TRIBOLOGICAL BEHAVIOUR OF COPPER HYBRID NANO COMPOSITES MATERIAL PREPARED THROUGH P/M METHOD

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Abstract

In this project, full factorial design has been used to optimize the wear test conditions of the copper–multi-walled carbon nano tubes and Nano boron carbide reinforced composites prepared through entrenched cold-press sintering method of powder metallurgy. The factors boron carbide particle, applied load and sliding distance of the wear test have been selected as the independent variables. This technique has been designed to achieve momentous effects on two responses, namely specific wear resistance and coefficient of friction. To study the micro structural morphology, particle size, worn surface and wear debris of the prepared copper hybrid nano composite, Scanning Electron Microscopy, Atomic force microscopy and X-ray Diffraction analysis were used for characterization.

Introduction

Metal Matrix Composites

Metal Matrix Composite (MMC) is material consisting of a metallic matrix combined with a ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) dispersed phase. Most commonly used matrixes are aluminium, magnesium, copper, titanium and zinc. The most commonly used reinforcements are silicon carbide, alumina, boron, graphite and fly ash. Development of these materials is a subject of great interest as they offer attractive combination of physical and mechanical properties, which cannot be obtained in monolithic alloys.

The major advantages of MMCs compared to unreinforced materials areas follows

1) Higher strength-to-density ratios
2) Higher stiffness-to-density ratios
3) Better fatigue resistance
4) Better elevated temperature properties
5) Lower coefficients of thermal expansion
6) Improved abrasion and wear resistance
7) Improved damping capabilities

Composition

MMCs are made by dispersing a reinforcing material into a metal matrix. The reinforcement surface can be coated to prevent a chemical reaction with thematrix. For example, carbon fibers are commonly used in aluminium matrix to synthesize composites showing low density and high strength. However, carbon reacts with aluminium to generate a brittle and water-soluble compoundAl_4C_3on the surface of the fiber. To prevent this reaction, the carbon fibers are coated with nickel or titanium boride.

Reinforcement

The reinforcement material is embedded into a matrix. The reinforcementdoes not always serve a purely structural task (reinforcing the compound), but is also used to change physical properties such as wear resistance, friction coefficient, or thermal conductivity. The reinforcement can be either continuous,or discontinuous. Discontinuous MMCs can be isotropic, and can be worked withstandard metalworking techniques, such as extrusion, forging, or rolling. In addition, they may be machined using conventional techniques, but commonly would need the use of polycrystalline diamond tooling (PCD).

Method of Preparation

The method of preparation of copper matrix composites (CMCs) has a crucial role to attain a clear interface and homogeneous distribution of ceramic particles in the matrix, powder metallurgy (P/M) is the most suitable technique. Even though there are several techniques to fabricate the copper basedcomposites such as thermal spraying, hot pressing, and hot extrusion and stir casting, the most suitable technique for even dispersion of reinforcement in the matrix and grain refinement was powder metallurgy. Particle strengthening of metal matrix with even distribution of reinforcements and without the agglomeration of CNTs is the major problem. The effect of ball milling time study conducted, to assess the mechanical properties of metal matrix reinforced with carbon nanotubes, revealed the even dispersion of CNTs in the matrix by the mechanical alloying method. The specimens prepared through the P/M method always being porous, decreases the strength of the sintered composites. Though,hard nano reinforcements can be employed to improve the mechanical properties and also to fulfil the porous regions of the powder metallurgically prepared composite specimens. In this study, the effect of intrinsic and extrinsic factors on the friction coefficient and wear (responses) are optimized using full-factorial design methodology. In order to enhance the wear and friction properties, powder metallurgy technique was used to produce copper-matrix/carbon nanotubes and nano boron carbide composites with high strength and without affecting the density. We also explored the percentage of contribution of the nano boron carbide content, the sliding distance and the normal loadings on the tribology behaviour in the dry wear tests using ANOVA. Finally, the experimental data wereanalyzed and discussed.

Materials

Copper, multi-walled carbon Nanotubes (MWCNTs) and Nano boron carbide (B_4C) powders were used in the present research. Pure electrolytic copperpowder with an average particle size less than 10 µm and 99.7% purity brought from M/s. Metal Powder Company Private Limited, India was selected asthe matrix material in the present study. Multi-walled carbon Nanotubes with anaverage tube diameters 5-20 nm and length 5 µm and boron carbide particles withan average size of 44 µm were purchased from M/s. Sigma Aldrich Private limited, India.

