wear Rate of Copper hybrid metal matrix composites, at 10N & 500 RPM

| **Reinforcements** | **0.5% CNT** | **1% CNT** | **1.5% CNT** |
|---|---|---|---|
| **1 % µ-Ti** | 1110 | 850 | 770 |
| **3 % µ-Ti** | 655 | 460 | 356 |
| **5 % µ-Ti** | 467 | 358 | 280 |

Table 3.4.Wear Rate of Copper hybrid metal matrix composites, at 20N & 200 RPM

| **Reinforcements** | **0.5% CNT** | **1% CNT** | **1.5% CNT** |
|---|---|---|---|
| **1 % µ-Ti** | 753 | 476 | 220 |
| **3 % µ-Ti** | 625 | 358 | 178 |
| **5 % µ-Ti** | 530 | 296 | 150 |

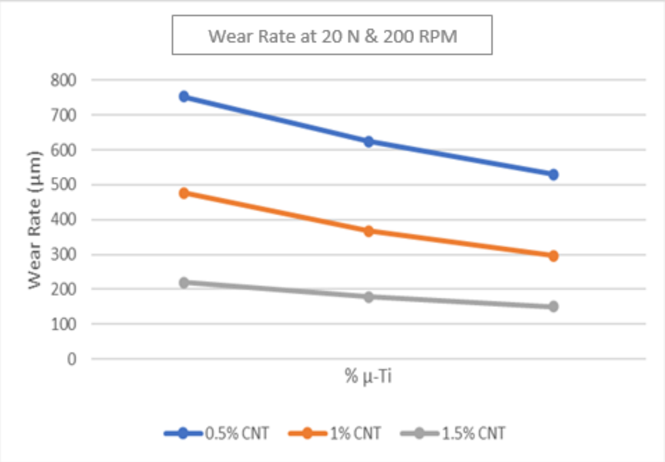

Figure 3.4: Wear Rate at 20 N & 200 RPM

Though the wear rate of copper composite increases with the load, the behaviour of wear rate vs reinforcement curve shows trend of inclination towards the lower value. This is mainly due to the high integrity interface formed between the copper matrix and micro-titanium particles and CNTs, prevents reinforcement pull-out and damage during wear.

