A Review on Mechanical and Tribological Behaviors of Stir Cast Copper–silicon carbide Matrix Composites

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Abstract - *In the past few years the global need for high performance, low cost and good quality materials has caused a shift in research from monolithic to composite materials. In case of MMC's, copper matrix composite due their low cost high strength to weight ratio and high wear resistance are widely manufactured and used in structural applications along with aerospace and automobile industry. Also a simple and cost effective method for manufacturing of the composites is very essential for expanding their application. Reinforcement silicon carbide can easily be incorporated in the melt using cheap and widely available stir casting method. This paper presents a review on the mechanical and tribological properties of stir cast copper matrix composites containing silicon carbide reinforcement. Addition of Sic in copper has shown an increase in its hardness and wear resistance.*

***Key Words*: Tribological study, Cu/SiC Composite, Pin on disc, Stir casting, wear.**

1. INTRODUCTION

A composite can be defined as combination of two or more materials differing in form or composition on a macro scale to form an effective third material. The key is the macroscopic study of a material wherein the component can be identified by naked eye. Different material can be combined on Microscopic scale, such as in alloying of metals, but the material which obtained is, for all practical purpose macroscopically homogenous. The advantage of composite material is that, if well designed, they usually exhibit the best qualities of their component. Some of the properties that can be improved by forming composite material are

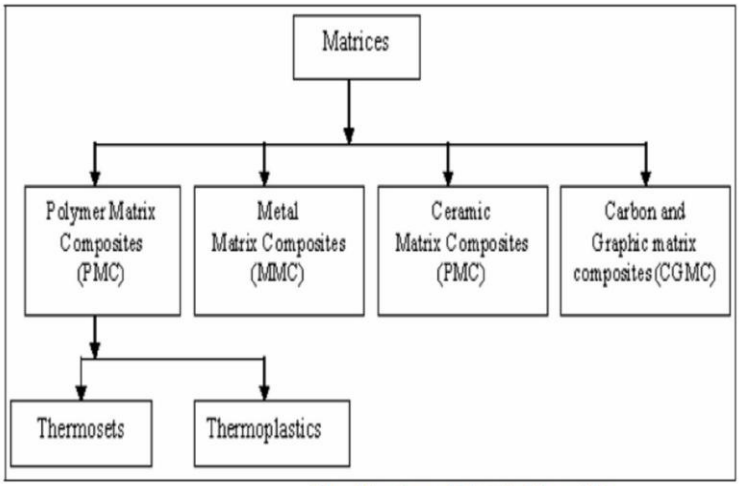
- Stiffness
- Strength
- Wear resistance
- Corrosion resistance
- Weight
- Attractiveness
- Fatigue life
- Acoustical insulation
- Temperature-dependent behaviour
- Thermal conductivity
- Thermal insulation

Classification and characterization of composite materials

1) Laminated composite materials that consist of layers of various materials.
2) Fibrous composite material that consist of fibers in a matrix.
3) Particulate composite materials that are composed of particles in a matrix.
4) Combination of some or all the first three types [11].

Composites are combinations of two materials reinforcing material and matrix material. Composite materials are classified with respect to the matrix constituent. The major composite classes include

- Metal Matrix Composites (MMCs) and
- Ceramic Matrix Composites (CMCs).
- Polymer Matrix Composites (PMCs)
- carbon carbon composites (CCCs)



