# Characterizing copper-based composites using powder metallurgy technique as fabrication process.

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## Abstract:

In tribological industries metal matrix composites are now being more commonly used because of their inherent properties such as high stiffness, high strength, high toughness etc. The effect on tribological properties of silicon carbide-reinforced copper-based metal matrix composites was investigated. In a copper matrix, silicon carbide metal powders of 60µm particle size were reinforced to yield composite samples of ratios 5, 10 and 15 percent by means of powder metallurgy technique. As per ASTM G99, the manufactured composite specimens were subjected to sliding wear tests using pin-on-disc system. The sliding wear experiments were carried out by following the Taguchi methodology and the variance approach analysis was used to assess the effect of wear factors such as applied load, sliding speed, material composition and sliding distance on wear resistance of manufactured composites. In addition, signal-to-noise ratios were used to analyze copper based metal matrix composite wear behaviour. The injection of silicon carbide metal powders into copper matrix material as reinforcement material increases the tribological characteristics.

## 1. Introduction:

The ability of bearings to reduce friction between mating components makes them essential to component performance. Hydrodynamic journal bearings and rolling component bearings are two of their primary uses in equipment. The bearing's main function is to support load in order to reduce wear between a rotor and the casing. Because copper alloys combine high strength, resistance to chemical reactions, and auto-lubrication properties, they have been used for bearing applications for a long time [1]. Copper based composites are popularly electrical applications, shafts and bearings, packing and other things [2].

By adding alumina, the aluminum bronze composite's tribological properties and hardness have enhanced [3]. The wear rate of Cu–Sn bronze has increased once alumina was introduced [4].

The addition of nano SiC particles has enhanced the bronze matrix's microhardness and sliding wear performance [5]. The addition of Cr and Ag to bronze composite has enhanced its lubrication and wear performance [6]. By adding SiC, $SiO_2$, and graphite, the corrosion resistance of bronze composite has increased [7].

The size of the SiC particles also affects the composites' electrical conductivity. The electrical conductivity value increases with particle size because the addition of coarse particles to the copper matrix facilitates electron scattering, which raises the conductivity of the composite [8]. The particulate metal matrix composite is mostly used in tribological applications because to its exceptional wear resistance during sliding. Because of their inability to self-lubricate due to high temperatures, gases and oil are not suitable for use. Therefore, a high-quality solid lubricant that works throughout a wide temperature range is needed [9].

## 2. Material and fabrication technique:

A 60 micron particle size of copper and SiC material was used. The components are made using the powder metallurgy process [10–12]. This method's benefit is that it always yields a neatly shaped component and does away with the need for subsequent machining. The specimens are made to be 20 mm long and 8 mm in diameter.

Proper mixing of the powder is maintained for its uniform distribution. The load to be given to the die was then set at 90 KN at room temperature based on standard experiments, and the Universal Testing Machine was pressed from the top and bottom. Green sintered components are first made, and then they undergo a sintering process to give them the required strength and hardness. For seven hours, the temperature is kept at $600^0$C, and for four hours, regular cooling is done. A temperature of 12ºC per minute was reached. According to the weight % of powders, the percentage of SiC in the current job varies. The different composite material compositions are displayed in the table below.

**Table 1: Composition of Composites**

| **Copper** | **Silicon Carbide** |
|---|---|
| 95 | 5 |
| 90 | 10 |
| 85 | 15 |

## 3. Experimentation:

At room temperature, fabricated specimens are put through a wear test in various settings. For the current investigation, pin-on disc equipment with a disc hardness of 65HRC is utilized. Weight loss is used to quantify wear resistance. The primary impacts and interactions are studied using statistical tools such as the Taguchi technique. Several factors, including load, speed, sliding distance, and material compositions, are taken into account while analyzing wear resistance. These parameters' values are set based on the standard experiment. The impact of applied weight, sliding distance, sliding speed, and material composition on the composites' wear was investigated [13–19]. The criteria and levels taken into consideration for the Wear Test are displayed in the table below.