Table 1 Specifications of the Selected Matrix Element

Matrix / Reinforcement	Grain size	Density, g/cm^3	Morphology
Copper (as received)	≤ 10 (µm)	8.96	Irregular shape
MWCNT (as-received)	5-20 (nm)	2.10	Stiff and straight
B_4C (as-received)	≤ 44 (µm)	2.52	Small flake-like
B_4C (after milling)	100-200 (nm)	2.52	Agglomerated Sphere

As evident in the Table, the selected Nano reinforcements have dissimilar morphologies. However, both the types of reinforcements are probablyhaving different morphologies, which have an influence for the improvement of strength and reduction in wear behaviour while incorporated into the copper matrix. Figure 1 ,2 and 3 shows scanning electron micrographs (SEM) of the as-received copper matrix and shows multi-walled carbon nanotubes.

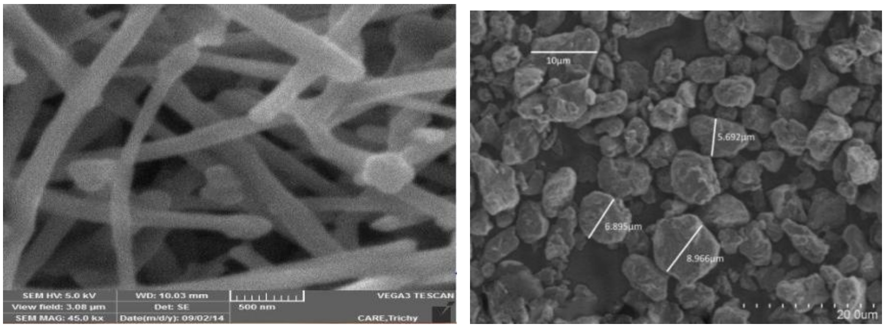

Figure 1 SEM of Copper Matrix

SEM of Multi-Walled CNT Scanning Electron Micrographs (SEM)

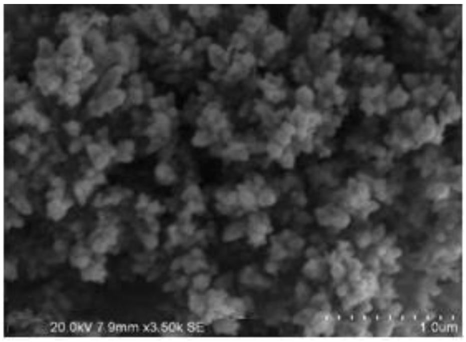

Figure 2 SEM of B_4C

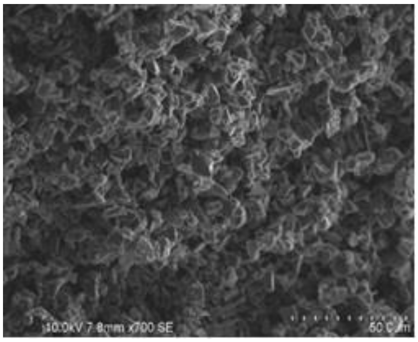

Figure 3 SEM of B_4C in 25 h Milling

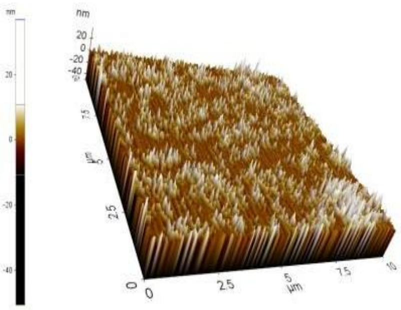

Figure 4 AFM Image of MWCNTs

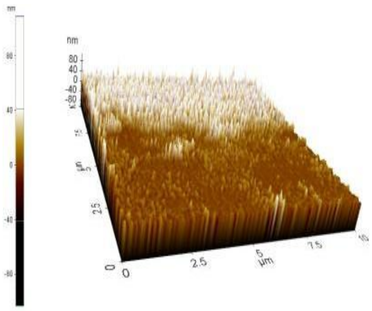

Figure 5 AFM Image of B_4C

The zetasizer results of the milled nano-boron carbide particles are shown in figure. The particle sizes were found to be in the range of 100-200 nm.

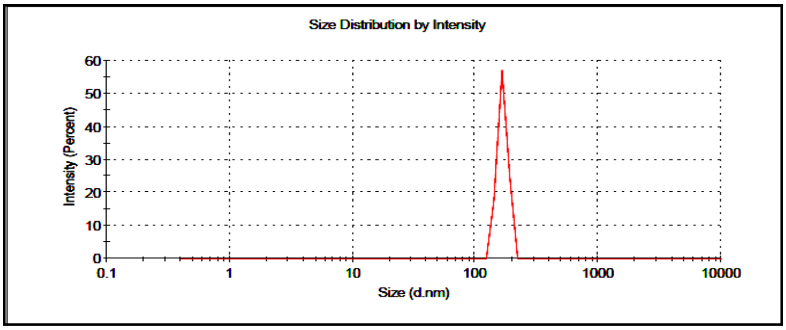

Figure 6 Intensity of Nano-Boron Carbide Particles

Interpretation of Residual Graphs

The normal probability plot (NPP) of the residuals was plotted to check the normality of the data. The residuals are the difference between the experimental and predicted values from the linear regression. From the Figure shows the normal probability plot for copper hybrid nano-composite. These probability plots clearly indicates that the observed experimental values lies very closer to the normal probability line (straight line) inferring that the errors are nneglected.