Table 3.5. Wear Rate of Copper hybrid metal matrix composites at 20N & 300 RPM

| **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 |

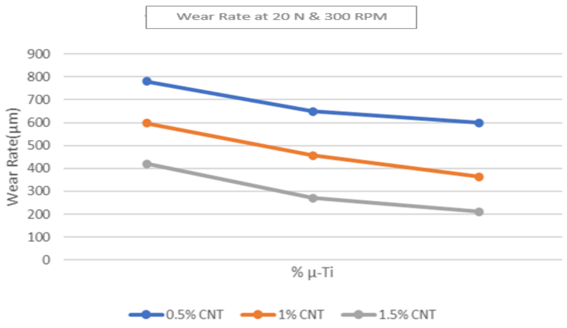

Figure 3.5.Wear Rate of Copper hybrid metal matrix composites at 20N & 300 RPM

Table 3.6.Wear Rate of Copper hybrid metal matrix composites at 20N & 400 RPM

| **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 |

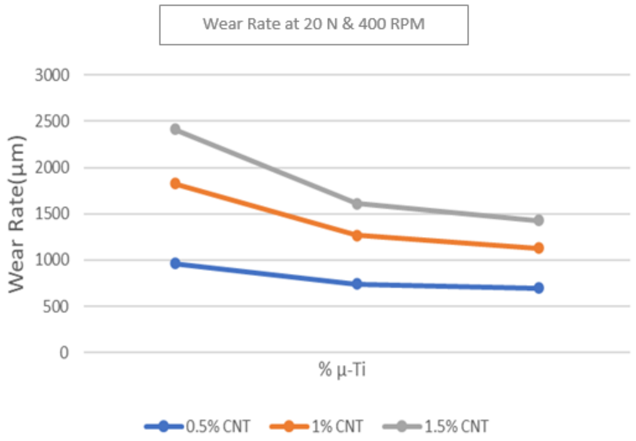

Figure 3.6.Wear Rate of Copper hybrid metal matrix composites at 20N & 400 RPM

Table 3.7.Wear Rate of Copper hybrid metal matrix composites at 20N & 500 RPM

| **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 |

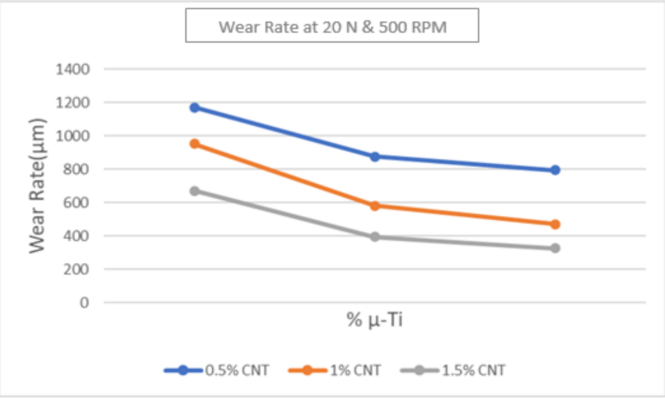

Figure 3.7 Wear Rate of Copper hybrid metal matrix composites at 20N & 500 RPM

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 the reduction in pull out of CNTs.

Table 3.8.Wear Rate of Copper hybrid metal matrix composites at 30N & 200 RPM

| **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 |

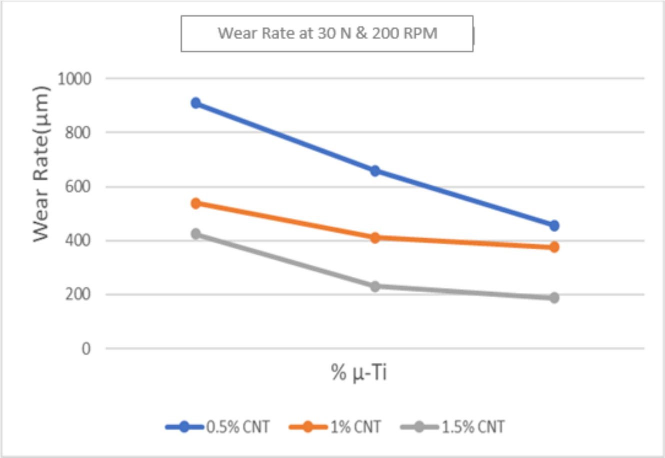

Figure 3.8.Wear Rate of Copper hybrid metal matrix composites at 30N & 200 RPM

Table 3.9.Wear Rate of Copper hybrid metal matrix composites at 30N & 300 RPM

| 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 |

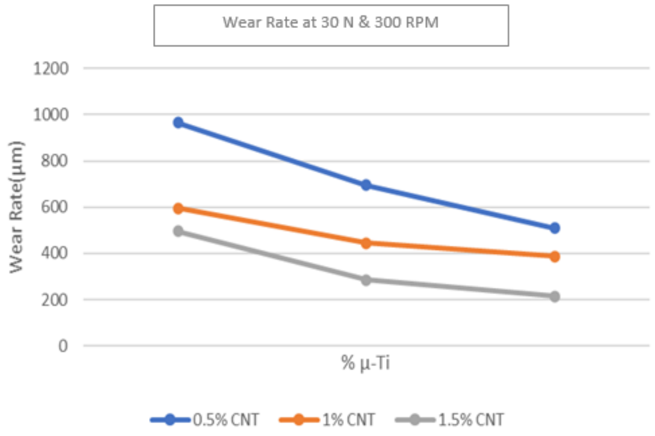

Figure 3.9.Wear Rate of Copper hybrid metal matrix composites at 30N & 300 RPM.

