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Tribo-evaluation of Iron Based Metal Matrix Nanocomposites for Heavy Duty Applications

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Abstract. The present paper reports dry sliding wear behavior of Iron based Metal Matrix Nanocomposites (MMNCs). Specimens were synthesized by ball milling followed by compaction and sintering in an argon atmosphere. Dry sliding wear behavior of undoped and doped Fe-Al_2O_3 metal matrix nanocomposite system was evaluated respectively. It was found that due to the reactive sintering between iron and alumina particles a nano iron aluminate phase ($FeAl_2O_4$) forms as a result of which the various structural and mechanical properties were found to improve. The results so obtained are critically analyzed and discussed to illustrate the interaction of various process parameters involved. It is expected that the results of the present work will be beneficial in developing quality MMNC products for heavy duty applications.

Keywords: Metal Matrix Nanocomposites (MMNCs); Powder Metallurgy (P/M); Wear; Scanning Electron Microscopy (SEM)

INTRODUCTION

In today's world, engineering application demands presence of new materials which can serve with improved wear behavior and high loading capacity. Metal Matrix Nanocomposites (MMNCs) is a new class of material which relatively serves with better mechanical, metallurgical and electrochemical properties [1]. MMNCs employ ductile metallic matrix into which ceramic material is added as reinforcement. Various techniques used for the development of the MMNC products include stir casting, powder metallurgy (P/M), physical vapor deposition (PVD), chemical vapor deposition (CVD) etc [2]. Amongst all, P/M technique is used widely because it can attain a more uniform distribution of particles in the metal matrix with or without less excessive reactions between matrix and the reinforcement [3]. Another important factor which plays a vital role in the development of the quality MMNCs is the particle size and its distribution. Tribology is a new field which specifies the relative interaction of surface with respect to others leading to the generation of debris. Three major phenomenons which come under tribology is wear, erosion and abrasion respectively. A lot of work has already been reported on the various tribological properties of aluminum, magnesium and copper as the matrix material [4-6]. However, no systematic studies have been carried to study the tribological behavior of iron as the matrix material.

The present paper therefore is an attempt to study the wear behavior of Iron based Metal Matrix Nanocomposites (MMNCs) synthesized via powder metallurgy technique. Specimens were fabricated using powder metallurgy technique. Dry sliding wear characteristics of undoped and Fe-Al_2O_3 nanocomposite systems were studied. It was found that due to the reactive sintering between iron and alumina particles a nano iron aluminate phase ($FeAl_2O_4$) forms as a result of which the various structural and mechanical properties were found to improve. The results so obtained are critically analyzed and discussed to illustrate the interaction of various process parameters involved. It is expected that the results of the present work will be beneficial in developing quality MMNC products for heavy duty applications.

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EXPERIMENTAL ROUTE FOR THE DEVELOPMENT OF NANOCOMPOSITES

Test specimens in the present study have been fabricated using iron as the matrix and aluminium oxide as the reinforcement. 5 and 10 wt% of aluminium oxide has been used in the present study. Specimens were fabricated by weighing, ball milling, compaction and sintering. Specimens were sintered in the temperature interval of 900-1100 °C for 1-3 hour respectively. One face of the specimen was polished using emery paper and diamond paste. Dry sliding wear test of the specimens was carried out using pin on disc wear and friction testing machine at a load of 0.5, 1.0 and 2.0 kg respectively. Weight loss was calculated after each test. Worn out surface of the specimen was characterized using scanning electron micrograph.

RESULTS AND DISCUSSION

Wear Behavior of Iron-(5wt%) Alumina Metal Matrix Nanocomposites

Wear characterization of all the iron-(5wt%) alumina nanocomposite specimens was carried out. Fig. 1 shows the wear rate vs. load plot for specimens sintered at 1000 °C. Results of 1000 °C sintered for 1, 2 and 3 hour time interval has been shown here. It was found that the amount of wear from the specimens sintered for 1h, 2h and 3h at 1000 °C is almost the same and its values are less as compared to the specimens sintered at 900 °C. It was found that the wear rate of pure iron specimen was found out to be 0.2010 mm^3/Km at 0.5 kg load, 0.3266 mm^3/Km at 1.0 kg load and 0.9122 mm^3/Km at 2.0 kg respectively. It can be seen from the above discussion that the amount of wear rate from the fabricated nanocomposite specimen is low as compared to the pure iron specimen.

