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WEAR BEHAVIOR OF POWDER METALLURGY IRON COMPOSITE REINFORCED WITH 20WT.% SILICA PARTICLES

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Abstract: In an effort to find a cheaper production of particles reinforced metal matrix composite for tribological applications, this study focuses on iron, which is known as the oldest and cheapest tribological material. The composite was prepared via powder metallurgy fabrication technique and silica particles processed from natural sand used as the reinforcement. Wear test was performed with ball-on-disk apparatus in dry sliding condition. The effects of sliding distances, rotational speeds, and applied loads on the wear behaviour of the composite were investigated. Examination from Scanning Electron Microscopy (SEM) had revealed that the dominant wear mechanisms for the composite were delamination, followed by oxidation while pure iron exhibited adhesion, delamination and oxidation as the wear mechanisms. Interestingly, reinforcement of silica particles had evidently changed wear behaviour of the iron composite.

Keywords: silica particles; iron composite; powder metallurgy; wear mechanism; ball-on-disk

1 INTRODUCTION

Everything that man makes wears out, almost always as a result of relative motion between surfaces. From the perspective of a single machine, the losses seemed insignificance, however, when the same loss is repeated on a bulk of machines, then it become very costly. The enormous cost of tribological deficiencies to any national economy is mostly caused by the large amount of energy and material losses occurring simultaneously on virtually every mechanical device in operation. According to Tribology Centre in Danish Technological Institute, the cost of friction and wear is approximately 2-4% of an industrialized country's Gross Domestic Product [1]. In an order to curb this enormous loss, there have been extensive works on wear behaviour of ceramic reinforced metal matrix composites [2-5]. However, study in iron composite reinforced with ceramic particulates is scarce despite the fact that iron is the oldest and cheapest tribological material. Many studies on ceramic reinforcement in metal matrix composites found delamination wear to be dominating the wear mechanisms [6-9]. The worn surfaces usually consist of massive plastic deformation with pulled out wear debris accumulated on the surface and along the wear track. Another important characteristic of wear behaviour in ceramic reinforced metal matrix composite is the oxidation wear [6,8,10,11]. In this study, authors attempt to examine wear behaviour of iron composite reinforced with silica particles in dry sliding condition tested using ball on disk apparatus.

2 METHODOLOGY

2.1 Materials

Iron powder (10 µm) in this study was commercially supplied. The silica particles (0.4 µm) was produced in-house from raw sand collected from Tronoh ex-mining land and subjected to series of milling process. The iron powder was mixed with 20wt.% of silica particles then compacted using hydraulic press Carver PW 190-60 with pressure 50 MPa. The compact mixture was measured for green density using Densitimeter Mettler Toledo AX 205. Then, it was sintered in Hot Isostatic Press in argon atmosphere for 2 hours at temperature 1150°C. After that, the composite was measured again for sintered density. Three point bending test was performed using a 5 kN Universal Testing Machine Llyod LR5K Plus adhered to ASTM 133. The macrohardness of the sample was determined on the Rockwell 15T superficial scale using a 1/16 inch diameter steel ball indentor with 60 kgf load, in accordance with ASTM E18-94. These mechanical properties are presented in Table 1. Details of the fabrication process and characterization was provided elsewhere [12].

Table 1 Mechanical properties of wear sample used in this study

Wear Sample	HRF	Bending Strength (Pa)	Green Density (g/cm^3)	Sintered Density (g/cm^3)
Pure Iron	59.3	184	5.3	6.5
Iron with 20wt.% silica particles	75.9	1650	4.0	4.6

2.2 Wear Test

CSM Instrument Tribometer was used to carry out the wear test. The apparatus is ball-on-disk in dry sliding condition at room temperature. Disk specimen of diameter 6 mm and thickness 4 mm was made of iron composite reinforced with 20wt.% silica particles. The ball is Inconel of 3 mm diameter. Prior to wear test, the disk was ground against silicon carbide papers grit size 320, 600 and 800 then it was carefully cleaned with acetone and weighed. After wear test, the disk was cleaned with acetone, dried and weighed for weight loss. Load was applied from 1 to 10 N, while rotational speed selected were 0.05, 0.1, 0.15, 0.2 and 0.25 m/s. As for the sliding distance, the distance ranges from 25 to 225 m. All weight loss data were converted to volume loss using the measured densities. Volumetric wear rates were calculated from the volume losses. The worn surfaces of the composite disk were observed and analyzed using Scanning Electron Microscopy (SEM) model Leco 1430VP.

