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Studying the Effect of Different Lubricant Materials on the Tribological Properties & Hardness of Cu-Fe Composite Prepared By PM

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Abstract

In this work, three Cu-Fe composite samples are prepared by powder metallurgy technique. This alloy has a superior mechanical property makes it suitable for different engineering applications. The first sample, is the Cu-Fe reinforced with Pb, Sn, Si, Al, Zn and graphite as a lubricant material. The second sample is the Cu- Fe reinforced with only Pb, Sn & 10% $BaSO_4$ which is another type of lubricants, the reinforcements of the third one is 7% $BaSO_4$ with 1% $CaCO_3$ & 5%SiC. All the three samples are prepared by mechanical alloying by 6 :1 ball to powder ratio & 300 rpm for 6 hrs milling time. Then, the mixed composite powders were compacted under 700 Mpa by a uniaxial press and sintered in a vacuum furnace at 950◦C for 90 min. Density and EDAX analysis were examined. The hardness, wear resistance & COF also estimated. The results indicated that sample contains 10% $BaSO_4$ has the highest density & hardness with a homogenous microstructure & the lowest COF. While, the wear rate is the lowest for samples 1&3.

Keywords: Copper composites, $BaSO_4$, Microstructure, Hardness, Wear rate, Lubricant materials.

Introduction

Composite material is a new material that can collect the properties of two or three constituents. It is consisting of two phases, the matrix and the reinforcing agent. They are mostly insoluble in each other, but have a good adhesion at their interface (Vincent, 1999; Mikell, 2011). Copper metal has high electrical & thermal conductivities with good strength, but it suffers from low wear resistance & a high coefficient of thermal expansion (CTE). When copper reinforced with a hard ceramic material the CTE & wear rate are decreased. Graphite is a ceramic material has a lamellar structure which helps in decreasing the friction coefficient & wear rate. As it has a lubricant nature with low cost, it is considered one of the most important lubricant materials that used for improving the wear resistance and friction coefficient also it decreases the CTE & density, consequently reduces the weight (Samal et al., 2013; Rohatgi et al., 1992; Xiao et al., 2013). Copper-graphite is widely used as brushes, electrical contacts and sliding bearing materials (Nunesa et al., 2011; He & Manory, 2001) due to the excellent thermal and electrical conductivities, and the favorable self-lubricating performance.

Friction materials are used in brake linings and clutches by converting kinetic energy to heat and then either to absorb or otherwise dissipate the heat while simultaneously, through friction, reducing the relative movement between the friction material and the part to which it is engaged. In order to achieve these objectives, the coefficient of friction must be as high as possible, independent of variations in operating conditions, and the necessary energy conversion must be accomplished with a minimum of wear on the contacting parts. The friction material, in addition to having a relatively high coefficient of friction, should be durable and heat stable, and should generate little or no noise while in rubbing contact with the engaged part (He & Manory, 2001). Since the early stage of vehicle developments, single material has never been sufficient to satisfy these performance characteristics. Therefore, composed friction material has been used in brake linings and clutches. In general; more than 10 ingredients have been used for commercial brake friction materials to accomplish the above-mentioned requirements. Types and relative amounts of ingredients have been determined by empirical observations and the ingredients comprise binder resin, reinforcing fibers, solid lubricants, abrasives, fillers, and friction modifiers (Choa et al., 2005). Generally, the friction materials may be classified into four categories, metallic, metallic ceramic, asbestos filled resin composites and asbestos-free composites (Liu et al., 2023). In the case of a brake lining, the control of the friction characteristics by changing the ingredients is a very complicated task, since it requires a large number of experiments to obtain reliable results and also involves synergistic effects from multiple ingredients. A limited number of studies investigating the compositional effect are available in the literature and a complete analysis concerning all the ingredients in a friction material is seldom found. The limited information about ingredients used in the friction material and their effects on the friction characteristics is partly ascribed to proprietary reasons (Choa et al., 2005). The ingredients used in developing brake friction composites are mainly classified into four major categories, viz. reinforcing fibers, binders, property modifiers (abrasive and lubricants), and fillers (Yu et al., 2023). Extensive investigations concerning each category's role in friction materials' tribological performance have already been reported (Sathyamoorthy et al., 202; Rajan, et al., 2021). Space fillers are typically employed among the various components in brake friction composites to reduce their cost and increase composition volume (Menapace et al., 2018). The tribological performance of brake composites has also been influenced by space fillers, whose high-volume fractions substantially impact the production and destruction of third-body layers on the friction surface (Park et al., 2022). Barium sulphate, an inorganic mineral, is the most commonly used space filler due to its beneficial properties, high thermal stability, minimal water solubility, and low cost (Park et al., 2022; Vijay et al., 2019).

This work aims at studying the effect of barium sulfate as a lubricant material on the physical, mechanical, tribological properties of Cu-Fe as a brake lining has been studied.

