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Experimental study on dry sliding wear behaviour of sintered Fe-C-W P/M low alloy Steels

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Abstract

Powder metallurgy (P/M) manufacturing process is one of the rapidly emerging fields and has extended the applications in aerospace, automotive, manufacturing industries replacing all traditional methods of metal forming operations because of its less energy consumption, maximum material utilization, low relative material wastage, low capital cost. Unlike wrought materials, wear behaviour of porous materials is different and is influenced by the pores present in the materials. The presence of pores leads to weakness and also acts as origin of crack initiation in sintered materials. The present investigation is made to study the dry sliding wear characteristics of P/M Fe-1% C-1%W low alloy steel with different densities (85%, 90%, 95%), as they find several applications in manufacturing industries, particularly in automobile industries. The wear behavior of the as-sintered preforms were studied under dry conditions on pin-on disc arrangement (ASTM G99) against EN 38 steel disc of Hardness HRC 60 with a sliding speed of 2 m/s and at a normal loads of 30, 50, 70N respectively. Wear regimes of P/M steels has been characterized using optical microscopy. From the microstructure of wear pattern it is evident that, presence of carbides of the carbide forming elements W offers greater wear resistance. The elements gets embedded as hard particles in a soft matrix of Fe-C, resulting in non-uniform wear pattern in higher density preforms (95%), whereas uniform wear was observed in low density preforms (85%) even at higher loads during the test. Delamination is a common wear mechanism found in both P/M alloy steels with an increase in applied load, but oxidation wear was observed in all the preforms at low levels of applied load.

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*Keywords:*P/M alloy steels; Wear loss; Sliding distance; Coefficient of friction

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1. Introduction

The steels produced through powder metallurgy (P/M) manufacturing process has immense potential for industrial applications, in view of requirements of mass production, lean manufacturing, improved reliability and replacing all traditional methods of metal forming operations because of its lesser energy consumption, maximum material utilization, low relative material wastage and competitive cost. Sintered low alloy steels find numerous applications in making components for the machine parts, automobile parts, structural components, etc. The mechanical properties is mainly depends on the final density of sintered P/M alloys. The presence of voids or porosity in compacted preforms and sintered products is one of the major factors causing reduction in mechanical properties of P/M alloys. Porosity may contribute to strength degradation in two ways. First, pores will act as local stress concentrators, and second, they may act as crack precursors. The final density of the sintered P/M parts plays a vital role in determining the component properties and characteristics. Danninger et al. (1993) investigated on sintered iron under different loads to establish the mechanical behaviour of sintered iron preforms in correlation with micro structural parameters. Also impact test and fatigue test were carried out on sintered iron preforms with different sintering parameters such as time and temperature and resulted that the mechanical properties were most sensitive to the sintering intensity. The strengthening of sintered P/M low alloy steels can be achieved through densification, alloying and heat treatment (1989). The wear mechanisms of P/M alloy steel parts has similar properties compared to wrought materials, under the same tribological conditions, but the porosity plays a significant role in wear behaviour of alloy steels (2004, 2001). Engstrom et al. (1992) has developed some new high strength alloy material based on Cu, Mo and Ni with varying composition levels and studied their mechanical behaviour and dimensional tolerances with respect to the mode of mixing of alloy powders such as partially pre-alloyed, admixed and fully pre alloyed and conclude that the partially pre alloyed powders will dominate the future, as the alloy material processed through this route yields better mechanical behaviour and dimensional tolerance. Yousuffiet al. (2000) studied that the mechanical properties of P/M Fe-Mn steels with the addition of 0.5% Mo and varying levels of Mn and C, and reported that the steel with 3%Mn, 0.5%Mo and 0.7%C exhibits better mechanical properties and also that the addition of Mo has beneficial effect on tensile properties. Wang et al. (1994) investigated and compared that the sintering processes of preforms by varying the variables such as sintering temperature, initial density and preforms design used for fabrication of steel parts for various powder forging processes. Philips et al. (2000) studied about the adding of alloying elements to steel, especially those which help to retain austenite, improves the tensile and toughness properties of sintered steels. Lack of homogeneity in structure is reported to exhibit mixed modes of crack propagation, cleavage and micro void coalescence in the case of sintered alloy steels. Micro void formation is promoted by the presence of metallic alloying elements. The wear resistance of high speed steel is enhanced due to the formation of hard carbides by the addition of TiC rather than the addition of MnS and CaF_2. On the other hand the later improves self-lubricating property of the steel (2004). Fodor et al. (1995) reported the effect of carbon addition on the microstructure of mixed elemental powder alloy systems cooled at moderate rates after sintering and concluded that at moderate cooling rates the amount of martensite increases with increase in carbon content (0.5% to 0.8%) and the amount of martensite is doubled during furnace hardening. Molinari et al. (1999) observed that increase in mechanical properties such as hardness, impact strength along with wear resistance because of the formation of bainitic and martensitic microstructures in the Fe-C-Cr-Mo alloy system. The addition of W to P/M alloys could enhance the wear resistance due to the formation of hard phases in the microstructure. The hardened carbide based P/M alloy steels could be the best choice for replacing the HSS in view of the economics of production (2012). Senthur prabu et al. (2013) studied the dry sliding wear behaviour by addition of tungsten in the plain carbon steel and resulted that the wear resistance of the P/M low alloy steel gets significantly enhanced. In view of the emerging importance of low alloy P/M steels in various applications stated above, and due to their potential high strength and economic structural applications it is important to have a complete understanding of the wear behavior of P/M steels in order to evaluate their suitability for frictional wear applications. The present study is mainly focused on the dry sliding wear behavior of sintered P/M low alloy steels with the addition of W as alloying elements with various densities such as 85%, 90% and 95% under dry conditions on pin-on disc arrangement against EN 38 steel disc of Hardness HRC 60 with a sliding speed of 2 m/s and at a normal load of 30, 50, 70 N.

