Abrasive Wear Behavior of Fe-C-Cu Sintered Steels Containing MoS_2

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ABSTRACT

In some applications, the abrasive wear resistance of the material decides the useful life of a product. In this paper, the abrasive wear behavior of MoS_2 added sintered steel is reported. The sintered steel specimens prepared from atomized elemental powders were compacted using a hydraulic press. Abrasive wear tests were carried out at room temperature under unlubricated dry sliding contact condition. Silicon carbide abrasive paper of grit size 150μm is used as the abrasive medium. The wear loss of sintered steel with MoS_2 additions is significantly lower then the base compositions under similar loading and sliding conditions. The wear mechanism of the sintered steels was discussed on the basis of microscopic observations of worn surfaces.

Key words: Sintered steels, Abrasive wear, MoS_2 addition

1. Introduction

The use of sintered products is rapidly increasing because of both economical and technical reasons. Complex shaped machine parts are made to close tolerances in large quantities using powder metallurgy process. Gears and bearings used in automotive and other engineering industries are made by powder metal processing route economically. These machine elements require lubrication for smooth noiseless performance and are lubricated internally or externally. Solid lubricant added sintered steel compositions were developed for improved performance [1]. They are found to exhibit low coefficient of friction under pure sliding conditions when slide against steel surfaces. The suspended solid lubricants increase the compressibility of the sintered steels leading to the increase in part density [1, 2]. Presence of pores affects the mechanical properties severely and thereby the wear characteristics also. The adhesive wear behavior of sintered steels has been investigated [3]. Abrasive wear resistance of material is also important in many applications [4]. High speed steels produced by powder metallurgy processing posses evenly distributed primary carbides, and these primary carbides improve the resistance to two body abrasion [5]. Steam treatment improves the abrasive wear resistance of sintered steels because the oxides formed on the surface close the pores and increase the hardness [6]. Porosity reduces the effective cross sectional area, increasing the value of stress transferred across the material bridges between the pores [7].

In the present investigation, the abrasive wear behavior of sintered steels containing MoS_2 is studied. The abrasive wear mechanisms of the sintered steels are discussed.

2. Test material and experimental procedure

Test samples were prepared from the elemental powders using single stage compaction and sintering. Atomized iron powder (ASI 100.29) was mixed with carbon, copper and MoS_2 powders in a double cone mixture for 30 min. The size of molybdenum di sulphide powder is $\sim 10\ \mu$m. The nominal chemical composition of the samples developed is given in Table 1. Cylindrical pins of 10 mm diameter and 15 mm length were compacted using a hydraulic press. The compacted specimens were sintered in a pusher type furnace at 1393K in 90% nitrogen and 10% hydrogen atmosphere for 30 min.

Density and interconnected porosity of the as-sintered samples were measured according to ASTM standards [8]. Pore morphology and microstructure of the samples were studied using metallographically prepared samples. Hardness was measured with an applied load of 5 kg. Compressive strength of sintered samples was measured using cylindrical pins of 10 mm diameter and 15 mm length. Compression tests were conducted using a universal testing machine [9, 10].

The abrasive wear behavior of sintered steel pin is studied using a pin on disc wear test rig. SiC abrasive emery paper of grit size 150μm is fixed on the rotating disc. Tests were performed under dry sliding contact conditions at room temperature. All tests were performed at a constant velocity of 0.3 m/s and up to a sliding distance of 400 m. Sintered cylindrical pins were machined to a diameter of 5 mm up to a length of 8 mm. The initial surface roughness was measured using a profilometer at three places. The initial weight of pins was measured after cleaning in acetone followed by drying using an electronic weighing balance with 0.0001 g accuracy. Tests were conducted at different normal loads ranging from 5 N to 15 N. A fresh surface of the SiC emery sheet is used for each test. The wear was determined as the change in weight of the sintered steel pin measured before and after the test. The friction force was continuously measured using a load cell. The wear rate was evaluated from the volume of worn out material divided by the sliding distance. The volume of worn out material was evaluated from the weight loss divided by the density of material. Wear surfaces and sub surface regions were examined using scanning electron and optical microscope.

3. Results and discussion

3.1 Microstructure and density

Typical microstructures of as sintered Fe-C-Cu, Fe-C-Cu-3% MoS_2, and Fe-C-Cu-5% MoS_2 are shown in Figures 1 (a) (b) and (c). A large number of pores are seen in the base composition and the pore size is ~10μm. The pore shapes are not uniform and are interconnected with each other. In sintered steels the mechanical behavior of material is highly dependent on the microstructure, pore volume, pore size and pore shape. In MoS_2 added composition the number of pores and size of pores are small. Hard sulphide phases were found uniformly distributed in the samples. In MoS_2 added compositions the pores are not interconnected with each other and the pores have rounded corners. The density and interconnected porosity of the compositions are presented in Table 1. The density of MoS_2 added compositions are higher. The presence of the lubricants in the power mix aids in improving the density of sintered compacts. The volume fraction in 3% MoS_2 added composition is ~ 4% and in 5% MoS_2 added composition it is ~ 9%. As the addition of MoS_2 increased the part density also increased.