3 RESULTS AND DISCUSSIONS

3.1 Wear Rates

Volume rate for pure iron and iron composites reinforced with 20wt.% silica is plotted against rotational speed in Fig. 1. Apparently, the composite's wear behaviour only differs slightly from pure iron's. It started a little bit higher in volume rate then ended a little bit lower. Both samples showed a linear increase from sliding speed 0.05 to 0.15 m/s then, volume rate for both samples declined when the rotational speed was increased to 0.2 m/s. After that, volume rate for the composite continued to decrease whereas pure iron showed an increase at rotational speed 0.25 m/s. Fig. 2 depicted volume rate for pure iron and iron composites reinforced with 20wt.% silica versus sliding distance. The graph showed a notably big gap between volume rate of pure iron and its composite. From the graph, it can be seen that the composite demonstrated higher wear resistance than pure iron at all distances. Next, in Fig. 3, volume rate for pure iron and iron composites reinforced with 20wt.% silica against applied load is shown. The trend for both samples is quite similar, with the composite produced lower volume rate compared to pure iron, which implied the composite had higher wear resistance than pure iron, and the same trend is displayed at all applied loads. Overall, wear test using rotational speed variable produced lowest volume losses, that is in the range of 0.0045 to 0.0035 mm^3/s, while wear tests using another two variables, namely applied load and sliding distance produced volume losses in similar range, that is from 0.007 to 0.005 mm^3/s.

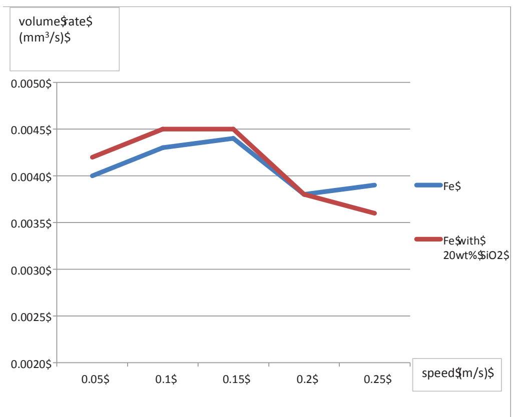

Fig. 1 Volume rate of iron composite reinforced with 20wt.% silica against rotational speed

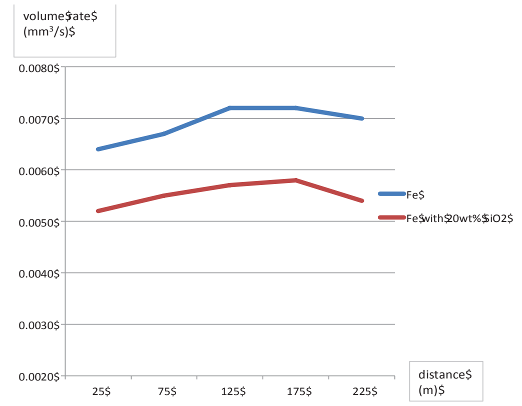

Fig. 2 Volume rate of iron composite reinforced with 20wt.% silica against sliding distance

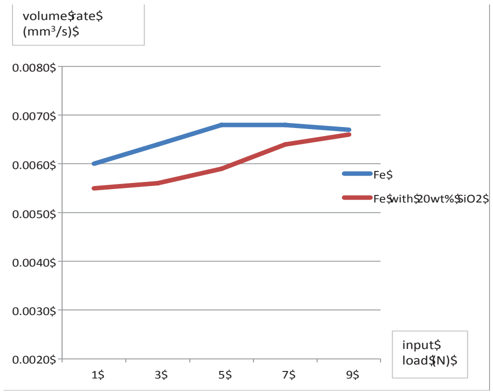

Fig. 3 Volume rate of iron composite reinforced with 20wt.% silica against applied load

3.2 Wear Mechanisms

Figure 4 displayed the worn surfaces of composite's samples from wear test using rotational speed as the variable. All samples tested against rotational speed were covered with intersection cracks and subsurface cracks, features linked to delamination type of wear. Detachment of wear debris was also found on the worn surfaces of the composite, while Fig. 5 depicted worn surfaces of pure iron under the same condition. Although pure iron displayed more or less comparable wear resistance as the composite, its worn surface shown lesser damage compared to the composite. It consists of smearing marks along the sliding direction and some irregular pits were identified. This suggests that pure iron's surface layers is more compact compared with composite. This observation supports previous finding by Y. Zhan and G. Zhang [7], whom noted reinforced composite is less compact than its alloy by comparing degree of damages seen on the worn surfaces of both samples.