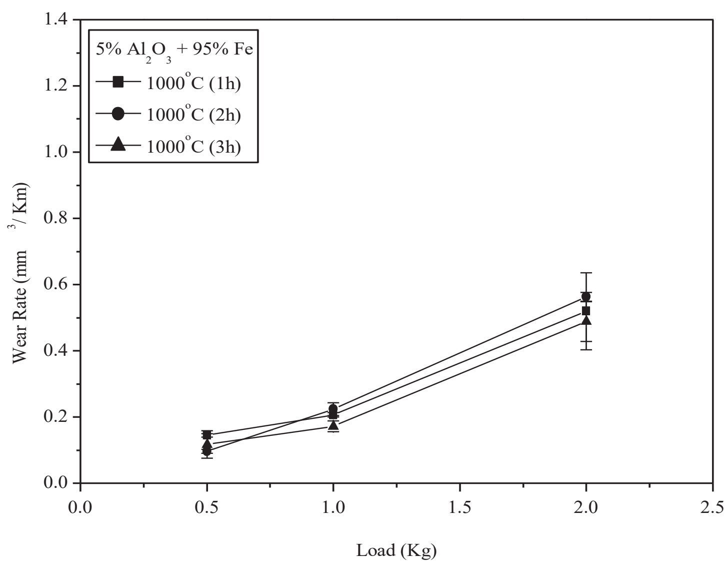

FIGURE 1. Wear Rate vs. Load for specimens sintered at 1000 °C [8]

Figure 2 shows the SEM micrograph of specimen 5AFe1000(3) at 200X which shows light wear marks along with the generation of discernible layer of transferred material. The same micrograph also shows some scoring marks due to which there are some uneven patches generated over the entire surface of the specimen. The marks generated on the specimen surface are less severe in comparison to the specimen 5AFe900(3). These features suggest that adhesive wear was operative and its severity intensified with the progress in the time interval. Figure 2(b) and 2(c) show the microstructure of the same specimen at 5000X and 10000X magnifications respectively. The micrograph shows the eroded surface of the specimen. The focused surface mainly shows the presence of the iron, alumina and iron aluminate phases respectively. SEM image also shows the iron aluminate particles which are mainly present on the periphery of the iron.

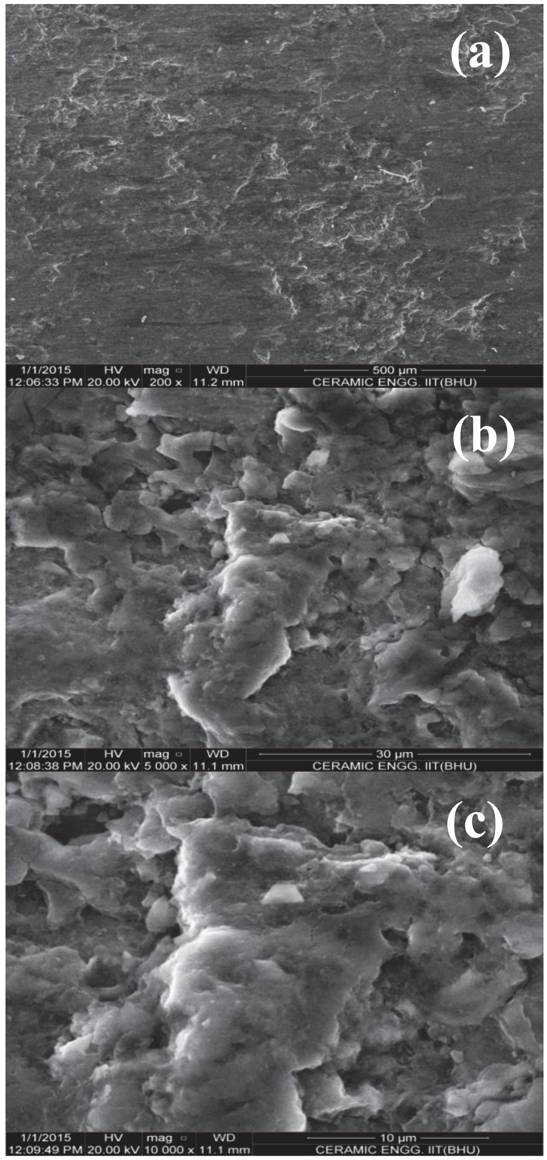

FIGURE 2. SEM micrograph of 5AFe1000(3) (a) 200X (b) 5000X and (c)10000X magnification after measurement at 2 kg load