3. 2 Hardness and compressive strength

Addition of MoS2 plays an important role in deciding the mechanical properties of sintered steels. The hardness of MoS_2 added compositions are higher compared with Fe-C-Cu composition (Table 1). The gray colored hard sulphide secondary phase spreads throughout the material and increases the overall hardness. In Fe-C-Cu compositions the presence of higher volume of pores reduces the hardness. The compressive strength of MoS_2 added composition is higher then base composition. The compressive strength mainly depends upon the particle morphology and density of sintered steel samples. In Fe-C-Cu composition, the porosity reduces the effective load bearing cross sectional area and act as site for stress concentration. So the deformation starts from the pores and material fails rapidly. Also the presence of interconnected pores in Fe-C-Cu composition causes an increase in strain localization at relatively small loads. Whereas in MoS_2 added samples strength was dictated by the secondary phase particles, relatively strong inter particle contact and reduced the pore level.

3.3 Coefficient of friction

The coefficient of friction variation in Fe-C-Cu and Fe-C-Cu containing 3% and 5% MoS_2 under abrasive contact conditions at the applied normal load of 5 N are shown in Figure 2. Similar behavior was observed at all normal loads investigated. Although the initial coefficient of friction is higher due to the presence of fresh abrasive particles, subsequent blunting and removal of abrasive particles in emery sheet led to a drop in friction coefficient which reached a steady state in a short time. The steady state friction coefficient of MoS_2 added materials are high compared with base composition. The steady state coefficient of friction for both 3 and 5% is more or less constant. In MoS_2 added composition, friction coefficient was high at high normal loads. As the load increased the fluctuation also increased. In Fe-C-Cu-3% MoS_2 added samples, during abrasive wear process; the hard sulphide particles liberated gets accumulated on the sliding interface. These wear debris act as a load bearing third body particles and increase the coefficient of friction before they get fixed to the abrasive paper. The fluctuation of friction coefficient normally depends upon the accumulation and removal of debris in abrasive wear process.

3.4 *Wear resistance*

Figure 3 shows the linear wear of the pin plotted against the sliding distance. The linear wear of Fe-C-Cu pin is high compared to hard and dense MoS_2 added compositions indicating the improved abrasive wear resistance. High hardness MoS_2 added material smoothens the abrasive medium or removes the abrasive grits away from the sheet and improves the wear resistance. The larger debris was transferred to abrasive paper and gets accumulated in between the SiC indenters. This also reduces the intensity of linear wear. In 3% MoS_2 added compositions the linear wear is lower then 5% MoS_2 compositions. Excessive addition of MoS_2 (beyond 3%) decreased the hardness and strength of the material (Table 1). The reduction in the strength and hardness of the 5% MoS_2 material compared with 3% MoS_2 material contributed to the decreased wear resistance.

The mass losses of all the test materials evaluated from the weight measurements carried out before and after the tests are shown in Figure 4. The Fe-C-Cu compositions exhibited a higher mass loss compared to MoS_2 added material. With increase in load, there is a higher mass loss in all the materials investigated. The wear of material depends on the mechanical properties [11]. The primary wear mechanism is related to hardness, strength and toughness of the material. These parameters govern the amount of material removal. Increase in strength and density is expected to improve the fracture toughness of the material and thereby the wear resistance [12]. The 3% MoS_2 added samples exhibit a higher abrasive wear resistance because of high hardness and strength compared with 5% MoS_2.

3.5 *Wear mechanism*

Figure 5 (a) (b) and (c) shows the worn surface of sintered steel pins. Severe abrasive wear tracks can be seen in Fe-C-Cu base compositions (Figure 5a). At all loads the Fe-C-Cu composition experiences more wear due to the higher porosity and lower material hardness. In 3% MoS_2 added compositions, at low loads, a less number of grooves were observed and the depth of grooves was also low. The main reason for the difference in the behavior can be attributed to the higher hardness and strength. The sulphides are hard enough to cut and blunt the cutting edges of abrasive indenter, thus decreases the cutting efficiency of SiC. This wear resistance effect is mainly related to the blunting of the cutting edges of the abrasive particles [13]. The small debris particles are also expelled on the worn surface (Figure 5 (b)). These particles transferred to the counter face, cap the ends of the abrasive grits and hinder the abrasive action of the grits. This would also have a tendency to reduce the deformation rate. In 5% MoS_2 added composition, there is a decrease in abrasive wear resistance, and grooves are also deeper then the 3% MoS_2 compositions (Figure 5c). The reduced hardness and strength increase wear of 5% MoS_2 added samples.