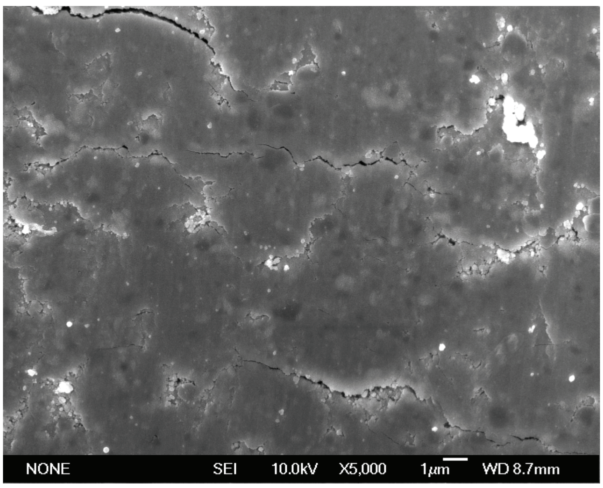

Fig. 4 Fine cracks are indication of delamination process

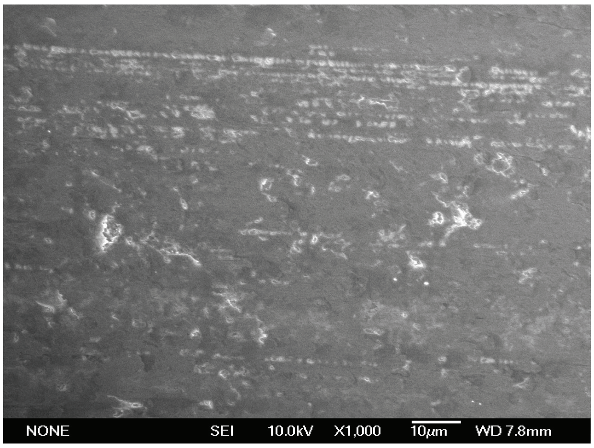

Fig. 5 Irregular pits and smearing along the sliding direction

Figure 6 displayed the composite's worn surface from wear test using load variable. Delamination is clearly to be more extensive when higher load is applied. Previous researchers have similarly found increasing dominance of delamination with load [6,7,13]. Since delamination involves subsurface deformation, crack nucleation and crack propagation, an increase in load will hasten these processes and produce greater wear. As the reinforced silica particles provide void nucleation sites, it easily turned into crack propagation paths [9-10]. This agrees with the findings of C. Lim whom reported that particulate reinforcements were not beneficial when delamination was dominant [6]. The composite had massive plastic deformation resulted from severe case of delaminated wear. H. Gulsoy et al [9] had recorded mechanism of delamination with deformed layers and tracks along the direction of sliding during wear, thus, concluded that contact pressure of wear surface increased with the increasing amount of porosity. Nevertheless, worn surface of pure iron of the same condition revealed lesser damage than its counterpart as viewed in Fig. 7, it has quite pronounce subsurface layers, which indicated delaminated wear is dominant.