Experimental work

Materials and Experimental work

Pure Al, Sn, Fe, Pb, $BasO_4$, $CaCO_3$ and SiC powders with purity 99.99 % and particle size ranging from 5 Mm up to 25 microns were used. All the powders were mixed by specific percent as recorded in Table (1) for 4 h using ball mill with 5:1 ball to powder ratio with the presence of hexane as a process controlling agent and argon atmosphere to prevent oxidation. The mixed powders were then compacted under 20 ton using a diaxially press. The heating cycle is used to sinter the material in a vacuum furnace at 900^{o}C for 70 min as holding time. The cycle included four holding steps: one at 250^{o}C, which removes all paraffin wax from the samples in the form of carbon dioxide and water vapor and melting of Sn and another at 400^{o}C for 15 min, the third one at 800oC for 20 min and the last one at 900^{o}C for 70 min. holding time to complete the full sintering process.

Sample	Cu	Sn	Fe	Pb	Si	Al	C	$BaSO_4$	$CaCO_3$	SiC
1	59.1	7	4	5	11	0.5	7	0	0	0
2	74	6	10	0	0	0	0	10	0	0
3	64	8	10	5	0	0	0	7	1	5

Table 1: Chemical Composition of the Prepared Composite

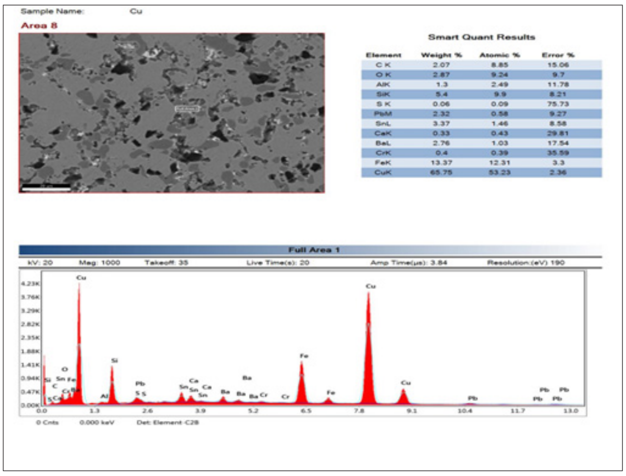
Composite Characterization

Density of the prepared specimens was calculated according to the Archimedes principle. The microstructure of the sintered samples was studied by a scanning electron microscope (SEM) equipped with energy dispersive X-ray analysis (EDs) to estimate the morphology and chemical composition. Vickers hardness was measured as the average of 5 readings along the polished cross section surface of the specimens by applying 1 Kg load, and loading time of 15 sec. Wear test (WR) & coefficient of friction (COF) were carried out of sintered samples with dimensions of 8mm x 8mm x 12 mm using a pin-on-ring tribometer with a SiC ring of 73 mm in diameter, by applying 5 & 10 N at a velocity of 350 rpm for 20 minutes.

Results and Discussion

Microstructure of the Cu- Fe Composite Reinforced with 10% $BaSO_4$

Figure (1) shows the microstructure of the sintered copper composite reinforced with 10% $BaSO_4$ (sample number 2). It shows a good homogeneous distribution of the reinforcement materials in the copper matrix. In which there are many phases, one of them is the major which is the white gray area that represents the copper matrix, the dark gray belongs to the iron metal, that is distributed homogeneously all over the copper matrix. The white spots represent the stannous metal and the small black spots for the barium, while the bigger black spots represent the formed prose. The particles are distributed in the grain boundaries of the copper matrix. The EDAX analysis reveals that by making a spot on an area, all the constituents are estimated, which gives a good mechanical milling parameter, and sintering process.



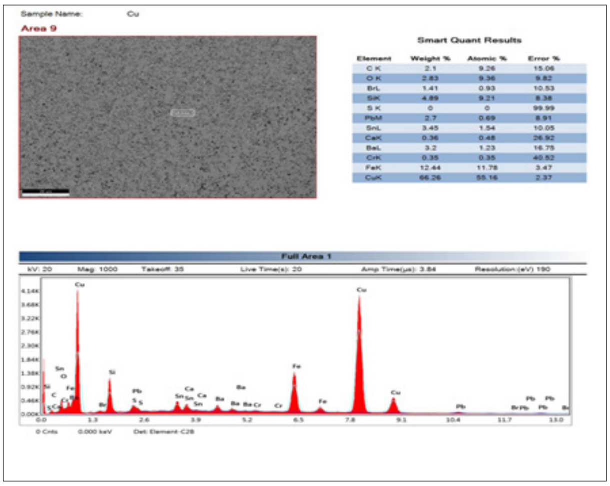


Figure 1: Microstructure & EDAX analysis of the prepared sample containing 10Wt.% $BaSO_4$

Density Values of the Prepared Samples

The density of sintered samples was measured by Archimedes principal using water as a floating liquid. Figure (2) shows the actual density values. From the above results it can concluded that nearly all samples have near density values. Sample contains 10% % $BaSO_4$ has the highest density which is about 7.47 g/cc.

This can be attributed to the absence of a ceramic material, in which for sample one it contains about 7% graphite, while sample number three contains 5% SiC. Both of them are ceramic materials have a non-wet table character with all the other metals in the composite as the surface energy between them is very high , so some agglomerations takes place, consequently the density was decreased (16). Also these ceramic materials (Graphite or SiC) makes as an internal barriers that hinders the full densification.