4. Conclusions

The abrasive wear behavior of MoS_2 added sintered steel is investigated. The MoS_2 added compositions exhibit excellent abrasive wear resistance compared to the base composition. Mechanical properties such as strength and hardness increased in MoS_2 added compositions. The wear loss decreased with increasing hardness and strength. Experimental results indicate that the abrasive wear of sintered steel pin depends upon the hardness, density, porosity and applied normal load. In MoS_2 added composition wear resistance improved because of lesser porosity, higher hardness and strength.

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Table 1. Density, interconnected porosity, hardness, and compressive strength of test materials

Composition	Density (g/cm^3)	Inter-connected porosity (%)	Hardness (HV)	Compressive strength (MPa)
Fe-0.6%C-2.5%Cu	6. 30	16. 5	91	497
Fe-0.6%C-2.5%Cu-3%MoS_2	6. 52	9.1	136	1006
Fe-0.6%C-2.5%Cu-5%MoS_2	6. 57	8. 8	126	840

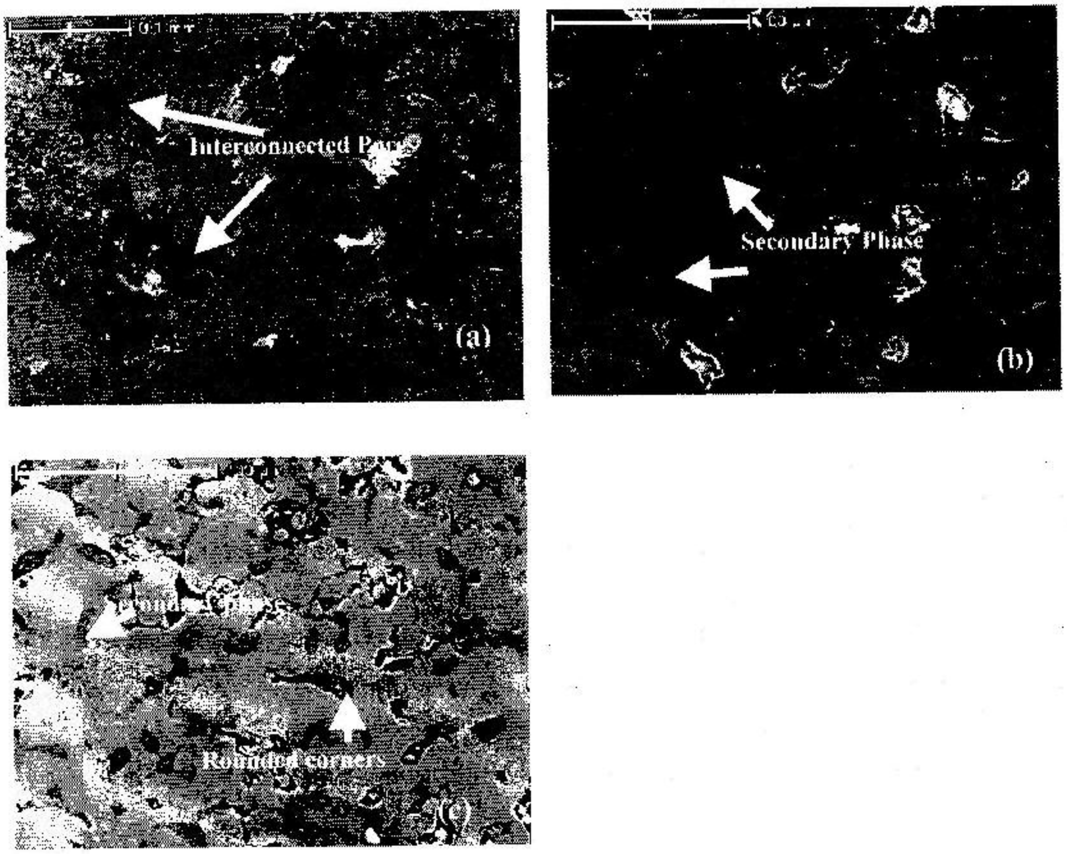
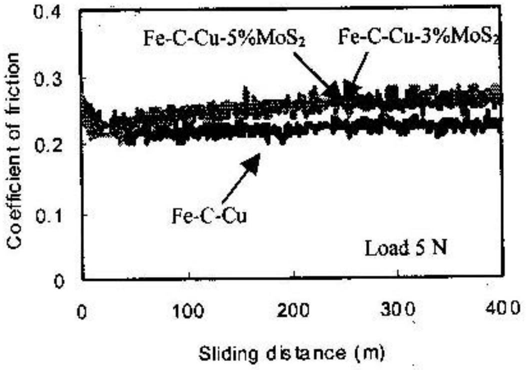


