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Thermal, corrosion and wear analysis of copper based metal matrix composites reinforced with alumina and graphite

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The wear and corrosion resistances are important in marine applications, especially when it comes to structural support components like bearings, bushes and blocks. The copper hybrid metal matrix components are the new avenues explored in this front. A novel combination of alumina and graphite were considered as the reinforcements in a copper base for the development of a metal matrix composite. Power metallurgical techniques were used for the development of the MMC. The Vickers's hardness value of 64.9Hv has been observed by increasing the volume of alumina. Thermogravimetric analyses were carried out on material samples to estimate the exact sintering temperature and identified that 450 −700 °C would be conducive. The TGA curves shows two step decomposition exists between 430^{0}C–460 °C. FT-IR analysis was done to confirm the peak values of the materials. FTIR exposed the peak value of 1600 cm^{-1} for alumina where as for Copper and graphite peak values have been 2840 cm^{-1} and 17260 cm^{-1} respectively. The potentio dynamic analysis was done to estimate the rate of corrosion on the samples. The sample with nano and micro reinforcements offered intensive resistance to corrosion. The presence of graphite minimized the weight loss of the samples during the corrosion test. Finally the wear rates of the samples were estimated using the Pin On Disc experimental setup. The samples with nano material reinforcement and with a maximum proportion of graphite exhibited a better wear rate of 1.52×10^{-12} m^2/kg under maximum load conditions.

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1. Introduction

Fretting wear is a greater phenomenon happens in the mechanical joints right from household applications to automobiles. A low amplitude oscillatory sliding between the mating surfaces without lubrication causes this wear in applications ranging from aircrafts to human body implants, describes Roy et al. [1]. There are certain heavy loading conditions where metals slide against each other, without the benefits of lubrication, as mating components, as analyzed by Kovalchenko et al. [2]. Hybrid composite materials with copper as the base and other suitable reinforcements like graphite and alumina could prevent scuffing and catastrophic damages. The composites developed with Copper as matrix and with the dispersoids capable of providing lubrication like graphite alongside a sizable proportion of a ceramic either SiC or Alumina as hard reinforcement have experimentally proved the increase in tensile strength, lower co-efficient of friction and an appreciable hardness. These reinforcements have greater influence on the machinability of copper and its inherent conductivity as well, reveals Ramesh et al. [3].

Mechanical properties, wear and corrosion behavior of composite materials are greatly influenced with the reinforcements of steel machining chips. These copper matrix composites are being extensively used, in the design of radiators for its ability to resist corrosion. Kenneth et al. [4], comprehends that copper based heterogeneous combinations are used in digital devices for their better conductivity. Also used in the casing of jet engines where combined effects of corrosion, wear and thermal conductivity are predominant. Such components are widely used in the intricate components of automotive industry. The wear resistances keep on increasing with the addition of alumina in the nano regime as reinforcement in copper matrix and it also helps to maintain stability in the thermo dynamical aspects. The compressive strength

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also increases with the addition of nano alumina particles [5,6]. Two different materials are used as the matrix materials in an investigation, copper as the matrix and chromium as the matrix-alloying element with copper coated carbon nano tubes as reinforcements. These combinations not only enhance the mechanical properties but also find solution for the interfacial problem of non wetting with other constituent element in the composite, as explained by Ke chu et al. [7].

Rajmohan et al. [8], justifies the inclusion of two different ceramic reinforcements one in microns and the other in nano scale to form the hybrid composites. The investigations justify the hybrid nature of the composites upon the inclusion of Mica or graphite along with a metal and a ceramic in appropriate proportions. The powder metallurgical techniques have been used to develop the composite materials [8,9]. Wear rate exhibited by copper coated graphite are better than the uncoated ones similar to the differences between coated and uncoated silicon carbides, as investigated by Sapate et al. [10]. The increase in volume fraction of ceramics, be it silicon carbide or alumina, keeps the rate of wear at the low level. Alumina and graphite have been the predominant reinforcements in any metal matrix composites to improve wear resistances, as hinted by Gheorghe Iacob et al. [11].

The presence of graphite, with the size in the range of 10^{-9}, shows excellent wear resistances in the copper matrix composites as ascertained by Rajkumar [12]. Kannan et al. [13], says that stir casting and squeeze casting techniques have also been widely used in the fabrication of hybrid nano composites and comprehensive analysis have been made to study their mechanical and microstructural changes. The load carrying capacity and material loss due to friction have drastically come down with the reinforcements of carbon nanotubes and $NbSe_2$ in the copper matrix, as reported by Beibei Chen et al. [14]. N. Ch. Kaushik et al. [15], observes a higher wear resistance and a lower surface roughness for hybrid metal matrix compared to that of metal matrix composites.