Classification of Matrix Materials

Brief overview of MMC's

Metal Matrix Composites (MMC) Metal matrix composites, at present though generating a wide interest in research fraternity, are not as widely in use as their plastic counterparts. High strength, fracture toughness and stiffness are offered by metal matrices than those offered by their polymer counterparts. They can withstand elevated temperature in corrosive environment than polymer composites. Most metals and alloys could be used as matrices and they require reinforcement materials which need to be stable over a range of temperature and non-reactive too. However the guiding aspect for the choice depends essentially on the matrix material. Light metals form the matrix for temperature application and the reinforcements in addition to the aforementioned reasons are characterized by high moduli. Most metals and alloys make good matrices. However, practically, the choices for low temperature applications are not many. Only light metals are responsive, with their low density proving an advantage. Titanium, aluminium and magnesium are the popular matrix metals currently in vogue, which are particularly useful for aircraft applications. If metallic matrix materials have to offer high strength, they require high modulus reinforcements. The strength-to weight ratios of resulting composites can be higher than most alloys. The melting point, physical and mechanical properties of the composite at various temperatures determine the service temperature of composites. Most metals, ceramics and compounds can be used with matrices of low melting point alloys. The choice of reinforcements becomes more stunted with increase in the melting temperature of matrix materials

2. Stir casting

In a stir casting process, the particulate reinforcement is distributed into the metal melt by mechanical stirring. Generally with stir casting process segregation of reinforcing particle problem associated due to settling of particles during solidification. The distribution of the particles in the final solid depends on wetting condition of the particles with the melt, strength of mixing rate of solidification and relative density. Melt temperature, Geometry of the mechanical stirrer, position of stirrer in the melt, and the properties of the particles added determines the distribution of particles in molten matrix. Nowadays stir casting process is a two-step mixing process or double stir casting. In stir casting process, first the matrix material is heated to above its melting temperature. The melt is then cooled down to a temperature between the liquidus and solidus points to a semi-solid state. At this point the preheated reinforcement particles are added and mixed. Again the slurry is heated to a fully liquid state and mixed thoroughly. In double stir casting the resulting microstructure has been found to be more uniform as compared with conventional stirring. The potency of this two-step mixing method is mainly due to its ability to break the gas layer around the particle surface which otherwise impedes wetting between the particles and molten metal. Thus the mixing of the particles in the semi-solid state helps to break the gas layer because of the abrasive action due to the high melt viscosity. The composite powder is then incorporated into the melt with along with mechanical stirring. After adequate stirring the composite slurry is sonicated using an ultrasonic probe or transducer in order to improve the distribution of reinforced particles. The major advantage of stir casting process is its applicability to mass production. Compared to other fabrication methods, stir casting process costs as low as 1/3rd to 1/10th for mass production of metal matrix composites. Because of the above reasons, stir casting is the most widely used commercial method of producing aluminium based composites. Conventional stir casting process has been employed for producing discontinuous particle reinforced metal matrix composites. The stir casting mostly used to fabricate the PMMCs because it shown to be a very promising for the manufacture of near net shape composites in a simple and cost effective manner. The major problem in this technology is to obtain sufficient wetting of particle by the liquid metal and to get a homogeneous dispersion of the ceramic particles [16]. Stir casting method is used to manufacture metal matrix composites (MMC) with an objective to develop a conventional low cost method and to obtain homogenous dispersion of ceramic material. Desired improvements in properties including hardness, hardness and impact can be achieved by intelligently selecting the reinforcement materials, their volume of fraction, size, and shape. It has been observed in experiment that melting and pouring conditions have directly or indirectly effect on mechanical properties of cast materials as percentage of elongation, percentage reduction in diameter, hardness, toughness and so on. [17]. Stir Casting is a fabrication process in which a dispersed phase (ceramic particles, short fibers) is well mixed with molten metal matrix by mean of mechanical stirring. The molten material is then casted by conventional casting methods. [18]

