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# Effect of carbon nanotube and silicon carbide on microstructure and dry sliding wear behavior of copper hybrid nanocomposites

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**Abstract:** Microstructure and tribological properties of copper-based hybrid nanocomposites reinforced with copper coated multiwalled carbon nanotubes (MWCNTs) and silicon carbide (SiC) were studied. Carbon nanotube was varied from 1% to 4% with silicon carbide content being fixed at 4%. The synthesis of copper hybrid nanocomposites involves ball milling, cold pressing and sintering followed by hot pressing. The developed hybrid nanocomposites were subjected to density, grain size, and hardness tests. The tribological performances of the nanocomposites were assessed by carrying out dry sliding wear tests using pin-on-steel disc tribometer at different loads. A significant decrease in grain size was observed for the developed hybrid composites when compared with pure copper. An improvement of 80% in the micro-hardness of the hybrid nanocomposite has been recorded for 4% carbon nanotubes reinforced hybrid composites when compared with pure copper. An increase in content of CNTs in the hybrid nanocomposites results in lowering of the friction coefficient and wear rates of hybrid nanocomposites.
**Key words:** copper; carbon nanotubes (CNTs); SiC; microhardness; wear mechanisms; nanocomposite

## 1 Introduction

Carbon nanotubes (CNTs) possess superior mechanical, thermal and electrical properties, and have received considerable interest globally from the scientific community. The extremely high elastic modulus of 0.9−2 TPa, ultimate tensile strength close to 63 GPa and thermal conductivity of 3000 W/(m·K), high electrical conductivity of $>10^6$ S/m for single wall carbon nanotube (SWCNT) and $>10^5$ S/m for multiwalled carbon nanotube (MWCNT) have prompted material scientists and engineers to use them as emerging reinforcement for polymer, ceramic and metal matrix composites [1−3]. The last decade has seen a surge in research papers on CNT reinforced metal matrix composites in particular aluminium, copper, magnesium and nickel matrices based ones. Most of the papers have reported improved mechanical properties with addition of CNTs to the metal matrices [4−6].

In recent years, hybrid composites with multiple reinforcements have been developed which possess the combined properties of both the reinforcements. For applications like electrical sliding contact materials, the material should not only have good electrical properties but also possess excellent wear resistance. Copper is well known for its high electrical ($5.8\times10^7$ S/m at 20 °C), and thermal conductivity (400 W/(m·K)), high coefficient of thermal expansion ($17\times10^{-6}$ $K^{-1}$) with low strength (<220 MPa) and poor wear resistance. The hard ceramic particles like SiC [7], $Al_2O_3$ and TiC [8] which possess higher hardness, good abrasion resistance and high melting point can contribute to improvement in the strength as well as wear resistance of metal matrix composites. On the other hand, soft solid lubricating materials like graphite [9,10], carbon fibers [11] and $MoS_2$ are used as secondary reinforcement. These solid lubricants enhance the tribological properties by

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formation of a thin solid lubricating film on the tribo-surface. This lubricating layer reduces the friction coefficient and decreases the wear rates. The inclusion of hard and soft reinforcement in copper matrix can enhance both strength and wear resistance which are much needed for sliding contact applications [12,13]. ZHAN and ZHANG [10] have reported the friction and wear behavior of copper matrix composites reinforced with SiC and graphite particles developed by powder metallurgy technique. The dry sliding wear tests have been conducted using block on ring type tribometer at different loads. Copper−SiC−graphite composites do exhibit better tribological properties than that of Cu−SiC composites. Delamination wear was identified as a predominant wear mechanism in hybrid composites when tested under high loads. The worn surface analysis showed the presence of graphite-rich mechanically mixed layer contributing towards good anti-friction properties. RAMESH et al [7] have developed Cu−SiC−graphite hybrid composites by liquid metallurgy technique. It is reported that there is beneficial effect of graphite on the tribological properties of developed hybrid composites. The friction coefficient and wear rate of the developed hybrid composites were in between the values obtained for Cu−SiC and Cu−graphite composites. RAJKUMAR and ARAVINDAN [8] have reported the tribological properties of microwave sintered Cu−TiC−graphite hybrid composites. The friction coefficient and wear rates of hybrid composites were lower when compared with those of unreinforced copper. This has been attributed to the formation of mechanically mixed layer with high graphite content at the contact region of the tribo-surface. However, with the increase in sliding velocity from 1.25 to 2.51 m/s, an increase in friction coefficient as well as wear rate of hybrid composites has been reported.

In recent years, CNTs have been considered as a possible replacement for graphite in the conventional and hybrid composites owing their lubricating nature in addition to their high strength, thermal and electrical conductivity. In this regard, there are reports about development of self-lubricating composites for automotive applications using carbon nanotubes as reinforcement [13−15]. However, limited research has been done in synthesis and characterization of metal matrix hybrid nanocomposites involving CNT and SiC as reinforcements.

In the light of the above, this work focuses on development of copper hybrid nanocomposites with CNT and SiC as reinforcements using powder metallurgy technique. The effects of varying CNT mass fraction with fixed content of SiC on the microstructure, hardness, friction and wear properties of copper hybrid nanocomposites are discussed.

## 2 Experimental

### 2.1 Materials

Multiwalled carbon nanotubes with diameter in the range of 20−40 nm, length1−10 μm and density of 2.1 g/cm$^3$, have been used as one of the reinforcement (As supplied by Chengdu Organic Chemicals Co., Ltd, China). The other reinforcement used is silicon carbide particles with size ranging in 20−30 μm and density of 3.21 g/cm$^3$(Supplied by Grind well Norton, India). Lab grade electrolytic copper powder with 99.5% purity having particle size ranging from 2 to 8 μm and density of 8.94 g/cm$^3$ was used as matrix material to develop copper-based hybrid nanocomposites.

### 2.2 Electroless copper coating on MWCNTs and SiC

It is well known that both MWCNT and SiC are non-wetting with copper owing to their high surface tension. In order to improve the interfacial bonding between MWCNT and SiC with that of copper, a conventional electroless coating method has been employed to coat both the reinforcements with copper. Precleaning of MWCNTs and SiC was carried out by $HNO_3$ for about 5 h and oxidizing of its surfaces using nitric acid for 15 min at 60 °C to remove any unwanted impurities on MWCNTs and SiC. Further, sensitization of cleaned MWCNTs and SiC particles in stannous chloride solution was carried out followed by activation in palladium chloride solution. The activated MWCNTs and SiC particles were introduced into the electroless copper bath and copper coating obtained under optimal process conditions as reported by previous works [16−18].

### 2.3 Synthesis of hybrid nanocomposites

Different mass fractions of MWCNTs (1% to 4%) and SiC (4% fixed) with pure copper powder were mixed in a planetary ball mill (Supplied by Insmart Systems, Hyderabad, India). The vial of planetary ball mill was filled with matrix and reinforcement powders with stainless steel ball maintaining the ball to powder ratio to be 8:1. The speed of the vial was kept at 300 r/min with milling duration being 3 h. In order to avoid oxidation of starting powders during ball milling, ethanol was added as a process controlling agent. The milled composite powders were compacted by applying a pressure of 400 MPa using a 100 t hydraulic press for duration of 5 min. These green compacted samples were sintered in an electric furnace at 900 °C for about 8 h under argon-protected atmosphere. This was followed by hot pressing of the sintered powder compacts at a pressure of 400 MPa to improve the density of copper and hybrid nanocomposites.