Table 3.10.Wear Rate of Copper hybrid metal matrix composites at 30N & 400 RPM

| Reinforcements | 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 |

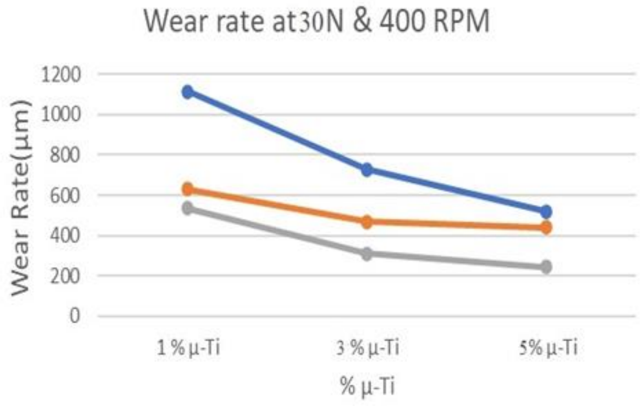

Figure 3.10 Wear Rate of Copper hybrid metal matrix composites at 30N & 400 RPM

Table 3.11.Wear Rate of Copper hybrid metal matrix composites at 30N & 500 RPM

| Reinforcements | 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 |

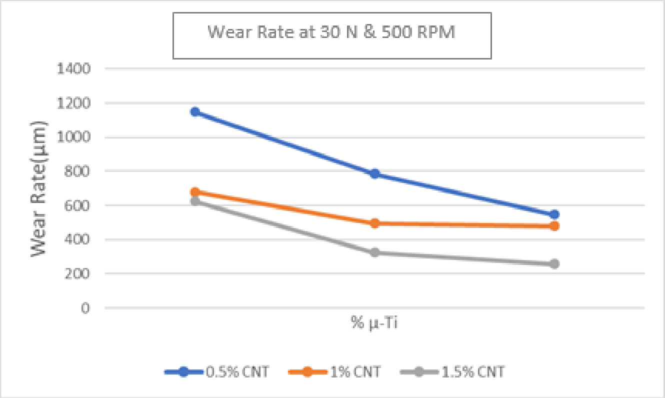

Figure 3.11. Wear Rate of Copper hybrid metal matrix composites at 30N & 500 RPM

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 and200, 300, 400 & 500rpm. 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.

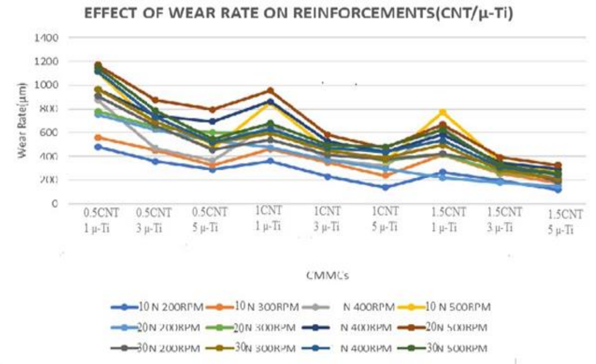

Figure 3.12. Effect of wear rate on reinforcements at different speeds and loads

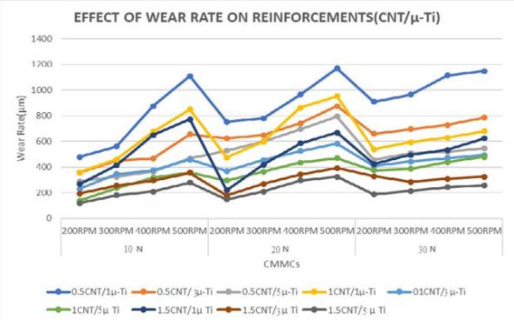

Figure 3.13.Effect of wear rate on reinforcements at different speeds and loads

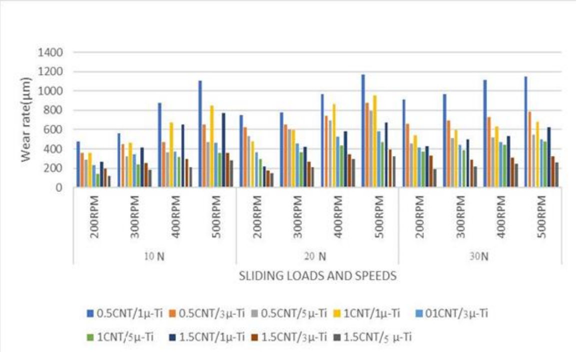

Figure 3.14 Comparative analysis of wear rate of Copper hybrid composites.