2. Experimental Details

For the present research work, atomized iron powder of particle size 150µm supplied by M/s Hoganas India Ltd, Pune, graphite powder of particle size 5µm supplied by Ausbury Graphite Mills, USA, and Tungsten (W) powder of 100 µm were used. The basic characteristics of elemental iron powder such as flow rate, apparent density, tap density, and flowability has been carried out using standard methods of testing. The sieve analysis of iron powders are showed in **Table 1**. Elemental powders of Fe, C and W were accurately weighed and thoroughly mixed in an indigenously made pot mill for 10 hrs to yield the alloy compositions of Fe-1%C-1%W. The physical characterization of elemental alloy powder results are exhibited in **Table 2**. The mass of blended powder was then compacted into cylindrical billets of size Ø25X33mm using a hydraulic press of 1000 kN capacity. Using compressibility chart suitable axial pressure was applied to obtain preforms of 85%, 90%, 95% theoretical density as shown in **Figure 1**.During compaction graphite was used as lubricant. After the compaction, indigenously made aluminium ceramic coating was applied over the exposing surface of green compacts immediately to avoid oxidation and dried for 24h. The coated and well dried compacts were sintered using 3.5kW capacity muffle furnace at 1100 ± 10°C, for a period of 120min, in nitrogen purged inert atmosphere to avoid oxidation. Sintered samples of P/M alloy steels were machined off to obtain standard wear test specimens of size diameter 6mm. The actual density of the P/M alloy specimen was measured using Archimedes' principle. Disc polishing was made before the specimens were subjected to wear test. The initial weight of the steel pin was measured after cleaning in acetone followed by drying using an electronic weighing balance of 0.01 mg accuracy. Computer assisted Pin-on-disk tribometer was used for carrying out dry sliding wear tests on P/M alloy steel pins against counter face EN 38 steel discs (HRC 60).The disc was cleaned in acetone before and after the commencement of wear tests to get the high precession results. The dry sliding wear tests were conducted at a normal load of 30, 50 & 70N with a sliding speed of 2m/s.The material wear loss was determined as the change in weight of the sintered steel pin measured accurately before and after the wear test. Coefficient of friction was also taken during the wear test from the tribometer. The wear mechanisms were studied by observing the worn out surfaces using optical and scanning electron microscopes.

Table 1. Sieve size analysis of Iron (Fe) powder.

Sieve size (µ)	Weight retained (%)	Cumulative weight retained (%)
+150	1.42	1.42
+125	13.42	14.84
+106	8.06	22.90
+90	1.2	24.10
+75	22.19	46.29
+63	13.49	59.78
+53	14.22	74.00
+45	6.37	80.37
+38	1.7	82.07
-38	17.54	99.61

Table 2.Physical properties of elemental mixed powder of alloy Fe-1%C-1%W.