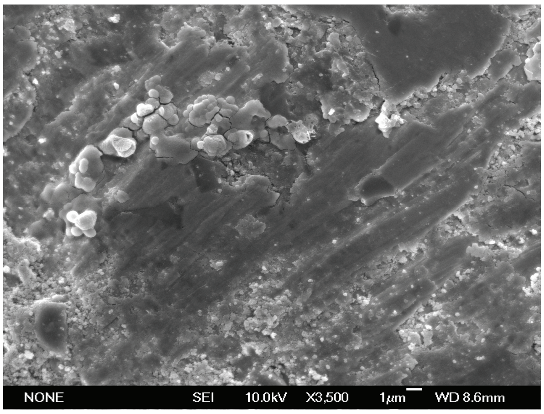

Fig. 6 Severe delamination wear

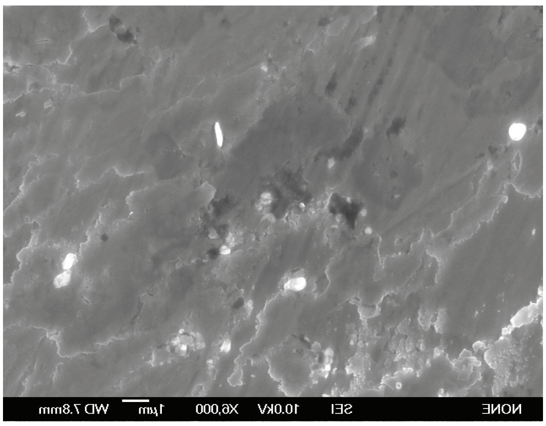

Fig. 7 Subsurface deformation

Existence of oxide films was noticed in all sliding conditions, however it is more pronounce in worn surface from wear test using distance variable. Probably, at both high load and high speed, frictional heating became more intense, which lead to oxidation wear. Fig. 8 shows an extensive oxide layer covered the composite's surface. Dominance of oxidation wear within this range of condition agrees with previous finding of Chen and Alpas [13]. Pure iron is presented in Fig. 9, where patchy oxide film appears on the edge of the surface, along with adhesion furrows marks at the centre. Gradual transition from adhesive wear to delamination wear as witnessed in pure iron was not evident in the composite. Probably it was due to composite's higher hardness. The advantage of possessing higher hardness had improved the composite's load-bearing capacity and imparted better resistance to adhesive wear [6,14]. From the examination on the worn surfaces, it become clear that composite had performed better wear resistance due to the accumulation of oxidation wear. When a near continuous oxide film formed on the surface, it prevents metal to metal contact during sliding, therefore the composite only suffers minimal volume losses compared to its counterpart that encountered direct metal to metal contact all the way during sliding.

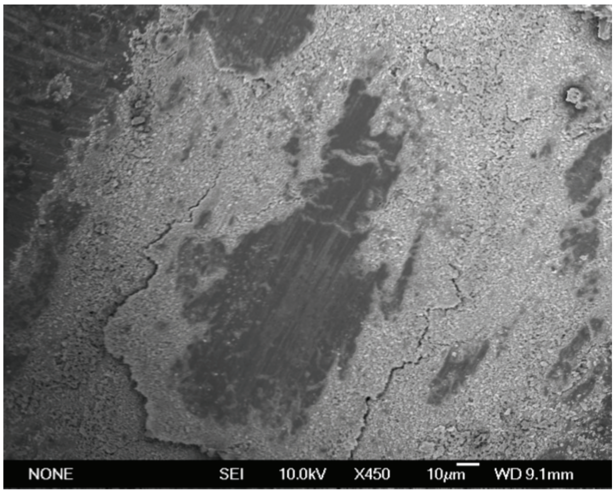

Fig. 8 Continuous oxide film formed on composite's surface

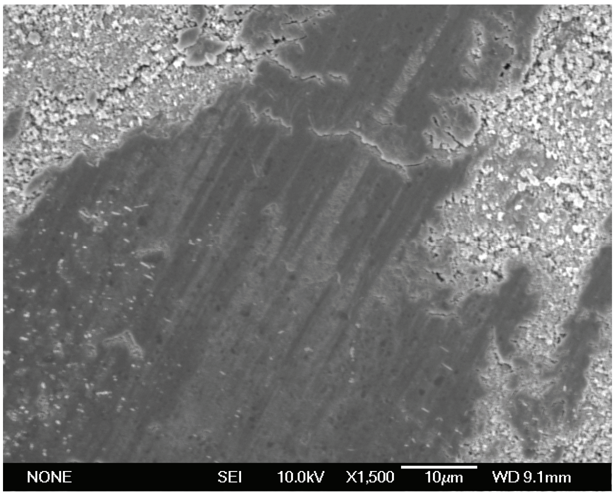

Fig. 9 Patchy oxide film with adhesion furrows

Present observation in pure iron and its composite proved that volume losses are not parallel with wear damage on contact area. Pure iron has demonstrated massive volume losses yet the damage to its worn surface was not as severe as observed in the composite. Altogether, reinforcement of silica particles into iron composite had evidently improved the mechanical properties which contributed to improve its wear resistance, however what is much more obvious is the reinforcement had changed the wear behaviour. The type of wear mechanism occurred in both samples is different. Dominant wear mechanism in composite is delamination wear but in pure iron it started with adhesive wear. Wear in composite was accelerated by propagation of intersections cracks and subsurface formation to the point it suffered a severely destructive plastic deformation with formation of large pits and accumulated large amount of wear debris. In the contrast, pure iron was worn out by smearing action of metal to metal contact during the sliding, which generated by adhesion. Then, the wear mechanism shifts from adhesion to delamination wear when subsurface deformation took place. Oxidation wear was present in both types of samples but pure iron only exhibit mild oxidation wear whereas its composite display severe oxidation wear.

4 CONCLUSIONS

Iron composite reinforced with 20 wt.% silica particles demonstrated an improvement in mechanical properties compared to pure iron. It produced higher hardness and higher bending strength. In the wear test using sliding distance and applied load as the variables, the wear resistance displayed is slightly higher wear resistance than pure iron, only during sliding with speed variable there is no significant improvement in wear resistance. Moreover, when the worn surfaces of the samples were examined, it was shown that delamination wear dominating the wear mechanisms, followed by oxidation wear, while wear mechanism found in pure iron was adhesive wear before shifting to delamination and oxidation.

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