Shows the results of wear rate of the CNTs/µ-Ti/Cu composites. Within the range of CNT contents from 0.5 wt.% to 1.5wt.% and µ-Ti from 1 wt.% to 3wt.%, the wear rate of CNTs/ µ-Ti/Cu composites decreases with increasing the CNT/µ-Ti content. This may be attributed to that the increase in CNT/µ-Ti content reduces the direct contact between the Cu matrix and the friction counterpart, and thus the wear rate of composites is reduced due to the self-lubrication of CNTs [9]. In addition, it can be seem in Fig. 5 that the wear rate of the composites with 1.5 wt.% CNTs/3 % µ-Ti is decreased by 75%, compared with that of 0.5 wt.% CNT 1 wt.% µ-Ti specimen, indicating the good wear rate reduction effect of CNTs/ µTi. Under dry sliding wear condition, the wear rate of CNT/µ-Ti specimen is lower than that of pure Cu specimen. This result means that the CNTs/ µ-Ti /Cu composite shows higher wear resistance compared with pure Cu specimen.

## 2. Corrosion Test Results

MMC's used in corrosive environment should have good mechanical properties and resistance to chemical degradation in air and acidic environment. It is essential to have a thorough understanding of the corrosion behavior of the copper composites. Present study is focused on corrosion of CNT and micro titanium reinforced copper metal matrix composites with NaCl and HCl solution with different normalities AND molarities i.e., 0.5N, 1N & 0.5M, 1M for 24, 48, 72 and 96hrs and the results are tabulated below.

Table 3.12.Corrosion rate of CMMCs at 0.5 N Normality and 24 Hrs

| Reinforcements | 0.5% CNT | 1% CNT | 1.5% CNT |
|---|---|---|---|
| 1 % µ-Ti | 0.006592 | 0.003954 | 0.001882 |
| 3 % µ-Ti | 0.005273 | 0.002108 | 0.001158 |
| 5 % µ-Ti | 0.00516 | 0.002107 | 0.001021 |

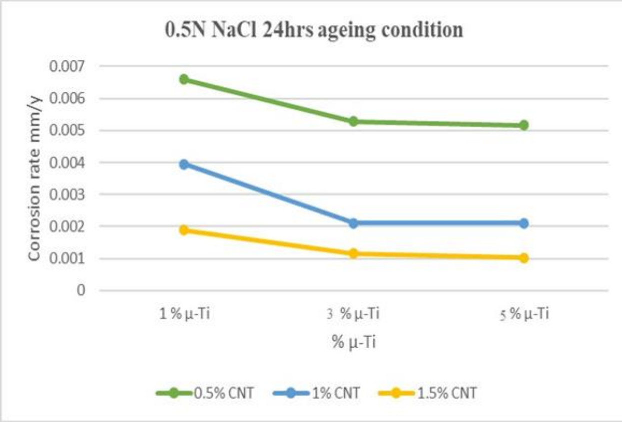

Figure 3.15.Corrosion rate at 0.5N NaCl 24Hrs Ageing condition

From the table the corrosion rate based normality at 0.5N, 24hrs as the following observations. The effect of CNT and micro titanium on corrosion rate, as seen in above graph, the corrosion rate decrease 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 0.5N and 24hrs, the corrosion rate decreased this is The combined effect of reinforcement as well as its bonding with copper prevents wear phenomena.