Sl. No.	Composition	Theoretical Density (g/cc)	Apparent Density (g/cc)	Tap Density (g/cc)	Flowability (s/g)
1	Fe-1 % C-1 % W	7.72	3.07	3.58	0.53

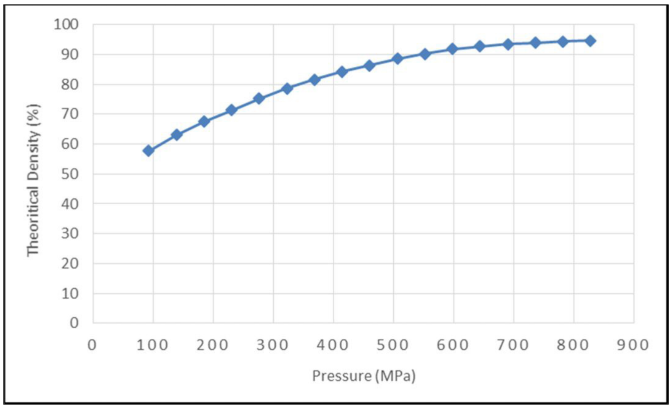


Fig. 1.Compressibility chart for Fe-1C-1W, Theoretical density V/S Pressure

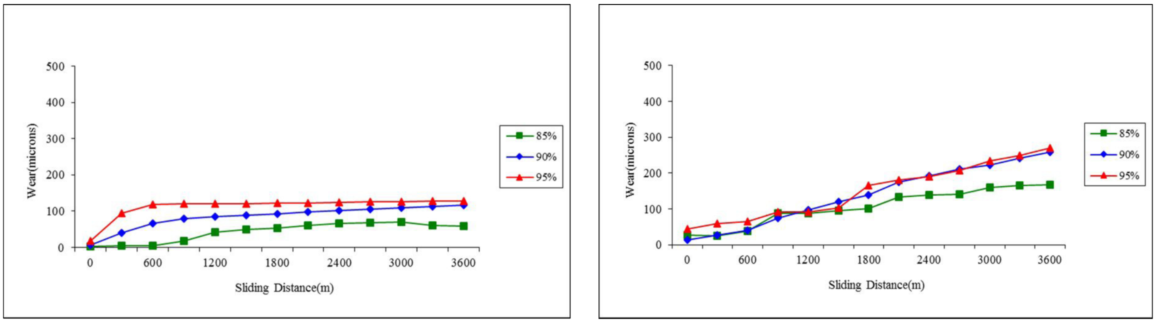
3. Results and Discussions

Basic dry sliding wear curves (wear loss and frictional coefficient versus sliding distance) of sintered tungsten alloyed plain carbon steel (Fe-1%C-1%W) for different densities (85%, 90% and 95%) at constant sliding velocity of 2m/s for an axial load of 30, 50, 70N were obtained.

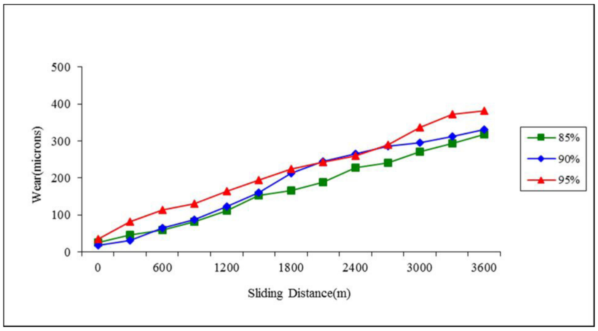
3.1. Wear Behaviour of Tungsten Alloyed Plain Carbon Steel

The dry sliding wear behaviour of sintered tungsten alloyed plain carbon steel (Fe-1%C-1W %) is illustrated in **Figure 2** (a-c).

From Fig 2(a) it was observed that with low level applied load of 30N, mass loss of all density preforms increases gradually with sliding distance. Mode of wear under these conditions appears to be oxidative. The wear rate rises abruptly above applied load of 50N and that is apparent in 70N also. It is observed from the plot 2 (c) the mass loss is increasing linearly with sliding distance particularly in higher applied load. The increase in the hardness of the higher part density can be attributed to the presence of Tungsten carbide, hard phase formed results in higher mass loss during the wear test. Heat generated for 95% density preforms at high load causes more oxidation but that is counteracted by continuous fracture under those conditions because of brittle and discrete oxide film formed and it acts as hard impurity or particle (third body) between mating surfaces results in delamination wear. The continuous fracture of oxide layer causing a piece of material to leave the surface as wear debris. This is so-called delamination wear.



(a) (b)

