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# Improvement the wear resistance of pure copper fabricated by powder metallurgy by nano and micro size TiC additions

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**Abstract**
**The purpose of this research is to evaluate how the micro TiC (1-4.5% wt%) and nano TiC (0.25-1) wt% additions to copper base composites prepared by powder metallurgy effects their wear resistance, surface roughness, compressive strength, and generated frictional heat during dry sliding. The powder mixtures were ball milled at 170 rpm for 7 hrs and uniaxial pressed at 700 MPa, and then sintered in an electric resistance furnace in an argon environment at 850°C for 2 hrs. The results revealed that as the micro and nano TiC content increases the wear rate of copper base composites decreases. Generally, the micro size TiC addition tends to increase wear resistance, surface roughness, and compressive strength of sintered copper samples with greater amounts than that obtained with nano-sized TiC particles addition.**

**Key Words:** Powder Metallurgy, Cu-TiC Composites, Cu-TiC Wear Rates.

## Introduction

There is a growing demand for innovative materials that have high strength, electrical, and thermal conductivity like metal matrix composites (MMC). They are materials made of a metal or alloy matrix in which a reinforcing material is ceramic. Metal and ceramic properties are combined in these materials [1]. When ceramic particles are used to strengthen them, they may show increased mechanical strength and wear resistance. The addition of various ceramic reinforcements, such as SiC or TiC, to the MMC is being studied extensively to boost its strength [2, 3].

The mostly employed in electronics and electro-mechanics for relays, switches, electric motor parts, and resistance welding electrode tips [4,7]. These materials are made by high-pressure infiltration casting and pressure-free metal infiltration, powder metallurgical procedures, plasma spraying of the matrix material, hot pressing, and self-propagating high-temperature synthesis. These processes are some of the other fabrication processes [8,9]. The powder metallurgy (PM) technique is perfect for creating Cu-matrix composites and it was chosen in the present research as the processing method because of the ease with which a hard phase may be incorporated into a metal phase by combining powders [10,11]. Copper is employed in industrial items because of its high electrical and thermal conductivities, low cost, simplicity of manufacturing, and resistance to corrosion. However, its uses are limited because of its low hardness, tensile strength, and wear resistance [13, 16]. Copper base metal matrix composites with ceramic reinforcement particles have been developed to improve the mechanical properties and wear resistance of copper, and are candidates for structural applications in the industry that require wear resistance, besides their high electrical and thermal conductivity [17,18]. Cu-TiC composites are widely used in industry, they connect between the ductility and conductivity of Cu and the insulation and hardness TiC [19]. Therefore, in this study, the additions of (1–4.5) wt% of micro-size TiC and (0.25–1) wt% for nano-size TiC to Cu powder were done to fabricate samples with cold press consolidation, followed by sintering. The effect of the TiC content on the, wear rate, surface roughness, and compression strength and generated frictional heat during dry sliding of the Cu base composites were investigated.

## Experimental Procedure

Commercial copper powder and TiC powder (99,9% purity), made in Jingan Chemicals and Alloy Limited Company-China were used as starting materials. Cu and TiC powders were milled for 7 hrs. in a ball mill. The weight ratio of the ball to the powder was 10:1, and the rotation speed was 170 rpm. Mixing powders containing varying amounts of TiC were placed in a steel die and cold compacted at 700 MPa [20, 21]. The first set of pressing molds was used to make 15 mm diameter cylindrical samples, while the second set was used to make 10 mm diameter cylinder-like shape samples, figure (1) depicts some of the green compact samples that have been manufactured.