Table 3.13. Corrosion rate of CMMCs at 0.5 N Normality and 48 Hrs.

| Reinforcements | 0.5% CNT | 1% CNT | 1.5% CNT |
|---|---|---|---|
| 1 % µ-Ti | 0.006592 | 0.003954 | 0.001882 |
| 3 % µ-Ti | 0.005273 | 0.002108 | 0.001158 |
| 5 % µ-Ti | 0.00516 | 0.002107 | 0.001021 |

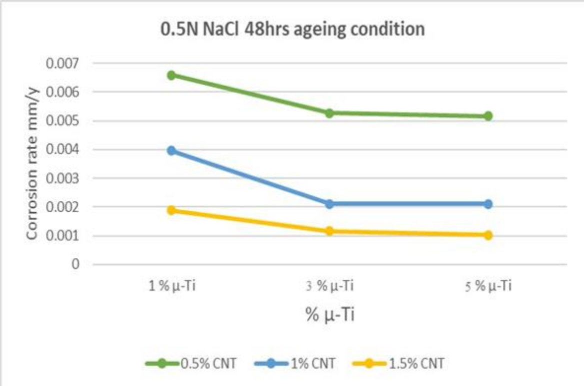

Figure 3.16. Corrosion rate at 0.5N NaCl 48Hrs Ageing condition

From the table the corrosion rate based normality at 0.5N, 48hrs as the following observations. The effect of CNT and micro titanium on corrosion rate, as seen in above graph, the corrosion rate decrease 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 0.5N and 48hrs, the corrosion rate decreased mainly due to the high integrity interface formed between the copper matrix and micro-titanium particles and CNTs, prevents reinforcement pull-out and damage.

Table 3.14. Corrosion rate of CMMCs at 0.5 N Normality and 72 Hrs

| Reinforcements | 0.5% CNT | 1% CNT | 1.5% CNT |
|---|---|---|---|
| 1 % µ-Ti | 0.006502 | 0.00395 | 0.001532 |
| 3 % µ-Ti | 0.00527 | 0.002108 | 0.001104 |
| 5 % µ-Ti | 0.005145 | 0.002104 | 0.001012 |

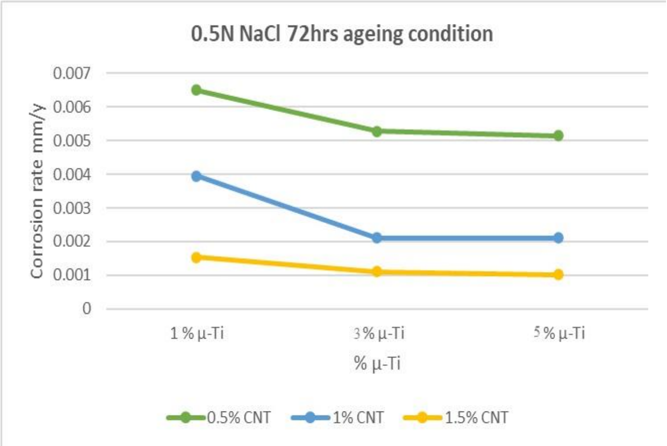

Figure 3.17.Corrosion rate at 0.5N NaCl 72Hrs Ageing condition

From the table the corrosion rate based normality at 0.5N, 72hrs as the following observations.The effect of CNT and micro titanium on corrosion rate, as seen in above graph, the corrosion rate decrease 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 0.5N and 72hrs, the corrosion rate decreased this is due to the reduction in pull out of CNTs.