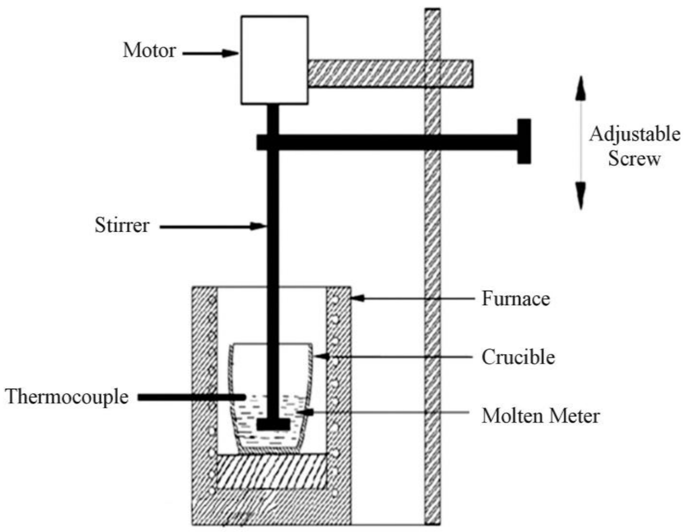


Figure 1: schematic diagram of stir casting [15]

3. Wear test on pin on disc

The pin-on-disk wear test, two specimens are required. One, a pin with a radiused tip, is positioned perpendicular to the other, usually a flat circular disk. A ball, rigidly held, is often used as the pin specimen. The test machine causes either the disk specimen or the pin specimen to revolve about the disk center. In either case, the sliding path is a circle on the disk surface. The plane of the disk may be oriented either horizontally or vertically. The amount of wear is determined by measuring appropriate linear dimensions of both specimens before and after the test, or by weighing both specimens before and after the test. If linear measures of wear are used, the length change or shape change of the pin, and the depth or shape change of the disk wear track (in millimeters) are determined by any suitable metrological technique.

Test Parameters

- Load—Values of the force in Newtons at the wearing contact.
- Speed: The relative sliding speed between the contacting surfaces in meters per second.
- Distance: The accumulated sliding distance in meters.
- Temperature: The temperature of one or both specimens at locations close to the wearing contact.
- Atmosphere: The atmosphere (laboratory air, relative humidity, argon, lubricant, etc.) surrounding the wearing contact.

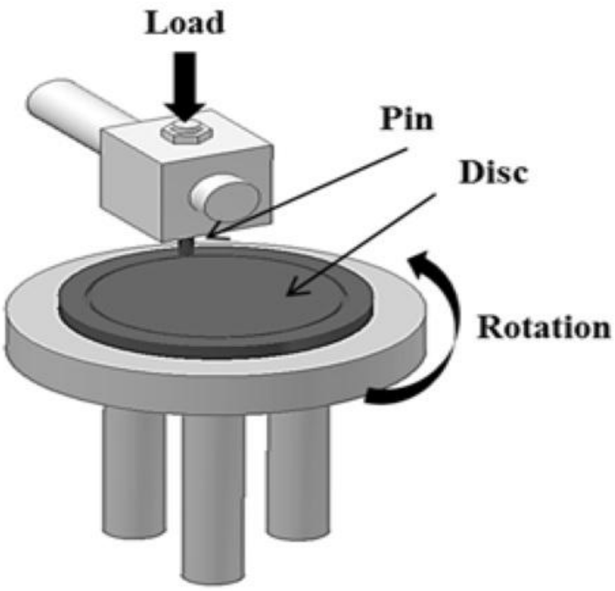


Figure 2: schematic diagram of pin on disc [22]

Methodology used in pin on disc

first of all remove all dirt and foreign particles from the specimen by using non chlorinated, non film forming cleaning agent and solvent

↓

Measurement of specimen dimensions to the accurately 2.5μm or weight of the specimen s to the nearest .0001g.

↓

Insert the disk carefully in the holding device so that the disk is fixed perpendicularly (± 1°) to the axis of the resolution.

↓

Insert the pin specimen securely in its holder and, if necessary, adjust so that the specimen is perpendicular (61°) to the disk surface when in contact, in order to maintain the necessary contact conditions

↓

Add the proper mass to the system lever or bale to develop the selected force pressing the pin against the disk

↓

Start the motor and adjust the speed to the desired valuewhile holding the pin specimen out of contact with the disk.Stop the motor

↓

Set the revolution counter (or equivalent) to the desired number of revolutions.

↓

Begin the test with the specimens in contact under load. The test is stopped when the desired number of revolutions is achieved. Tests should not be interrupted orrestarted. Remove the specimens and clean off any lweardebris.