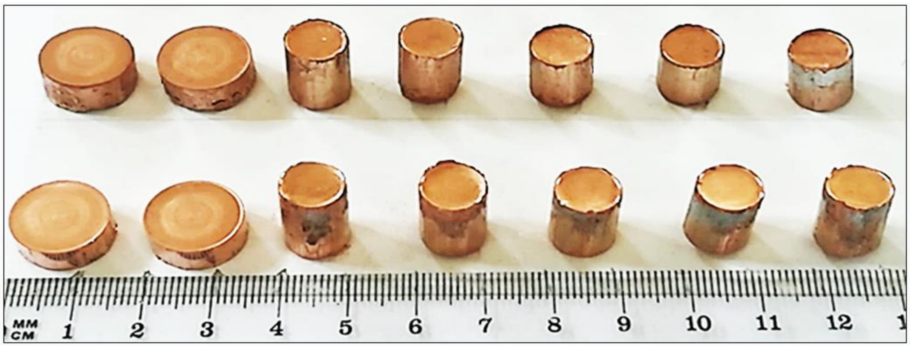



**Figure (1) Different types of compacted samples**

Muffle furnace type (CARBOLITE/UK) was used to conduct the sintering process. Cu-TiC compact samples were sintered at 850ºC for 2 hrs. at a heating rate of 10 degrees in a continuously applied argon gas stream. The parallel faces of the cylindrical samples were wet ground with (400, 850, 2000, and 3000) grit silicon carbide emery sheets, and then polished with a 2µm alumina suspension solution, washed with distilled water, and ethanol alcohol. It was then etched for 30 seconds using a solution of potassium permanganate 4g per 1000 cm3 water and 10-part $H_2SO_4$, and then rinsed with distilled water. The surface roughness of Cu-TiC composites was measured using a surface roughness tester (type Pocket Surf III/ PMD 90101). The wear rate test was carried out using a pin-on-disc device of Chinese origin in the metallurgy laboratory/Kirkuk Technical College. The steel disc surface of the device is cleaned before starting each wear test process. Wear rates of the samples were determined using equation 1 below, the wear rates were calculated using the gravimetric method, which includes calculating the amount of loss by weight for each sample by weighing the sample before the test and after completing the test by digital sensitive scale. The interval of each wear test was 15 mins.

$$W = \frac{\Delta w}{\Delta s}\,\frac{gm}{cm}$$

Where:
W indicates to wear rate
$\Delta w = w_o - w1$ indicates lost Weight, the difference in weight of the sample before and after the operation (gm)
$\Delta S$ indicates sliding distance and is equal to $\Delta S = \pi$ D n t
D denotes the diameter of the disc (cm), n denotes disc rotational speed (rpm).
t denote to test time (min).
The compressive strength test was performed using, model WDW-200E.

## Results and Discussion

### Wear Tests

From figure (2) it is noticed that the wear rate decreased when TiC micro-particles were added to strengthen copper base material. The decrease in wear rate when increasing the percentage of the reinforcement particles is due to the increased hardness of the composite than the pure Cu sintered compacts. The wear rate of pure Cu and composite with micro size TiC particle increases with the increase of the load from 5N to 20N as shown in figure (2). TiC-particles have impeded the progress of the dislocations resulting from generated tangential shear stress during the sliding on the steel disc that resulted from the contact of the sample surface with the rotating disc surface. However, the best wear resistance was detected at the greatest TiC particles addition. The same manner of wear resistance improvement happened when nano-sized TiC particles were added like the former case when micro-sized TiC particles were added. But it is important to observe the improvement of wear resistance was somewhat with lower values when nano-sized TiC particles were added to Cu. This is very clear when the curves of wear rates in the two figures (2 and 3) are compared with each other.