Table:3.14. Corrosion rate of CMMCs at 0.5 N Normality and 96 Hrs

| Reinforcements | 0.5% CNT | 1% CNT | 1.5% CNT |
|---|---|---|---|
| **1 % µ-Ti** | 0.006155 | 0.003925 | 0.00111 |
| **3 % µ-Ti** | 0.00521 | 0.002106 | 0.00101 |
| **5 % µ-Ti** | 0.005075 | 0.002083 | 0.001002 |

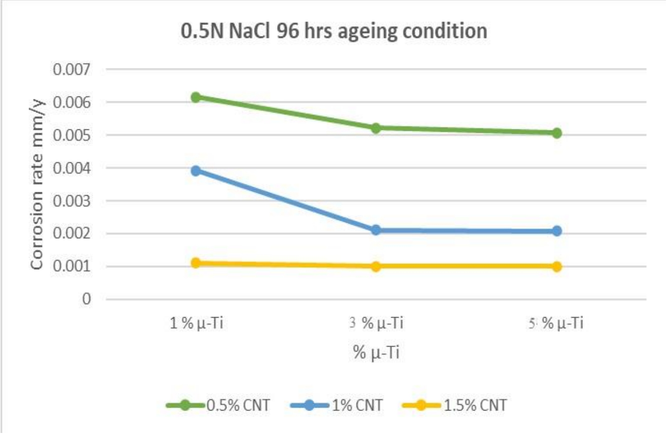

Figure 3.18.Corrosion rate at 0.5N NaCl 96Hrs Ageing condition

From the table the corrosion rate based normality at 0.5N, 96hrs as the following observations.The effect of CNT and micro titanium on corrosion rate, as seen in above graph, the corrosion rate decrease 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 0.5N and 96hrs, the corrosion rate decreased this is because of amount of reinforcements in MMC.

Table 3.15. Corrosion rate of CMMCs at 1N Normality and 24 Hrs

| Reinforcements | 0.5% CNT | 1% CNT | 1.5% CNT |
|---|---|---|---|
| **1% µ-Ti** | 0.009803 | 0.00511 | 0.002556 |
| **3% µ-Ti** | 0.008513 | 0.00386 | 0.002108 |
| **5% µ-Ti** | 0.00621 | 0.0031 | 0.0011 |

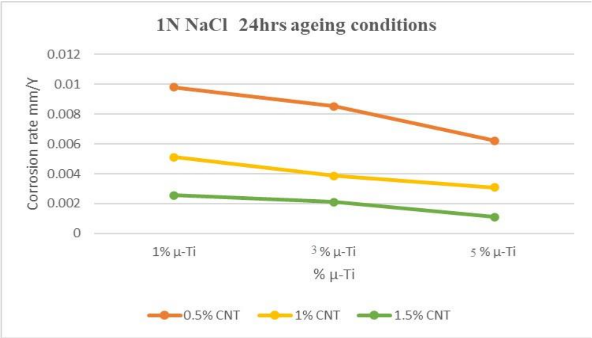

Figure 3.19.Corrosion rate at 1N NaCl 24Hrs Ageing condition

From the table the corrosion rate based normality at 01N, 24hrs as the following observations.The effect of CNT and micro titanium on corrosion rate, as seen in above graph, the corrosion rate decrease 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 01N and 24hrs, the corrosion rate decreased this is due to high interfacial bonding of CNTs and Micro-titanium particles with copper that prevents the pull out of micro-titanium particles.

Table:3.16. Corrosion rate of CMMCs at 1N Normality and 48 Hrs

| Reinforcements | 0.5% CNT | 1% CNT | 1.5% CNT |
|---|---|---|---|
| 1% µ-Ti | 0.008203 | 0.00501 | 0.002775 |
| 3% µ-Ti | 0.00711 | 0.00312 | 0.001178 |
| 5% µ-Ti | 0.006335 | 0.003075 | 0.001104 |