↓

Remeasure the specimen dimensions to the nearest 2.5 μm or reweigh the specimens to the nearest 0.0001 g, asappropriate. Repeat the test with additional specimens toobtain sufficient data for statistically significant results

Pin-on-Disk wear testing is a method of characterizing the coefficient of friction, frictional force, and rate of wear between two materials. During this tribological test, a stationary disk articulates against a rotating pin while under a constant applied load.

Pin-on-disk wear testing can simulate multiple modes of wear, including: unidirectional, bidirectional, omnidirectional, and quasi-rotational.

The pin-on-disk method of wear characterization is beneficial across numerous industries, including:

Characterization of wear between bearing surfaces for the medical device industry (hip, knee, shoulder, ankle, spine); Excellent option for comparing and Understanding material characteristics prior to longer term medical implant wear testing.

- Piston ring, cam bearings, and brake pad wear simulation for the automotive industry
- Hard metal coating and film integrity testing for the aerospace and manufacturing industries
- Analysis of the reduction in wear based on fluid variations for oil and lubricant manufacturers [19].

4. Hardness Testing Basics

Hardness is a characteristic of a material, not a fundamental physical property. It is defined as the resistance to indentation, and it is determined by measuring the permanent depth of the indentation. More simply put, when using a fixed force (load)* and a given indenter, the smaller the indentation, the harder the material. Indentation hardness value is obtained by measuring the depth or the area of the indentation using one of over 12 different test methods.

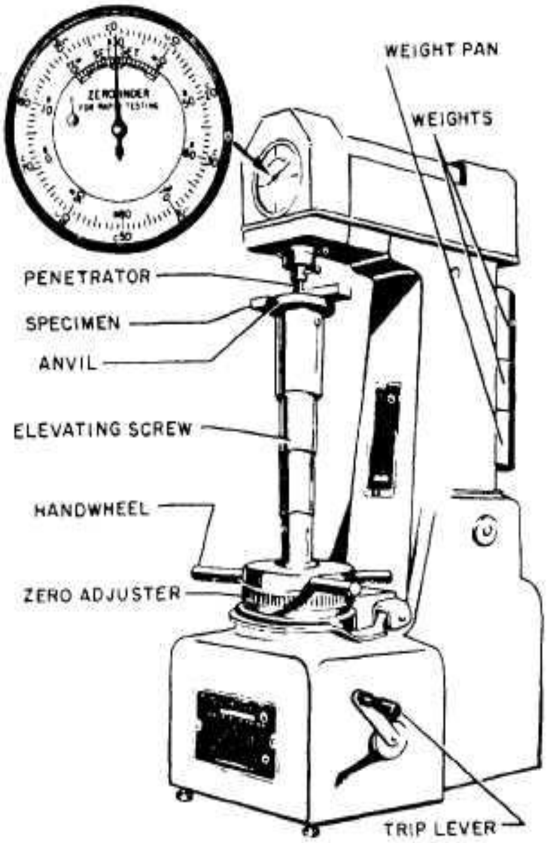


Figure 3: Rockwell Hardness testing machine[21]

Hardness Testing Considerations

The hardness testing method to use following sample characteristics should be considered:

- Cylindrical Samples
- Sample Size
- Sample Thickness
- Gage R&R
- Scales

The Vickers hardness test method, is mostly used for small parts, thin sections. On the optical measurement system Vickers method is based. The Microhardness test procedure, in which a range of small loads using a diamond indenter to make an indentation which is measured and converted to a hardness value. This method is very useful for testing on materials as long as test samples are carefully prepared. In this method we use square base pyramid shaped diamond is used for testing in the Vickers scale. The loads are very light, which from a few grams to one or several kilograms, although "Macro" Vickers loads can varied up to 30 kg or more. This methods used to test on metals, ceramics composites - almost any type of Material [19].