**Table 2: Parameters and levels considered for Wear Test**

| **Factors** | **L-1** | **L-2** | **L-3** |
|---|---|---|---|
| Composition of Material(M) Wt.% | 5 | 10 | 15 |
| Load (L) in Kg | 1 | 2 | 3 |
| Speed(S) RPM | 200 | 400 | 600 |
| Sliding Distance (D) in Meters | 1000 | 2000 | 3000 |

L27 orthogonal array is used to check the influence of the parameters and interaction among the parameters. The table 3 shows the orthogonal array of copper- sic samples.

**Table 3: L27 Orthogonal Array**

| **Expt. No.** | **Material Composition-(M)** | **Load-(L)** | **Speed-(S)** | **Sliding Distance-(D)** | **W1 -W2** | **SN Ratio-(dB)** | **Mean** |
|---|---|---|---|---|---|---|---|
| 1 | 5 | 1 | 200 | 1000 | 0.0017 | 55.39102 | 0.0017 |
| 2 | 5 | 1 | 400 | 2000 | 0.0022 | 53.15155 | 0.0022 |
| 3 | 5 | 1 | 600 | 3000 | 0.0043 | 47.33063 | 0.0043 |
| 4 | 5 | 2 | 200 | 2000 | 0.0059 | 44.58296 | 0.0059 |
| 5 | 5 | 2 | 400 | 3000 | 0.0077 | 42.27019 | 0.0077 |
| 6 | 5 | 2 | 600 | 1000 | 0.0062 | 44.15217 | 0.0062 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 7 | 5 | 3 | 200 | 3000 | 0.0177 | 35.04053 | 0.0177 |
| 8 | 5 | 3 | 400 | 1000 | 0.0071 | 42.97483 | 0.0071 |
| 9 | 5 | 3 | 600 | 2000 | 0.0154 | 36.24959 | 0.0154 |
| 10 | 10 | 1 | 200 | 1000 | 0.0014 | 57.07744 | 00.0014 |
| 11 | 10 | 1 | 400 | 2000 | 0.0021 | 53.55561 | 0.0021 |
| 12 | 10 | 1 | 600 | 3000 | 0.0039 | 48.17871 | 0.0039 |
| 13 | 10 | 2 | 200 | 2000 | 0.0047 | 46.55804 | 0.0047 |
| 14 | 10 | 2 | 400 | 2000 | 0.0063 | 44.01319 | 0.0063 |
| 15 | 10 | 2 | 600 | 1000 | 0.0056 | 45.03624 | 0.0056 |
| 16 | 10 | 3 | 200 | 3000 | 0.0164 | 35.70312 | 0.0164 |
| 17 | 10 | 3 | 400 | 1000 | 0.0063 4 | 44.01319 | 0.0063 |
| 18 | 10 | 3 | 600 | 2000 | 0.0145 | 36.77264 | 0.0145 |
| 19 | 15 | 1 | 200 | 1000 | 0.0008 | 61.9382 | 0.0008 |
| 20 | 15 | 1 | 400 | 2000 | 0.001 | 60 | 0.001 |
| 21 | 15 | 1 | 600 | 3000 | 0.0021 | 53.55561 | 0.0021 |
| 22 | 15 | 2 | 200 | 2000 | 0.0035 | 49.11864 | 0.0035 |
| 23 | 15 | 2 | 400 | 3000 | 0.0051 | 45.8486 | 0.0051 |
| 24 | 15 | 2 | 600 | 1000 | 0.0042 | 47.53501 | 0.0042 |
| 25 | 15 | 3 | 200 | 3000 | 0.0151 | 36.42046 | 0.0151 |
| 26 | 15 | 3 | 400 | 1000 | 0.0052 | 45.67993 | 0.0052 |
| 27 | 15 | 3 | 600 | 2000 | 0.0132 | 37.58852 | 0.0132 |