An elaborate study has been made by Michael oluwatosin Bodunrin et al. [16], in the philosophies behind the development of MMCs, the characterization techniques involved and a significant attention has been given to the tribological characterizations as well. N. Nemati et al. [17], enumerates on the worn out surface observations, it has been revealed that the dominant mechanism of wear for pure Al specimen without the reinforcements has been delaminating while the worn out surfaces of the nano-particle reinforced composites are smoother and the deformations due to depth of cut are smaller, fine grooves are seen in the unreinforced matrix specimens.

Scanning electron microscope, XRD, and TEM are the techniques being widely used for the morphological analysis. To determine the mechanical characteristics Hardness, compression test, tensile tests, bending strength tests and fractography analysis were studied. Pin-on disk analysis has been adopted to evaluate the wear rate of the developed composites [18–21].

Wear has been experimentally and numerically exemplified by the researchers and reported [22,23]. The nuances of development of composites, their characterization and fatigue analyses have been meticulously shown and comparative analyses between micro and nano reinforcement have also been made and reported by Senthilkumar et al. [24]. The mechanism of tribological wear given in the scientific article by Kovalchenko et al. [25], inspires to proceed further in the research. Material characterizations have been detailed by Saravanakumar et al. [26] and Suryanarayana et al. [27] in their investigations on hybrid nano composites. Extensive works have been done by researchers [28–30] on copper based nanocomposites and the work put forth by Preetkanwal et al. [31] stands as a guideline to the researchers to work on hybrid nano composites.

All the investigations show the elevation of material behavior resulting in the resistances to any adverse effects; they call for further refinement in finding a better combination of materials at appropriate proportions. To address the issue of minimizing the wear rate, a novel combination of copper, alumina and graphite has been tried in this investigation. The thermal effects have also been studied alongside the corrosion resistances in addition to the mechanical and metallurgical evaluations. Moreover, the works related to the combinations of copper, alumina and graphite are scanty.

2. Experimental procedures

Copper was selected as the base material. Since the objective is to develop hybrid reinforcement, it has been decided to choose the metal copper as the base and a proportionate combination of preferably alumina a ceramic along with graphite an allotropic form of carbon as the particulate reinforcements. This combination justifies the term hybrid reinforcements. These constituents were taken at different proportions as shown in Table 1.

The selected materials were subjected to mechanical alloying technique using a planetary ball milling machine. The constituent elements were subjection to milling at 550 rpm under atmospheric ambience for 3 h. The materials were kept in the air tight tungsten carbide coated vessel carrying 10 carbide coated balls so as to maintain the powder (in grams) to ball (in numbers) ratio of 10:1 [24], In order to avoid micro aggregation an intermediate cooling was carried out to facilitate the heat dissipation from the carbide coated vial.

Green pellets were made using pneumatic compaction techniques. Dies were fabricated to make circular pellets of 60 mm in diameter and 10 mm in thickness. Zinc Stearate was applied as the binder to make pellets. A compaction load of 23 tons was applied to fabricate the pellets. The compacted pellets were sintered in an induction furnace to the temperature of 700 °C and for a soaking period of 180 min. In this investigation, proper care was taken to avoid excessive oxidation. Many a researchers say that, the powder metallurgical processes are usually being carried out in inert gas ambience preferably argon [26,27,29,30]. The work piece was allowed to cool within the furnace [32,33]. Subsequent to sintering, the pellets were tested for their mechanical and metallurgical properties [34,35]. Pin-on disk apparatus was used to conduct the wear analysis.

3. Results and discussion

3.1. Scanning electron microscopy

The hybrid powders, a homogeneous blend of copper, alumina and graphite particles were characterized by SEM (JOEL) analysis after milling for 3 h. The morphologies of the observed particles lie in the nano range. The Fig.1–3(a,b) SEM images reveal the presence of nano alumina particles and also the clear visibility of interface between reinforcement particles and the matrix. The above image shows that nano alumina particles in the copper matrix were dispersed fairly well. Agglomerations of nano alumina particles were also observed in the composites but the absence of micro cracks is an indicator of good interfacial strength between the matrix and particles. It is also seen that dispersed phases of nano precipitate components are in the matrix phase. EDAX image shown in Fig. 4 confirms the presence of all the constituents.

3.2. X-ray diffraction techniques (XRD)

A Sample was taken for XRD study to estimate the crystallite size

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