PREFACE

Tribology extends a wide range of answers to meet sustainability by improvement in working life and reducing frictional losses. From a socio-ecological point of view, wear preservation can aid to increase the utility value of parts or components with the same resource-consumption. Researchers have suggested reduction in CO_2 emission by improving tribological performance either through improving surface topography or by introducing microcavities in lubrication conditions, which increases load-bearing capacity of mechanical parts. Tribology has a wide range of applications such as in machine parts, automobiles, marine, medical technology, etc. Copper-graphite (Cu-Gr) composites are extensively used for tribological applications, especially in electrical and machinery parts such as sliding electrical contacts, bearings, bushings, etc. Cu-Gr composites are found to be suitable material for tribological applications due to their high wear resistance with addition of graphite particle. They are utilized in electronics and electrical equipment as sliding contact parts and heat sinks. The machinery and equipment use copper-graphite composite as bushings, seals, and gaskets and as self-lubricating bearing materials. However, to widen the applications of Cu-Gr composites further improvements in mechanical and tribological properties are required. This created an interest in identifying appropriate reinforcement options for the composite. Titanium carbide (TiC) reinforcement can be utilized in the Cu-Gr composites for the improvement in strength.

Copper-graphite composites can be fabricated by casting and powder metallurgy techniques. However, due to poor wettability and a significant difference in their specific gravity, it is difficult to cast the copper-graphite composites. Hence, the powder metallurgy (PM) technique has gained popularity as an effective method for preparing these composites. The powder metallurgy approach stands out as a promising method for the commercial production of the copper- graphite composites owing to the use of a wide range of materials, complex geometries, precise dimensions and components produced close to their final shape resulting in cost saving and material waste. Present work has been divided into 7 chapters-

Chapter 1: This section provides an introduction and a comprehensive review of existing literature. It presents various composite types, focusing on Metal Matrix Composites (MMCs). The discussion encompasses the advantages associated with MMCs, their diverse applications, and the techniques employed for their fabrication of MMCs involving different matrices and reinforcements. Further the powder metallurgy technique has been discussed in detail and the various processes involved in it. Additionally, the chapter delves into the details of the different types of wear and friction and their underlying mechanisms. The designing of materials suitable for the use in bushing, bearing application demands a careful consideration of the matrix, reinforcement materials, and the fabrication method. This selection process is crucial to ensure the resulting materials possess a high strength and effective wear resistance.

Therefore, in the present study, TiC has been chosen as reinforcement phase in the copper- graphite composite. It is an ultra-high temperature ceramic exhibiting high hardness (28-35 GPa), high melting point (3067°C), superior high-temperature strength and high thermal conductivity. TiC could be a good candidate for reinforcement to improve the mechanical and tribological properties of copper graphite composite. The powder metallurgy technique has been chosen for the fabrication of composites.

The objective of the present study is to develop Copper-Graphite-TiC composites that have superior tribological properties to extend life and efficiency of certain parts.

Chapter 2: This chapter deals with a brief introduction of equipment used for the characterization of the composites. Composites have been prepared using powder metallurgy route. The formation of composites was identified with the help of a Rigaku Miniflex X-ray Diffractometer using Cu-Kα radiation (λ = 1.5405 Å). The morphology of the grains was examined under Leica DM 1750 M optical microscope (OM). The distribution of particles and their morphology were observed under FESEM Quanta 200 FEG scanning-electron microscope (SEM), and ZEISS (Model-EVO 18) SEM. The theoretical density was calculated by the rule of mixture, the experimental density of the composites was evaluated using the Archimedes principle and porosity was calculated with the help of theoretical and experimental density.