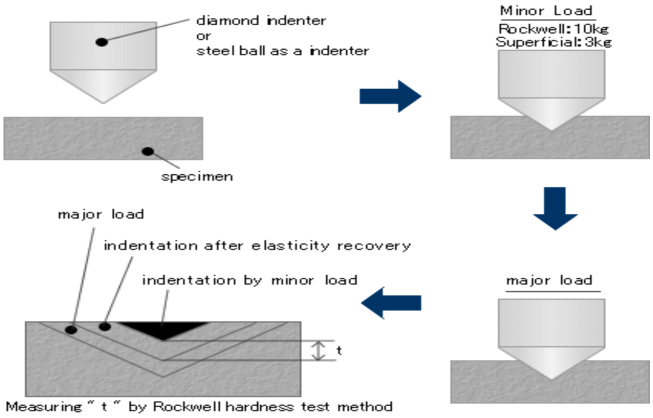


Figure 4: Rockwell hardness test method [20]

5. LITERATURE REVIEW

Mohammadmehdi Shabani et .al, has investigated the Influence of SiC particles and fabrication type on the tribological behavior of pure Cu and Cu/SiCp composites. The dry sliding wear tests described that the Cu composite with 60 vol.% SiC possess the lowest wear loss compared to other compacts. Moreover, the results indicated that applying compressive force bring sintering process of Cu and Cu/SiCp compacts has a significant effect on reducing and eliminating porosities, increasing hardness and attaining to higher bulk density. Therefore, wear loss of the Cu and Cu/SiCp compacts produced through sinter-forging process was improved remarkably compared to conventionally sintered Cu and Cu/SiCp composite compacts [8].

H.R. Akramifard et.al, made comparison between wear resistance of pure Cu and Cu/SiC composite. There are several reasons for explained several reason for enhancement of wear resistance such as: Orowan strengthening mechanism because of fine dispersion of SiC particles. Addition of SiC particles results in enhancing microhardness, and consequently wear resistance improved. The load distribution has takes placed between SiC particles and Cu so direct load contact decreased between Cu/SiC composite as compare to pure cu. Finally he conclude that Cu/SiC composite shows higher hardness and better wear behavior than pure Cu [5].

Mohsen Barmouz et.al, worked upon mechanical and tribological aspect of Cu/SiC composite. Cu/SiC composites were fabricated by the friction stir processing. Powder dispersion, microstructural, interfacial bonding, porosity content and mechanical properties including such as tensile, microhardness and friction coefficient behavior of Cu/SiC composites were significantly improved by multi-pass friction stir processing. Enhancement of electrical resistivity of composite observed while addition of SiC particles as compared to the pure copper. As a reinforcement SiC particles are of great technological importance because of their application in metal matrix composites and structural ceramics .Taking into consideration. As their excellent thermal and electrical conductivity, enhanced value of hardness, wear and frictional properties [9].

A.S. Prosviryakov has conduct a study on copper matrix composites reinforced with silicon carbide. Cu/SiC composites combine high electrical and thermal conductivity, increased hardness which results in high wear resistance as well as a low coefficient of thermal expansion (CTE) .That's the reason these composites used in electronic packaging and electronic contacts. In this study the author mainly focus on silicon carbide particle content which he takes in the range of 15-35 wt. % and observed the effect on density, porosity, hardness, electrical conductivity and CTE of Cu/SiC composite which is produced by mechanical alloying. Milling operation is carried out in which outcome is that with increase in SiC content (upto 25% wt.%) milling time increased that's shows higher hardness due to homogenization of the microstructure and refinement of the reinforcing particles. And further an increase in the SiC content to above 25 wt. % (48 vol. %), material hardness decreased. While in the entire range of SiC content the electrical conductivity and CTE of the composites decrease [2].

G. Celebi Efe, et.al carried out a study on copper matrix reinforced with varying % of SiC particle were fabricated by powder metallurgy method. The results of the study on mechanical and electrical conductivity properties of Cu-Sic composites indicated that with increasing SiC content hardness increased, but relative density and electrical conductivity decreased [4].