Figure 1. Pore morphology of sintered steel samples (a) Fe-C-Cu (b) Fe-C-Cu-3% MoS_2 and (c) Fe-C-Cu-5% MoS_2



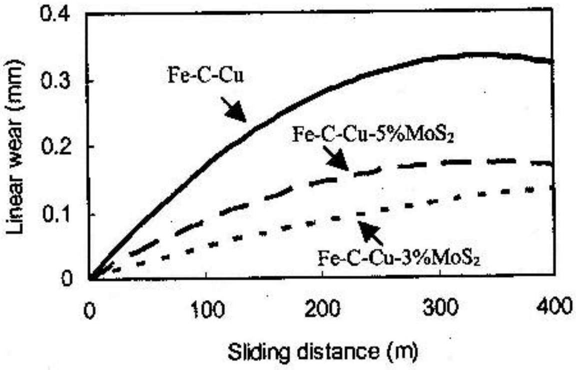


Figure 2. Variation of coefficient of friction

Figure 3. Linear wear of sintered steel pin

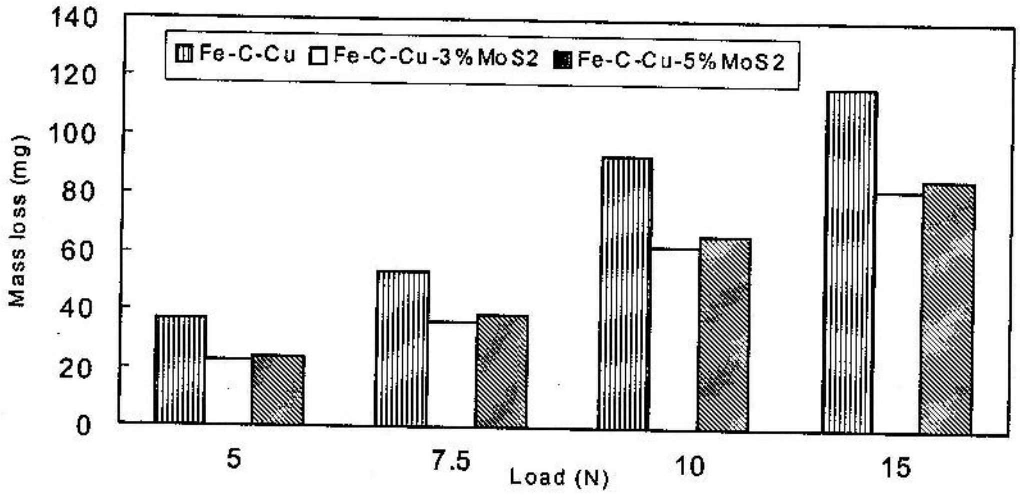


Figure 4. Mass loss variation with the varying applied normal load

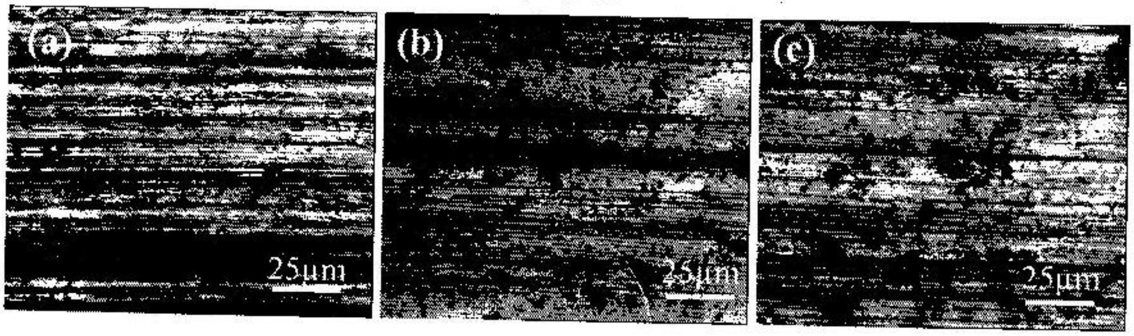


Figure 5. Optical micrograph of the worn surface at a normal load of 5 N a) Fe-C-Cu (b) Fe-C-Cu-3% MoS_2 and (c) Fe-C-Cu-5% MoS_2

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