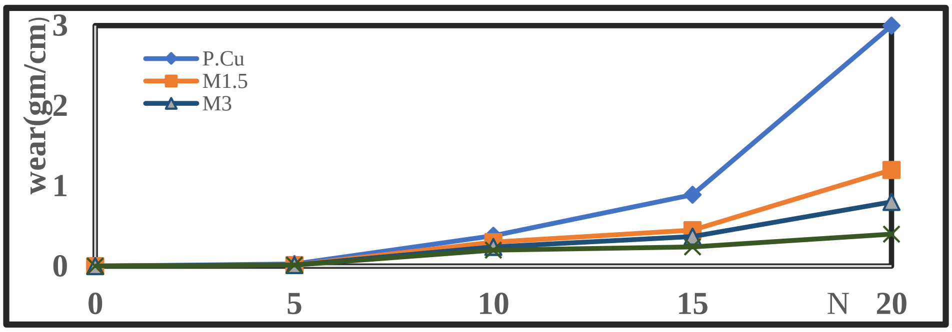



**Figure (2) Wear rate variation for sintered Cu - micro size TiC composites**

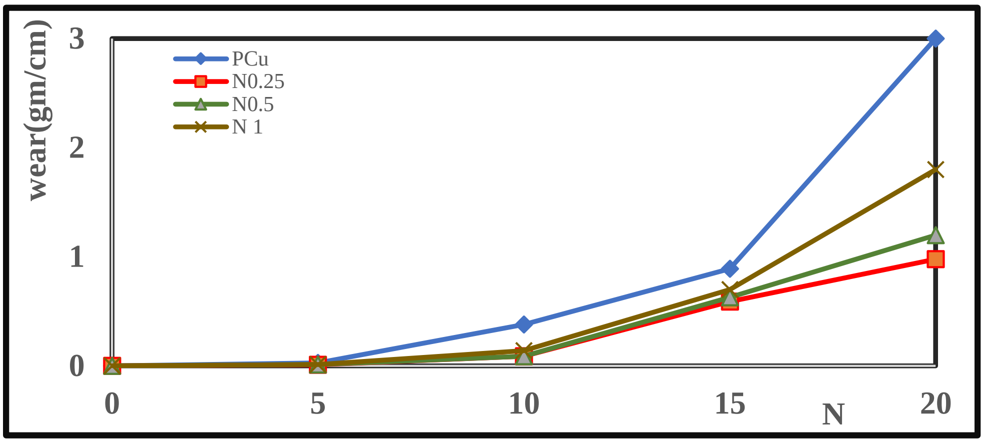



**Figure (3) Wear rate variation for sintered Cu - Nano size TiC composites**

It was seen that the particulate strengthening mechanism by which micro-size TiC particles reinforced the Cu matrix was more effective than the dispersion strengthening mechanism by which the nano-size TiC particles was reinforced the same Cu matrix, besides the difference in their added amounts which may have its effect from point of view of area fraction that the added particles will equip. This wear behavior can be also attributed to the good degree of bonding that occurred between Cu and TiC particles which is good evidence of the successes of milling pressing and sintering processes that applied in this study. It is important to refer to that wear behavior is also a direct reflection of the hardness value raised with the addition of nano and micro TiC particles additions, where the hardness of the fabricated composites generally was greater than that for pure Cu sintered compact samples. The results are agreeing with that the inverse relationship between hardness and wear rate as stated by [22]. Both plastic deformation and abrasive wear mechanisms were contributed in the wear process for pure Cu samples where serrated regions denote the plastic deformation effect m while the persons of the parallel g longitudinal grooves denote the abrasive wear occurrence that was initiated from the plowing of the Cu contact surface by asperities that were existed on the steel disc surface. Figure (4-a) explains the above-listed information. The addition of the micro and nano-size TiC particles to Cu matrix enhanced the resistance of the samples to wear as observed from wear rates and these results reflected on the morphology of the worn surfaces where the abrasive wear effect on the surfaces of the micro and nano Cu-TiC composites became lower which is clear from the lower formed abrasive wear grooves on the contact surfaces of the samples as shown in figure (4/-B, C, D, E, F, and G).