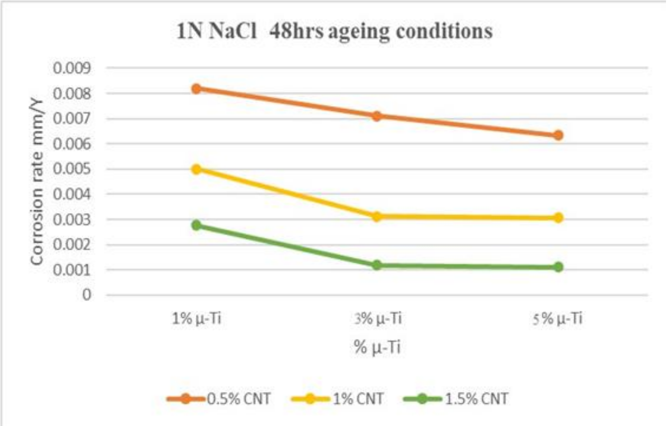

Figure 3.20. Corrosion rate at 1N NaCl 48Hrs Ageing condition

From the table the corrosion rate based normality at 0.5N, 48hrs as the following observations. The effect of CNT and micro titanium on corrosion rate, as seen in above graph, the corrosion rate decrease 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 0.5N and 48hrs, the corrosion rate decreased this is because of amount of reinforcements in MMC.

Table:3.17. Corrosion rate of CMMCs at 1N Normality and 72 Hrs

| Reinforcements | 0.5% CNT | 1% CNT | 1.5% CNT |
|---|---|---|---|
| 1% µ-Ti | 0.008115 | 0.005402 | 0.002202 |
| 3% µ-Ti | 0.007126 | 0.003226 | 0.00196 |
| 5% µ-Ti | 0.00623 | 0.002525 | 0.00123 |

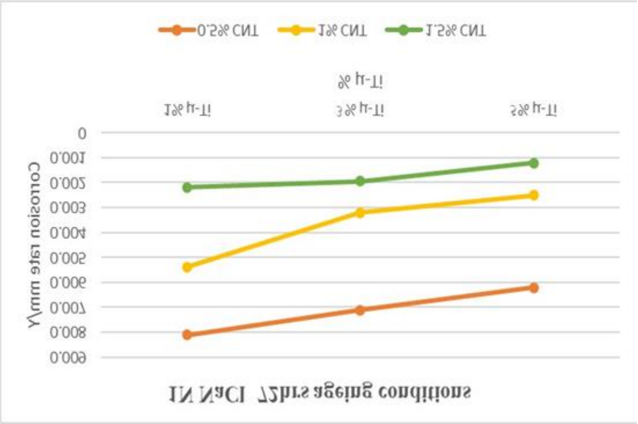

Figure 3.21 Corrosion rate at 1N NaCl 72Hrs Ageing condition

From the table the corrosion rate based normality at 0.5N, 24hrs as the following observations.The effect of CNT and micro titanium on corrosion rate, as seen in above graph, the corrosion rate decrease 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 0.5N and 72hrs, the corrosion rate decreased this is due to high interfacial bonding of CNTs and Micro-titanium particles with copper that prevents the pull out of micro-titanium particles.

Table:3.18.Corrosion rate of CMMCs at 1N Normality and 96 Hrs

| Reinforcements | 0.5% CNT | 1% CNT | 1.5% CNT |
|---|---|---|---|
| 1% µ-Ti | 0.006381 | 0.003022 | 0.00157 |
| 3% µ-Ti | 0.00545 | 0.00225 | 0.001078 |
| 5% µ-Ti | 0.005096 | 0.002096 | 0.001026 |

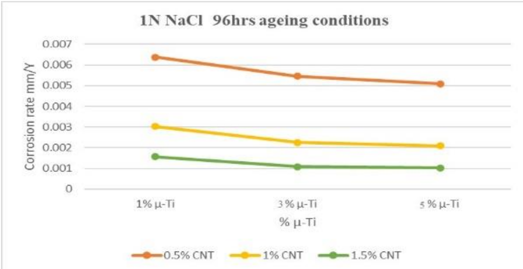

Figure 3.22.Corrosion rate at 1N NaCl 96Hrs Ageing condition

From the table the corrosion rate based normality at 0.5N, 24hrs as the following observations. The effect of CNT and micro titanium on corrosion rate, as seen in above graph, the corrosion rate decrease 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 0.5N and 96hrs, the corrosion rate decreased this is because of amount of reinforcements in MMC.