M. Barmouza et.al conduct study on friction stir processed cu/sic composite and microstructure, mechanical properties and wear resistance are investigated in which volume fraction of SiC particles taken as function. Decreasing the reinforcing particle size or increasing the volume fraction enhanced the tensile strength and wear resistance. The wear resistance of the composite enhanced with increasing the volume fraction of SiC particle. Hardness values of all composites with varying Sic volume fraction and particle size were more than the pure copper. He conclude with increasing SiC volume fraction or decreasing particle size hardness increased [7].

S.G. Sapate, et.al. prepared Cu/SiC composites varying SiC % on which Pin on Disc test carried out and reports the modeling of dry sliding wear behavior of composites. Powder metallurgy is used to fabricate the copper matrix composites with 10%, 20%, 30% and 40% SiCp reinforcement. To determine stress–strain relationship and relevant mechanical properties of Cu–SiCp composites compression test data was used. On Cu/SiC dry sliding wear test is conducted using pin on disc apparatus in which variation of load and sliding speed in the defined range. With the help of dimensional analysis method experimental data were analyzed [13].

T. Kock et.al carried out a study on SiC/Cu composites. The main objective of the study is to investigation of SiC/Cu system that exhibit an optimized metal-matrix composite which obtained with a reactive layer with a reactive between silicon carbide and copper [16].

N.B. Dhokey, et.al Carried out study of wear in Cu/SiC composite. The main objective of the study is to analyses wear rate which was conducted on Pin-On –Disc machine. The Cu/SiC composites were subjected physical, mechanical and microstructural characterization. The wear test conducted with experimental plan of four loads (15 N, 25 N, 45 N, and 65 N) and four sliding speed(0.6, 1.2, 1.8, 2.4 m/s) was conducted on pin on disc machine and record mass loss due to wear for a total 2500 m sliding distance. The wear rate (mm3/m) calculated for each load and sliding speed combination. The wear specimens were tested under dry (unlubricated) conditions at room temperature [10].

Jianhua Zhu et.al has conduct a study on Cu/SiC composite. In this study silicon carbide powder used as reinforced copper based composite which is fabricated by electroforming technology. In this study the influence of the concentration of SiCp in plating solution, current density on the SiCp content in Cu/SiCp composites the temperature of plating solution, and mechanical and thermophysical properties of composites were studied. Through optimizing the technology parameters, uniform distribution and integral copper-based composites fabricated with high SiCp content, adjustable thermophysical and mechanical properties were achieved successfully. The Cu/SiCp composite used in the fields of contact and electronic packaging [6].

S.C. Tjong, K.C. Lau conducts a study of SiC/Cu composite. The main objective of this study to analyses tribological behavior of composite and pure copper. The fabrication of pure copper and composite reinforced with SiC particle were prepared by hot isostatic pressing. Pin on disc tester is used to study tribological behavior of copper and composite. The study showed that copper exhibits high wear loss while additions of SiC particle upto 20 vol % improve the wear resistance of copper under the loads of 15-55 N. And dry sliding wear test also exhibit lower wear loss as compared to pure copper [12].

F.E. Kennedy .et.al this study is conducted for brake application in which friction and wear of Cu/SiC observed. The copper matrix is protected by large volume of the presence of large volume of SiC particle in metal matrix composite the hard carbide particle protected the copper matrix. Strength of the bond between Sic particle and copper matrix had an important effect wear of the particulate metal matrix composite (PMMC) material. Wear of the PMMC material is greater against softer counter faces [3].

6. CONCLUSIONS

The important conclusion comes out from the studies carried out on Cu/SiC composite are as follows:

- Generally stir casting is preferred to fabricate Cu/SiC composite.
- Addition of SiC particle results in enhancement of wear resistance.
- Hardness increased with increased SiC wt. %.
- Electrical conductivity and coefficient of thermal expansion decreased with increased of SiC wt. %.

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