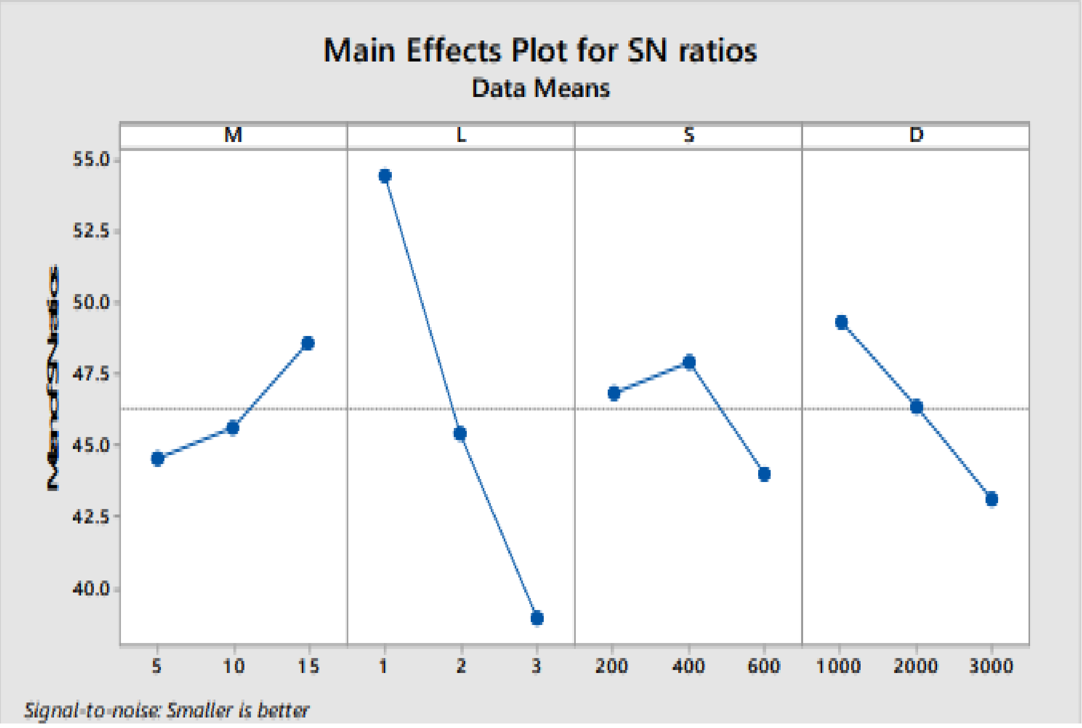

**Figure 1: The plot of primary effects illustrates material loss as represented by S/N ratios.**

Table 4: Response Chart for Degradation of Material Signal to Noise Ratios

| Levels | Composition of Material (M) | Weight (W) | Speed (S) | Sliding Distance (D) |
|---|---|---|---|---|
| 1 | 42.95 | 45.20 | 45.50 | 45.19 |
| 2 | 44.09 | 44.13 | 43.76 | 44.08 |
| 3 | 45.42 | 43.13 | 43.21 | 43.19 |
| Delta | 2.47 | 2.07 | 2.29 | 2.00 |
| Rank | 1 | 3 | 2 | 4 |

Table 5 Variance of analysis for loss of material

| Source | DF | Adj SS | Adj MS | F - Value | P - Value | P (%) |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| M | 2 | 0.000014 | 0.000007 | 98.72 | 0.000 | 1.22 |
| W | 2 | 0.000009 | 0.000004 | 62.08 | 0.000 | 71.10 |
| S | 2 | 0.000011 | 0.000006 | 79.45 | 0.000 | 6.35 |
| D | 2 | 0.000007 | 0.000004 | 52.40 | 0.000 | 14.95 |
| Error | 18 | 0.000001 | 0.000000 | | | 6.35 |
| Total | 26 | 0.000042 | | | | 100 |

## 4. Result & Discussion

As the distance increases there will be increase in the weight loss. This is due to continuous contact of the material with hardened disc. Weight loss is calculated by taking the difference between the initial and final weight. For a load of 3Kg maximum weight loss was recorded.