**The Effect of CNT and Micro titanium on Corrosion rate.**

The corrosion rate was measurement as a function of% of the both reinforcements in the static immersion test as shown in tabular column. Corrosion rate decreases monotonically with increase in the reinforcement content.

In the present case, the corrosion rate of the composites as well as the matrix alloy is predominantly due to the formation of pits, cracks on the surface. In the case of lower % reinforced hybrid composites, the severity of the acid and the alkaline salt used induces crack formation on the surface, which eventually leads to the formation of pits, thereby causing the loss of material. The presence of cracks and pits on the base alloy surface was observed clearly, since there is no reinforcement provided in any form the lower % reinforced hybrid composites fails to provide any sort of resistance to the alkaline and acidic medium. Hence the weight loss in case of lower % reinforced hybrid composites is higher.

The corrosion results indicate that an improvement in corrosion resistance as the % of CNT and micro titanium is increased in the hybrid composite. This shows that CNT and micro titanium directly or indirectly influence the corrosion property of the composites. Thus reinforcements act as a relatively inert physical barrier to the initiation and development of corrosion pits and also modifies the microstructure of the matrix material and hence reduces the rate of corrosion. One more reason for decrease in the corrosion rate is inter-metallic region, which is the site of corrosion forming crevice around each particle. Pitting in the composites is associated with the particle –matrix interface, because of the higher concentration in the region. With increase in time pitting would continue to occur at random sites on the particle-matrix interface. The active nature of the crevices would catholically protect the remainder of the matrix and restrict pit formation and propagation.

## IV. CONCLUSION

The research on composite materials where composites have a vital role in industrial application such as deference, aerospace, automobile, marine, etc, bring into the limelight various tailored properties that compete with monolithic materials. 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.

- The effect of CNT and micro titanium particles on the sliding wear resistance in Copper alloys varies with the applied load and speed.
- Wear rate increased with the increase in speed and load for every combination of the composite. However, with CNT being the main reinforcement with addition of CNT wear rate has reduced marginally. Addition of micro titanium also to some extent decreased the wear rate but CNT plays a major role in reducing the wear rate.
- Above the critical load, transition to severe wear occurs in unreinforced matrix alloy. But the reinforced MMCs have superior wear resistance. With increase in CNT wear rate has decreased and is clear from the 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.

- The best wear resistant combination is at 5% of micro titanium and 1% &1.5%of CNT as consideration.
- In material Metal-metal and metal-particle wear resistance increased with increasing distance from the center of the specimen. Worn surface examination of the material revealed formation of iron rich transfer layer during metal wear test. Abrasive wear progressed by grooving action of the abrasion grains. Abrasion resistance of the composite was decreased with the size of particle. Composites exhibited abrupt increase in abrasion rate for higher speeds and loads.
- At room temperature, the CNT and micro titanium reinforced Copper composites exhibited better corrosion resistance than the pure Copper matrix in NaCl and HCl aqueous solution
- Increasing the composition of the CNT and micro titanium particulates increased the corrosion resistance of the CNT and micro titanium Reinforced Copper composites.
- The corrosion resistance increases with increase in duration of time. The improvement in corrosion resistance is due to this factor is attributed to a protective layer formed on the surface of the material which gradually builds up and reaches a steady state with time.
- The Corrosion resistance was also found to improve with increase in micro titanium concentration, probably since they act as physical barriers to the corrosion process, as well as the Copper inter metallic compounds at the matrix, restricting pit formation and propagation.
- The composite specimens showed better corrosion /pitting resistance than the
- unreinforced matrix alloy, also it is seen that corrosion rate increase with increase in normality and molarity of the solution.
- The micro titanium content in Copper alloys plays a significant role in the corrosion resistance of the material. Increase in the percentage of addition will be advantageous to reduce the density and increase in the strength of the alloy, and thus the corrosion resistance is there-by significantly reduced.
- The corrosion resistance of the composites was higher than that of the corresponding matrix alloy, which may be due to dislocation density and porosity of MMC's

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