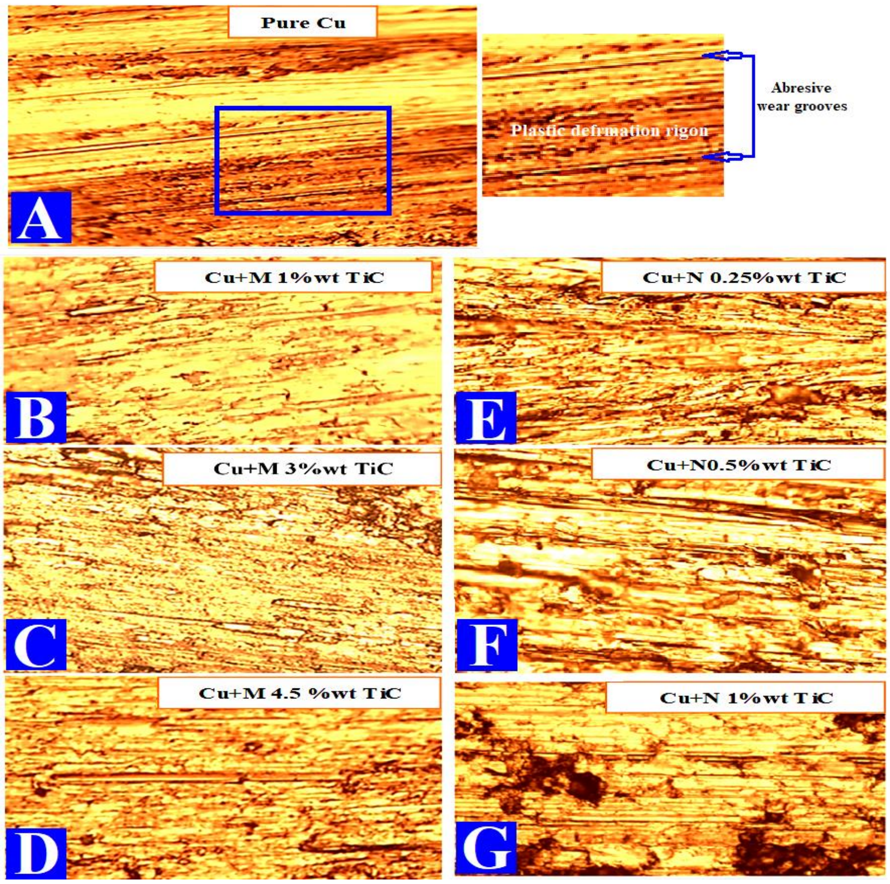
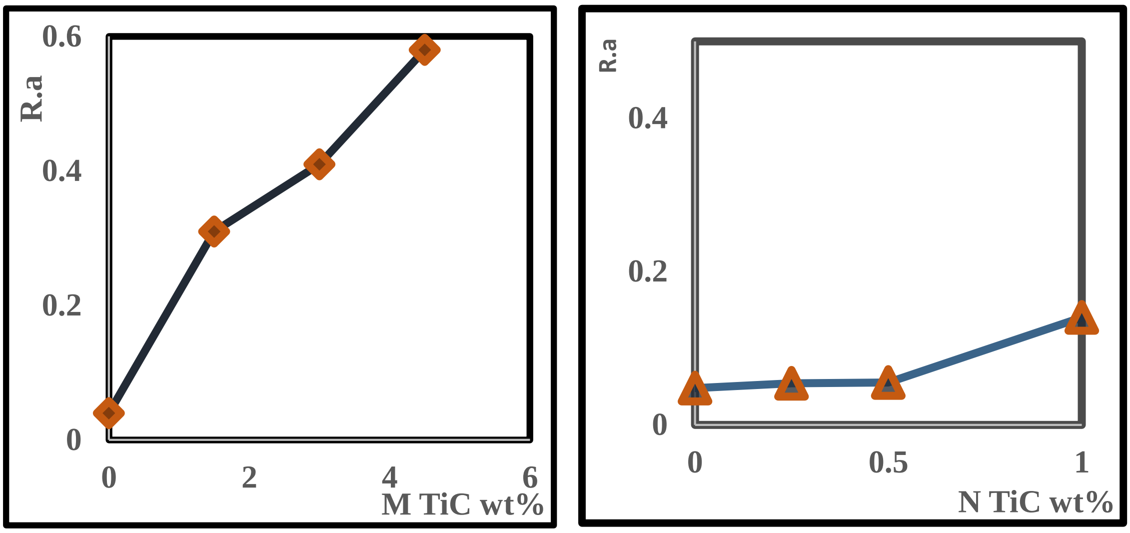



**Figure (4) Samples surface subjected to wear at 20 N applied load**

## Surface Roughness Measurements

Surface roughness is an important factor in the applications of engineering materials and wear tests. Figure (5a) explains the effect of micro-size TiC addition on the surface roughness of Cu. It is clear that by increasing the TiC content the surface roughness is increased. Because micro size TiC particles become protrusions on the surface of Cu particle. While the effect of nano-sized TiC addition on the surface roughness of Cu was lower as it is shown in figure (5b), because of the very small size of the nano TiC additions which was at 50 nm. The existence of micro and nano-size TiC as protrusions made the direct metal to metal contact probability lower which in turn reflected in the lower wear rates of the composites than pure Cu samples.