Wear Behavior of Cobalt Oxide doped Iron-(10wt%) Alumina Metal Matrix Nanocomposites

Figure 3 shows the wear rate vs. load plots for the specimens 10AFe0.5Co1100(1) 10AFe1.0Co1100(1) and pure Fe+0.5% CoO. For specimen 10AFe0.5Co1100(1) the wear rates under lower loads, 0.5, 1.0 and 1.5 kg were found to be 0.2246, 0.2951 and 0.2967 mm^3/km respectively. For load greater than 1.5 kg i.e. at 2.0 kg the wear rate was found to be 1.6444 mm^3/km, which is much higher in comparison with the wear at lower loads. Specimen 10AFe1.0Co1100(1) at 0.5 kg load showed wear rate of 0.0784 mm^3/km, the value of wear rate increased to 0.6911 mm^3/km at load of 1.0 kg and this value reached 0.9299 mm^3/km at a load of 1.5 kg. Finally after measurement under this load, the specimen failed when tested under load of 2.0 kg. However, the wear rate of the specimen pure Fe+0.5% CoO at 0.5, 1.0, 1.5 and 2.0 kg load was found out to be 0.3133 mm^3/km, 0.3456 mm^3/km, 0.9876 mm^3/km and 1.8888 mm^3/km respectively.

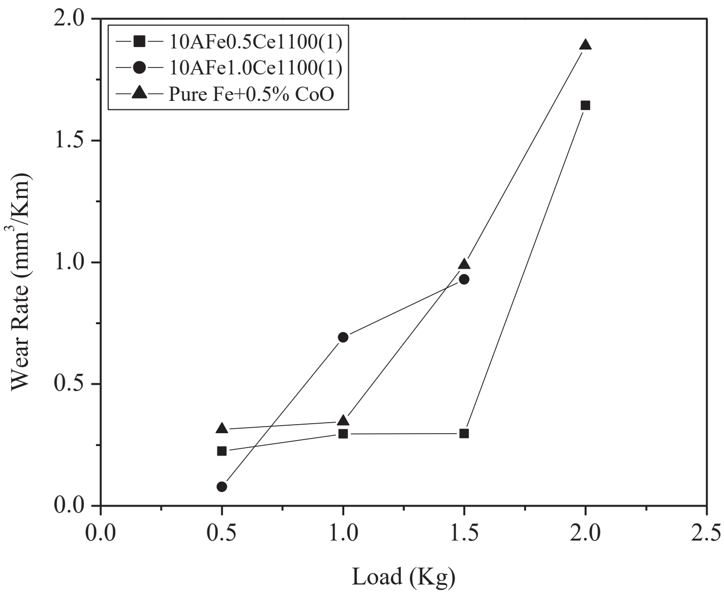

FIGURE 3. Wear Rate vs. Load plot for specimen (a) 10AFe0.5Co1100(1) (b) 10AFe1.0Co1100(1) and (c) Pure Fe+0.5% CoO [9]