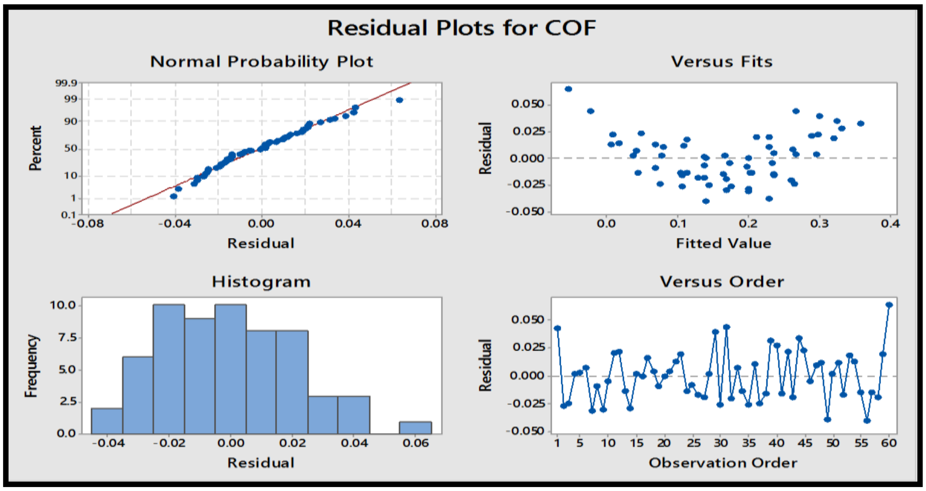

Figure 7 ANOVA for COF

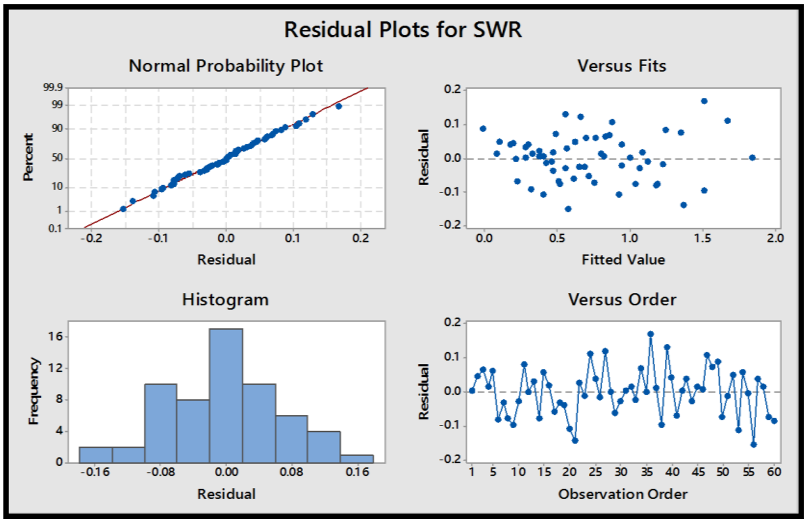

Figure 8 ANOVA for SWR

The distribution of residuals for all the interpretation (60 runs) is shown in the histogram. Almost bell-shaped symmetrical histogram can be inferred from Figure 4.12 and Figure 4.13. The residuals versus the fitted values for COF and specific wear rate are plotted in Figure. The scattering of the residuals are randomly about zero which implies that the errors are negligible having constant variance. Figures show the plots of the residual value and the order of the corresponding experimental measurements. The results (responses) are influenced by the order of the observation (runs) that takes place when a line sequence is used to collect the data. This plot is especially helpful to a developeddesign in which the runs are regular.

Worn Surface Analysis

The wear test results for the composites reported in specific wear rate for various loads and Figure 4.11 are supported by the SEM worn surface micrographs of all the fabricated composite grades. The analysis of the worn surface morphology of copper hybrid composites tested at 20N load conditions with a sintering temperature of 850°*C* are shown in following figure.