(a) (b)

**Figure (5) Surface roughness of (a) Cu–micro TiC (b) Cu–nano TiC composites.**

## Frictional Heat Measurements:

Figures (6 and 7) show the results of the average value of the contact temperature of Cu and its composites at two different applied loads. The generated frictional heat detected by mean of measured contact temperature between the sliding pairs explained the decrease of its value by increasing the of addition micro and nano-size TiC particles because TiC particles are a ceramic material that behaves like an insulator to the thermal and electrical properties. Also, the TiC particles cover some of the contact surface areas of Cu pins, therefore, the TiC particles generally contributed in the enhancement of wear resistance utilizing decreasing plastic deformation phenomena which is strongly related to contact temperature value.

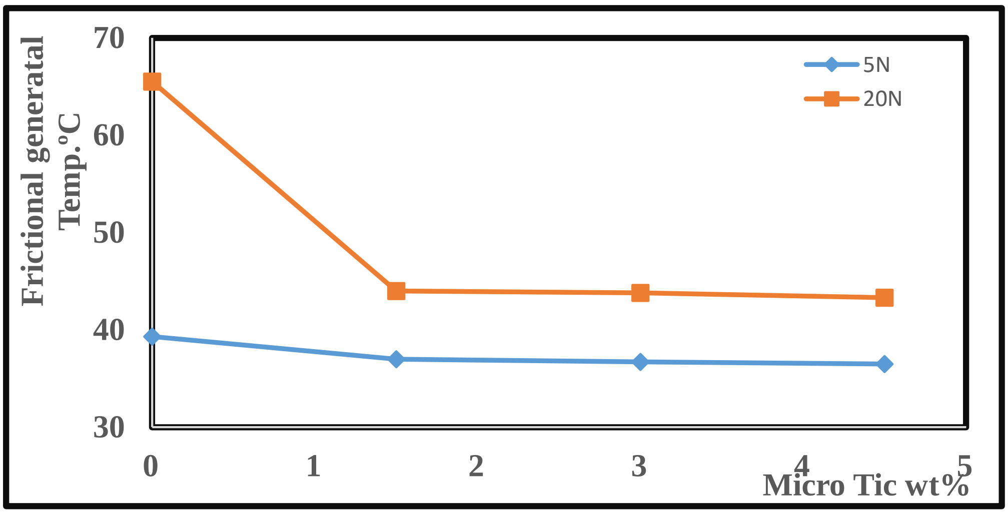



**Figure (6) Measured average contact temperature value of Cu without and with addition of micro size TiC particle at two different loads.**