The experiment demonstrates that the surface gets rougher as the sliding speed rises from 200 rpm to 600 rpm. When Cu composites come into contact with rotating discs under varying applied loads, such as 1 kg, 2 kg, and 3 kg, plastic deformation happens because Cu composite is known to have less hardness than the steel disc's counter surface (HRC 65). The hard counter surface's asperities promote metal-to-metal contact and plough action, which results in abrasive wear on the copper sample. However, at greater speeds (600 rpm) and Oxide layers such as CuO and $Cu_2O$ may occur at sliding distances of up to 3000 meters. Because hard SiC particles sustain the tension on the contact surfaces and stop plastic deformation and abrasion, they aid to improve wear resistance and lessen material wear.

When ceramic particles are added to the composite, the composite gets tougher, increasing its resistance to penetration and minimizing material loss from wear debris and other external particles in the wear environment. Figure 3 confirms that there is no reaction between the matrix and reinforcements during manufacturing by demonstrating that no interfacial product forms at the interface. The matrix and reinforcement exhibit appropriate interfacial bonding when viewed from a microstructural perspective. Consequently, when compared to copper, the wear characteristics of Cu–SiC composites are significantly better. Its negligible pore count indicates improved compatibility.

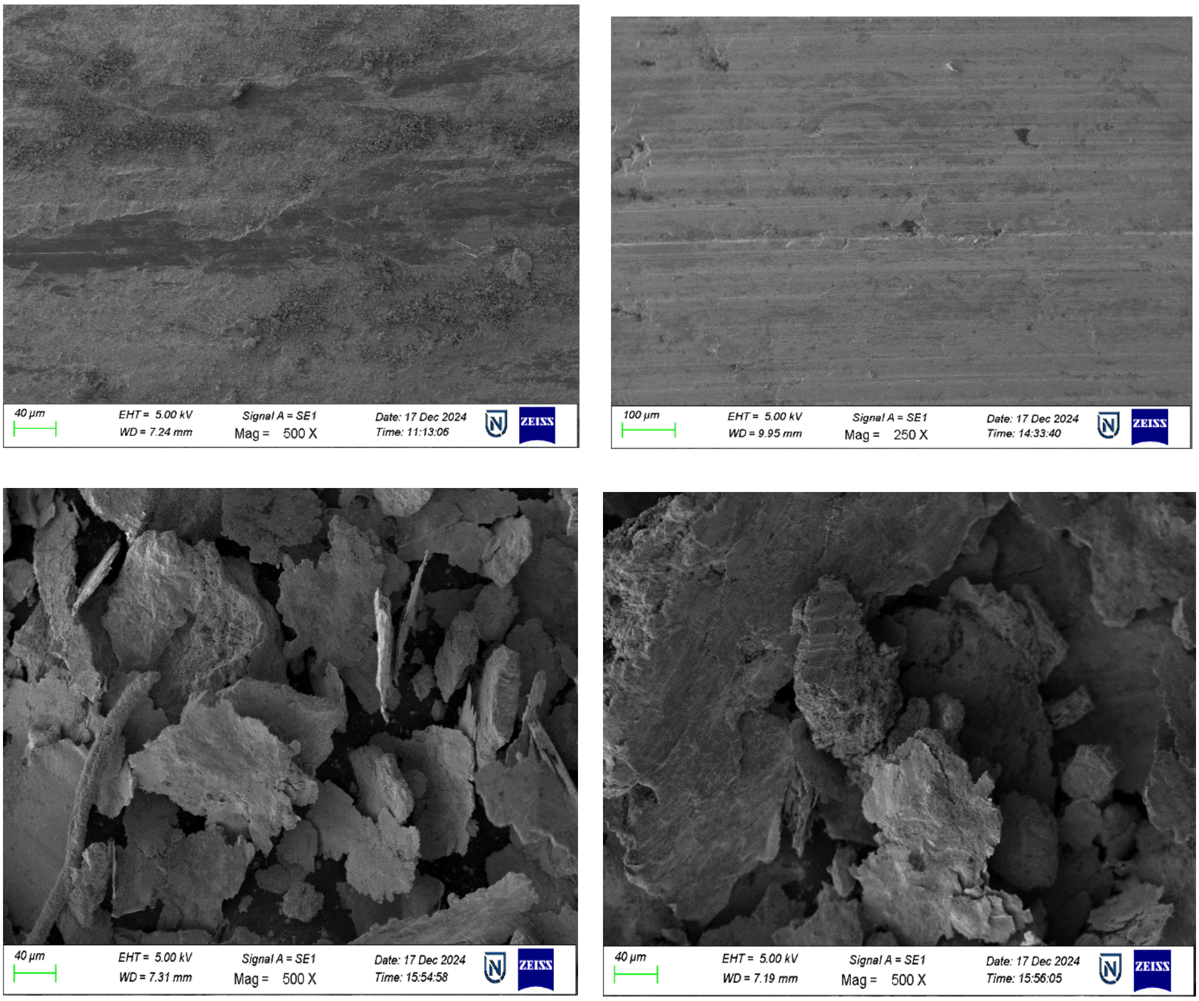

**Figure 2 The SEM micrographs of worn surfaces of (a) Copper -5wt.% SiC, (b) Copper -10wt.% SiC and (c) Copper -15wt.% SiC composites at load = 3 kg, speed = 600 rpm and sliding distance = 3000 m**

The wear micrographs above show that the Cu-5% SiC composite has more rubbing activity. This implies that the wear surface contains SiC particles, which result in abrasive wear. Since the sintered hardness of the 5% SiC sample is higher than that of the pure copper sample, it is clear that pure copper has seen more wear than Cu-5% SiC. The softer copper matrix may plastically deform under heavy pressures, causing material flow and surface damage. By serving as load-bearing components, SiC particles can limit the plastic deformation of the copper matrix, lowering overall deformation and preserving dimensional stability.