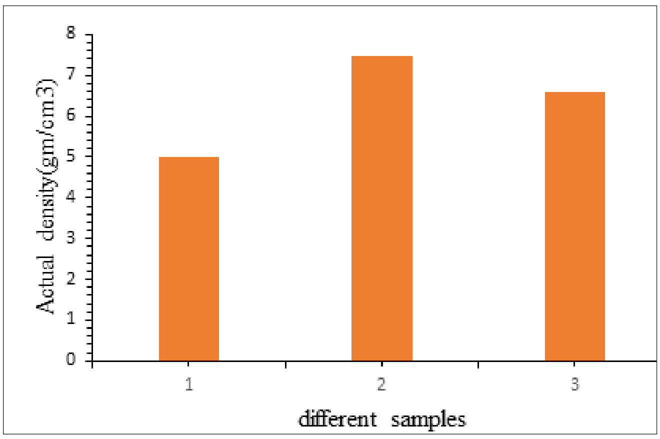


Figure 2: Density values of the prepared samples

Hardness Values of the Prepared Samples

Hardness is a very important parameter for the mechanical applications of copper composite material to have a suitable value to resist the scratches with a good strength. Figure (3) shows the hardness values for all the prepared samples. It is clear that sample 2 which contains 10% $BaSO_4$ has the highest hardness value (164 Hv) followed by sample 3 and the lowest one sample number one. This may be attributed to the highest density value for this sample & the lowest porosity. But sample number 3 which has the chemical composition clear in Table (1) has 56.6 Hv hardness compared with 50 Hv for sample one. This is may be attributed to the presence of either graphite or SiC which are a ceramic materials with a lubricant nature, where they causes the formation of some aggregates that decreases the hardness values.

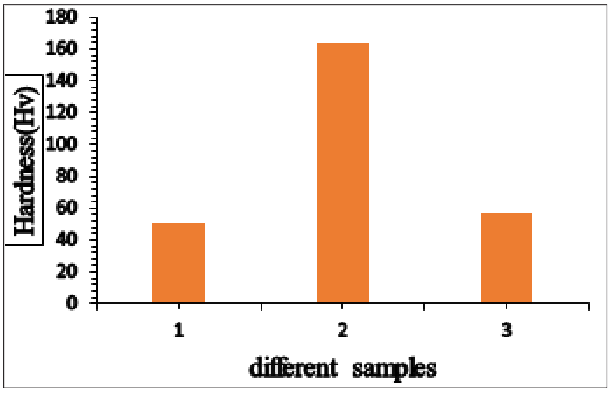


Figure 3: Hardness values of all the prepared samples.

Wear Rate & COF Estimation

Wear rate is very important factor for the fabrication of mechanical engineering spare parts that are exposed to a friction during it's work. It is measured for the prepared copper composites under two different loads 5& 10 N. Table (3) shows the wear rate & coefficient of friction (COF) results of the prepared samples. From the results one can concludes that for the three manufactured copper composites, samples 1 &3 have a near wear rate values which is lower than the third sample number 2. This may be attributed to the presence of a ceramic lubricant materials which are graphite in sample number one and SiC in the third sample. Graphite has a lubricant nature with very low density, so it acts as a tribo layer helps in decreasing the wear rate. The presence of SiC in sample 3 has also a good effect on the wear resistance due to it,s ceramic nature. Also sample 3 contains $CaCO_3$ with the SiC in which calcium carbonate is a viable alternative to environmentally hazardous anti-wear lubricant additives. So, for the samples 1 &3 graphite & $BaSO_4$ percentage acts as a lubricant material helps in sliding of the wear pin on the sample surface, consequently the wear rate was decreased. $BaSO_4$ with both SiC & $CaCO_3$ have a lower density value than copper, so it dissociates during sintering process into CaO floats on the sample surface causing the formation of a tribo layer that increases the wear resistance & CO_2 which evolves as a gas.

The wear rate was increased by increasing the applied load from 5 to 10 N. This is more logic as the force applied by the pin on the sample surface increased causing more weight loss for the samples.

The second phenomena in Table (3) is the lower COF of sample number 2 than the other two samples. This may be attributed to the higher density & hardness of this sample than the other two ones.

Samples	Wear Rate 5N 10N	Friction of Coefficient
S1	0.0045 0.009	0.23
(Cu-10Fe-6Sn-10$BaSO_4$)	0.006 0.013	0.15
(Cu-10Fe-8Sn-7$BaSO_4$-5Pb-1CaCO-5SiC)	0.0048 0.0097	0.4

Table 2: Mechanical Properties of the Prepared Samples

Conclusions

- Copper- Fe composites are prepared successfully by powder technology by reinforcing them with $BaSO_4$, Sn, Pb, SiC, $CaCO_3$ or graphite
- Using different lubricant materials for the fabrication of a composite material that can resist the wear and friction during the working process.
- The results indicated that sample number 2 that contains 10% $BaSO_4$ has the highest density & hardness values.
- Samples 1 & three which contains Graphite & SiC respectively have the lowest wear rate.
- Sample number 2 recorded the lowest COF value.

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