Hardness was evaluated by LM 248AT Vicker hardness tester at 0.5kgf load with 20s dwell time. The compressive tests were conducted at room temperature at a strain rate of 10^{-2} s^{-1} using a 100 KN screw-driven Instron™ Universal Testing Machine (Model 4206). Friction and wear properties were evaluated on a pin-on-disc tribometer at ambient room temperature. For dry sliding condition, the parameters were varied as sliding distance (1000 m – 4000 m), sliding velocity (0.75 m/s – 3 m/s) and applied loads (10 N - 40 N). For lubricating sliding condition, the parameters were varied as sliding distance (2000 m – 8000 m), sliding velocity (0.75 m/s – 3 m/s) and applied loads (10 N- 70 N). The samples after test were observed by SEM/ EDS and AFM to understand the operative wear mechanism under different conditions.

Chapter 3: It deals with the fabrication of composites with varying wt.% of TiC particles in the copper- graphite composites, identification of different phases formed by XRD, morphological study and effect of wt.% of TiC particles on the mechanical properties. Morphology study show slight grain refinement of the Cu matrix with the incorporation of TiC particles. SEM analysis reveals uniforms distribution of particles. Mechanical test results indicate improvement in hardness and compressive strength with an increase in the wt.% of TiC particles.

Chapter 4: It deals with the tribological performance of pure copper and composites in dry sliding conditions. The wear rate and coefficient of friction (COF) increase with an increase applied load and sliding velocity. The decrease in wear rate while an increase in COF was observed with increasing TiC content and the 4.5 wt.% of TiC composites exhibited the least wear. The worn surface study was carried out by SEM attached with EDS and AFM analysis. At a lower sliding distance and applied load, mild wear is observed while at higher load and sliding velocity, severe/oxidative-metallic modes of wear occurs. AFM study illustrated smoother topography with low average surface roughness with increasing the TiC content. The AFM results are in agreement with wear and friction data.

Chapter 5: In this chapter the behavior of composites under lubrication was studied to explore their applications as bushing and bearings. SAE20W40 motor oil was used as a lubricant with a flow rate of 5 cm^3/hr. Tribological behavior is investigated under varying sliding distance, applied load, sliding velocity and varying weight % of TiC. Worn surfaces have been investigated using SEM with an EDS and AFM. Observed results are investigated with the support of morphology, hardness, and texture studies. In lubricating conditions very less wear was observed at lower load and sliding distance while at higher loads and sliding distance mild wear is observed for composites while for pure copper relatively more wear. Also, at higher sliding velocity less wear is observed due to a persistent thin film of lubricant existing at larger velocity. However, it was noted that in the presence of lubricant, the COF values also decreased even with an increase in TiC content. It could be due to the presence of microcavities, which act as pockets for lubrication retention and the material system behaves as self-lubricating material and making them a suitable material for bearing applications. AFM study reveals smooth topography with minimum average surface values at higher wt.% of TiC. The least wear rate and COF was observed for 4.5 wt.% of TiC reinforced composite which indicates less wear of material and less frictional losses, thus an overall reduction in materials footprint and energy losses.

Chapter 6: This chapter is categorized into two sections. The first section deals with statistical modelling of tribological parameters in dry sliding conditions while the second section deals with statistical modelling of tribological parameters in lubricating sliding conditions. Response surface methodology (RSM) using Design expert 13 was used to optimize the response parameter (wear rate and COF). Based on RSM, CCD was generated, and based on the best-fitted curve quadratic model was suggested for both wear rate and COF with R^2 value very close to 1 and a p-value less than 0.05 signifying the efficacy of the model. Predicted and experimental values found to be very close, which confirms that the model can be used for prediction of properties to minimize unnecessary experimentation. Further, the optimum tribological parameters were obtained from the models. Regression equations were developed to predict or optimize tribological parameters at any given set of input parameters. Also, the 2D and 3D surface and contour plots for RSM are provided to see the wear rate and COF behavior with varying input variables and the results are in agreement with experimental results. However, the applied load was found to be the most contributing factor for wear rate and COF.

Chapter 7: It summarizes the main conclusions on the morphology, mechanical, and tribological properties of Copper-Graphite-TiC composites as discussed in different chapters of the thesis. In addition, the scope of the current work has also been presented.