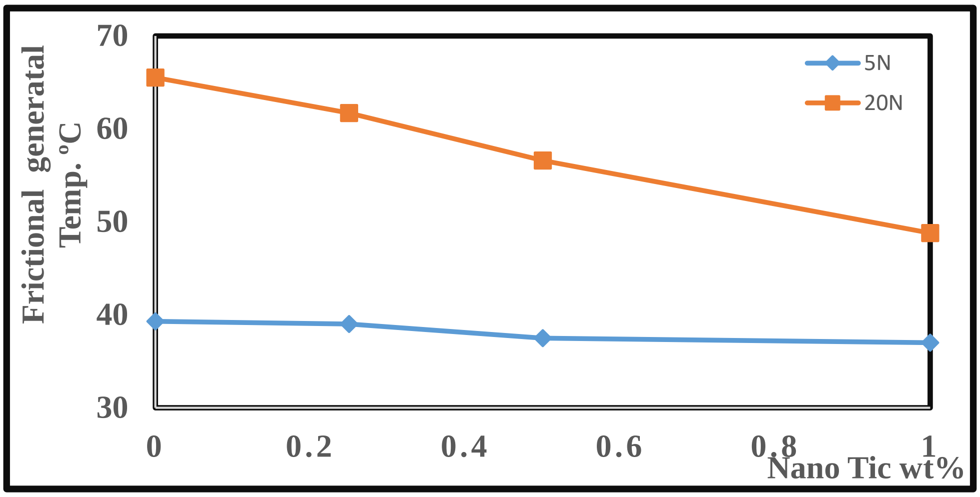



**Figure (7) Measured average contact temperature value of Cu without and with addition of nano size TiC particle at two different loads.**

Figure (8) explains the compression test stress-strain curves for pure Cu, Cu-micro size TiC and Cu-nano size TiC composites samples. It is clear from the figure that the Cu sample failed after the application of 405.6 MPa at a good strain value. These results are comparable to that of cast Cu products that means the followed PM route was good enough to obtain these results. The addition of nano-size TiC particles to Cu with 1 wt% tends to increase both the strength and ductility of pure Cu as shown from figure (8), where the dispersion hardening mechanism played the role of the enhancement of these properties. The micro-size TiC particles addition with its higher addition content which was 4.5 wt% also increased both strength and ductility properties of pure Cu but with a greater amount than nano-size TiC particles addition did. This is well illustrated in figure (8). The results of compression tests reveal that increasing the particulate hardening mechanism obtained from microsize TiC addition was more positively effective than the dispersion hardening mechanism that was obtained from nano-size TiC particles additions which were reflected on the better wear resistance of Cu-micro size TiC composites than Cu-nano size TiC composites.

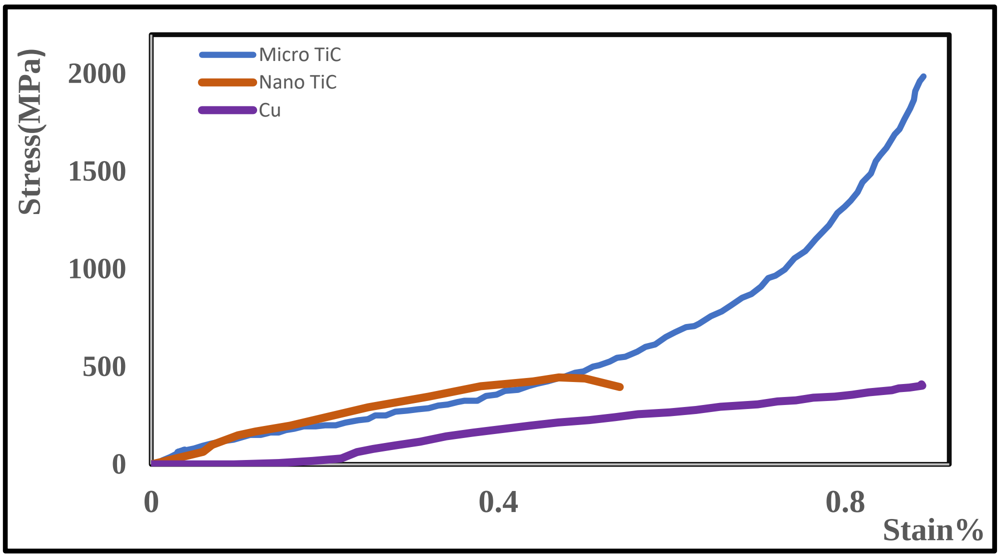



**Figure (8) Compression stress- strain curves for pure Cu, Cu nano and micro size TiC composites samples**

**Conclusions:**

1- The results revealed that as the micro and nano TiC content increases, the wear rate of the sintered Cu sintered composites samples decreases.
2- Generally the micro size TiC additions tend to increase the surface roughness of sintered Cu samples, while the increase of the surface roughness was in lower values when the nano TiC addition.
3- The increase in micro TiC addition is reflected in the increase of the compressive strength of Cu sintered compact samples with a great amount than that obtained from nano-size TiC particles addition.

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