Under the applied load, the pin and disc first come into contact at many asperities. With the exception of the filler's projecting tips, which have superior surface abrasion resistance, all of these asperities experience plastic deformation at their contact points due to their sharpness and the fact that the effective stress there is greater than the elastic stress. Furthermore, new asperities are created on both sides as a result of wear-induced distortion and fracture of the pin and disc's materials, which produces extremely fine debris.

The experiment shows that as sliding speed increases from 200 rpm to 600 rpm, surface roughness increases as well. Because the Cu composite is less hard than the counter surface (HRC 65 steel disc), plastic deformation happens when it comes into contact with the rotating disc under applied loads like 1Kg, 20Kg, and 3Kg. Due to enhanced metal-to-metal contact and plowing action brought on by the hard counter surface's asperities, the copper sample undergoes abrasive wear; as a result, the wear rate is higher in pure copper than in the other compositions.

## 5 Conclusion

By adjusting the percentage of silicon carbide, such as 5%, 10%, and 15% by weight, copper sic metal matrix composites were successfully created with the aid of the p/m approach. The samples' tribological characteristics were examined. The investigation's findings can be summed up as follows:

- Powder metallurgy is becoming an increasingly important tool is the fabrication of many products powdered-metal techniques are invaluable in the manufacturing of parts from the refectory materials.
- Sintering is carried out in a vacuum furnace for seven hours at the rate of $12^0$ C/min and normal cooling is done 7000 C temperature is maintained throughout the sintering process.
- The fabrication Cu based MMC justified specimens are subjected to wear test to check the performance. Wear test was conducted selecting parameters as the different levels of load, speed and distance.
- Increase in the reinforcement content in the MMC will increase the wear resistance property.
- Increase in the reinforcement particle size in the MMC the also increases wear resistance bigger the particle higher is the wear resistance.

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