Worn Surface Analysis of Composites At 20 N Loads

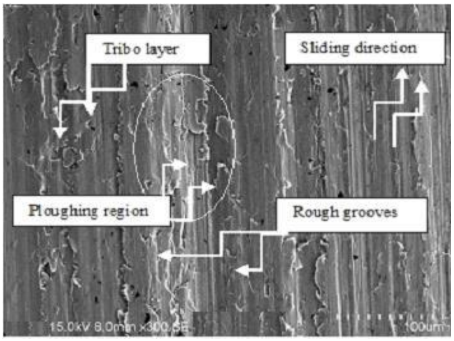

Figure 9 Cu–2MWCNT

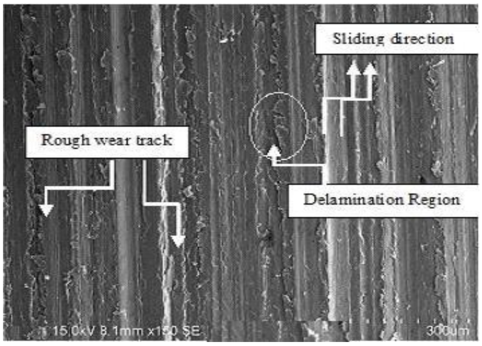

Figure 10 Cu–2MWCNT–0.5B_4C

As noted earlier, in the case of the copper with 2 wt. % multi-walled carbon nanotubes reinforced composite, the dominant wear mechanisms are the abrasion and delamination wear mechanisms.

The rough wear tracks with uneven surface compared to other composite specimens are shown in figure 9. Figure 10 shows a photo of wear track afterthe addition of B_4C to the copper matrix with a sintering temperature of 850°*C*, the dominant wear mechanism changed to being mostly abrasion wear. The smeared carbon particles from the contact surface of composites form a thin carbon rich tribo film at the interface region, which prevent direct metal contact between the specimens and the disc.

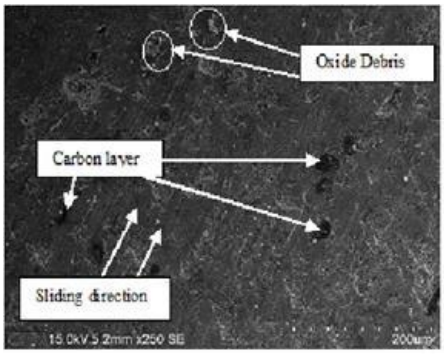

Figure 11 Cu–2MWCNT–1B_4C

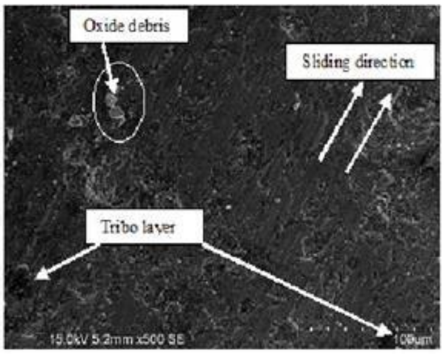

Figure 12 Cu–2MWCNT–1.5B_4C

From the Figure 11 and 12 represent the Oxidizer. It is a type of chemical which a fuel requires to burn. Most types of burning on earth use oxygen. Several researchers observed the formation of stable carbon rich layers in the interface region which acts as a protective layer (Tribo-layer) that evenly distributes the load over the metal matrix composites.

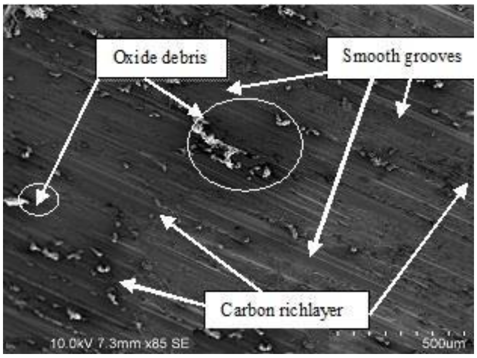

Figure 13 Cu–2MWCNT–2.0B_4C

Conclusion

Full-factorial design method was applied in this study to optimize the dry sliding wear test parameters. The results are summarized as follows.

The presence of the matrix (copper) and reinforcements (multi-walled carbon nanotubes and boron carbide) were confirmed using the XRD analysis technique. SEM micrographs of the copper composite powders showed a homogeneous distribution of both primary (MWCNTs) and secondary (B_4C) reinforcements in the matrix. Full-factorial design is a proper technique to statically analyse the tribological behaviour of copper hybrid composite specimens. The optimal combination of parameters is found to be 2% B_4C, 500 msliding distance and 5 N loads (highest level of secondary reinforcement, lowest level of sliding velocity and lowest level of load).As a result of the ANOVA, the load factor has the maximum contribution (P=58.83%) in controlling the friction coefficient and the factor sliding velocity (P=53.23%) on the specific wear rate of the copper composites. The composite fabricated through P/M method with good relative density enhances the wear resistance and hardness with the even distribution of primary (MWCNTs) and secondary (B_4C) reinforcements in the copper matrix.

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