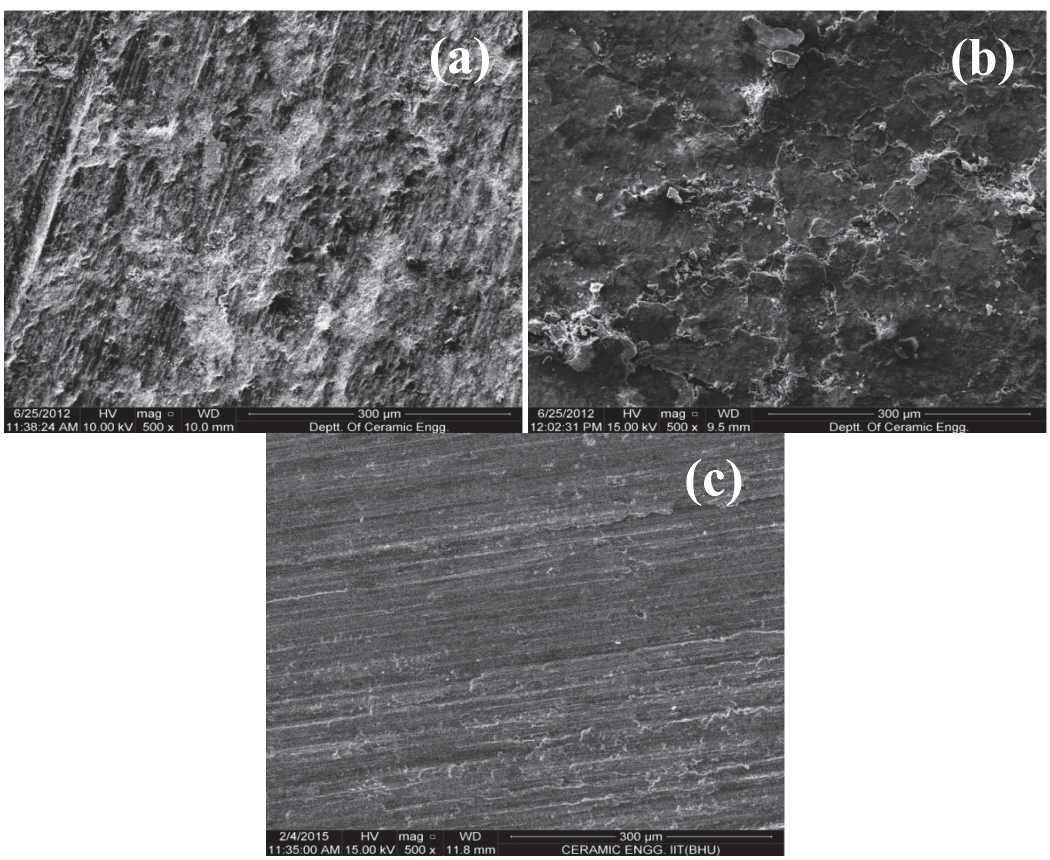

FIGURE 4. SEM of worn surface at 500X of specimen (a) 10AFe0.5Co1100(1) (b) 10AFe1.0Co1100(1) and (c) Pure Fe+0.5% CoO

Figure 4 shows SEM of worn surface at 500X of specimen (a) 10AFe0.5Co1100(1) (b) 10AFe1.0Co1100(1) and (c) Pure Fe+0.5% CoO. Figure 4(a) illustrates the worn out surface of specimen 10AFe0.5Co1100(1) at a load of 2.0 kg. This micrograph shows presence of scoring marks on the specimen surface. The removal of the material from the specimen surface is due to the entrapment of hard alumina particles between the disc and the pin surface. The present micrograph illustrates the removal of the material by adhesion in the starting i.e. upto a load of 1.5 kg while at 2.0 kg load it showed abrasive wear. This observation can be clearly seen in the present micrograph which shows the smoothened surface at some place whereas at some places the abraded particles can be seen. Figure 4(b) shows the SEM of worn surface of specimen 10AFe1.0Co1100(1) at 2.0 kg load. Some slight wear marks along with some irregular shaped peel type structure present on the pin surface was observed. The specimen failed after a load of 1.5 kg. The removal of material from the pin surface was abrasive from starting and therefore there is a smoothing as well as digging effect present on the specimen surface itself. Figure 4(c) shows the worn out surface of pure iron doped with 0.5% cobalt oxide. This specimen showed tangential skiving marks on the entire surface of the specimen with the presence of no grooves. It also shows some peeled off material from the parent surface.

CONCLUSION

The present paper reports the tribo evaluation characteristics of iron based metal matrix nanocomposites for heavy duty applications. Following are the important conclusions drawn:

- Due to reactive sintering between iron and alumina particles an iron aluminate phase forms [10].
- For 5% of alumina reinforced iron specimens it shows adhesive wear at lower loads whereas it shows abrasive wear at higher loads.
- For cobalt oxide doped iron-alumina metal matrix nanocomposite specimens, higher concentration of doping leads to reduction in iron aluminate phase formation due to which the specimen fails after testing it at a load of 1.5 kg.

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