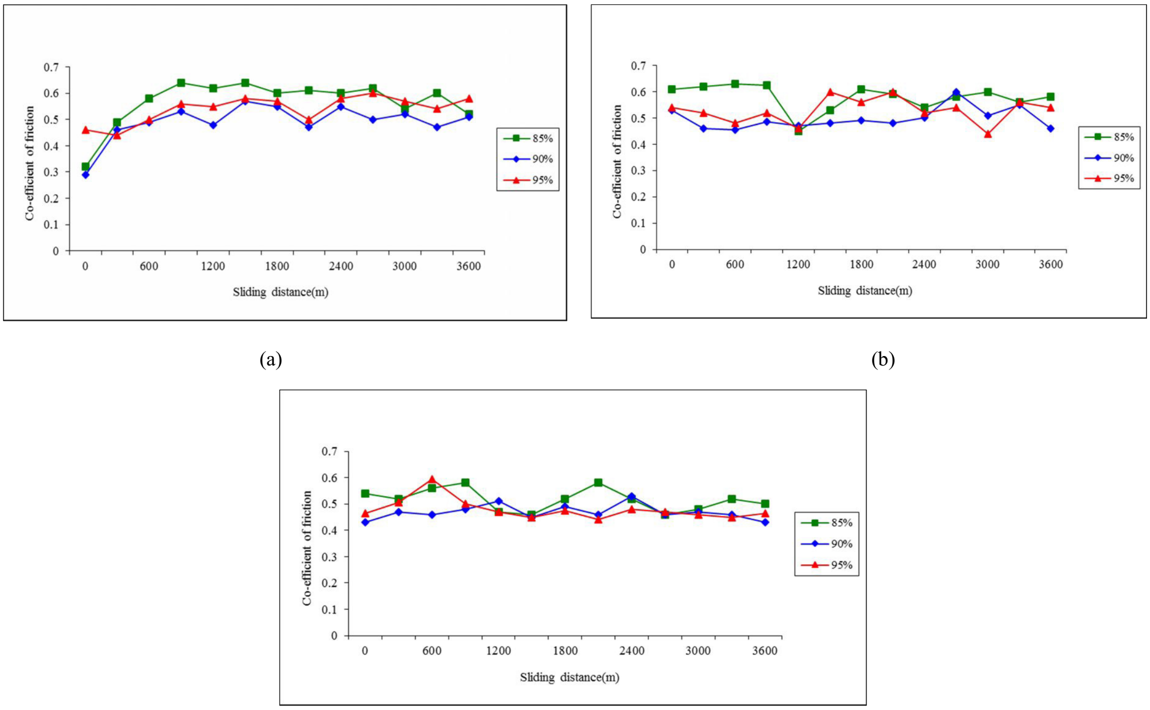


(c)

Fig. 2.Dry sliding wear behaviour of sintered Tungsten alloyed plain carbon steel (Fe-1%C-1%W) (a) 30N; (b) 50N; (c) 70N

3.2.Effects of Applied Load and Sliding speed on the Frictional Coefficient

Figure-3 illustrates the variations of the frictional coefficient of P/M alloy steels at different loads. From the plot 3(a) Initially coefficient of friction at the beginning of the test varies between 0.28 and 0.32 for 85% and 90% density preforms whereas 95% density it was 0.45. The initial lower value of frictional coefficient is due to contact between the oxide layers of the test specimen and disc material. Within a short period of sliding distance, the coefficient of friction raises to an average of 0.65 depending upon the density of preforms. Breaking and removal of surface oxide layer leading to the metal-to-metal contact causes an increase in the coefficient of friction. Interface temperature increases with incremental in applied load that may promote the surface oxidation and reduce the direct metal contact hence there was slight decline in friction coefficient (2007).



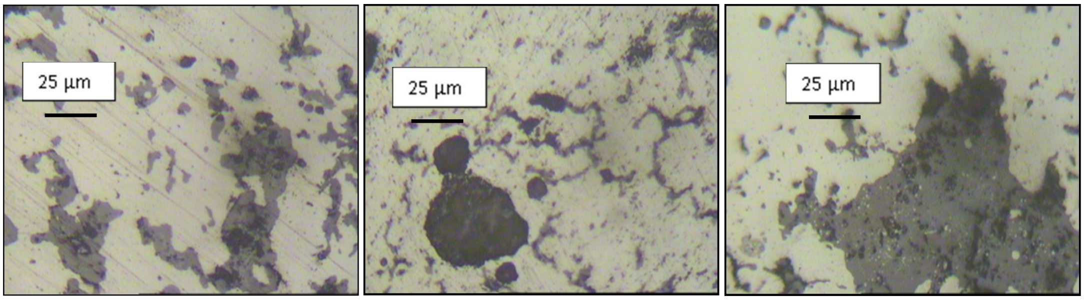
(a) (b)

(c)

Fig. 3.Variation of the frictional coefficient of P/M low alloy steel at different loads (a) 30N; (b) 50N; (c) 70N

3.3. Microstructure of As-Sintered P/M alloy steels

The microstructures of the sintered P/M alloy steels used for the wear test are shown in **Figure 4**. Basically the alloy steels are containing ferritic-pearlite microstructure and reveals that the uniform distribution of Tungsten particles. Tungsten is known carbide former. In higher density preforms 95% the carbide phase due to W embedded in between the ferrite grains is bigger in size. The carbides of alloying element embedded along the grain boundaries leads to enhance the wear resistance of the alloy steel (2013).

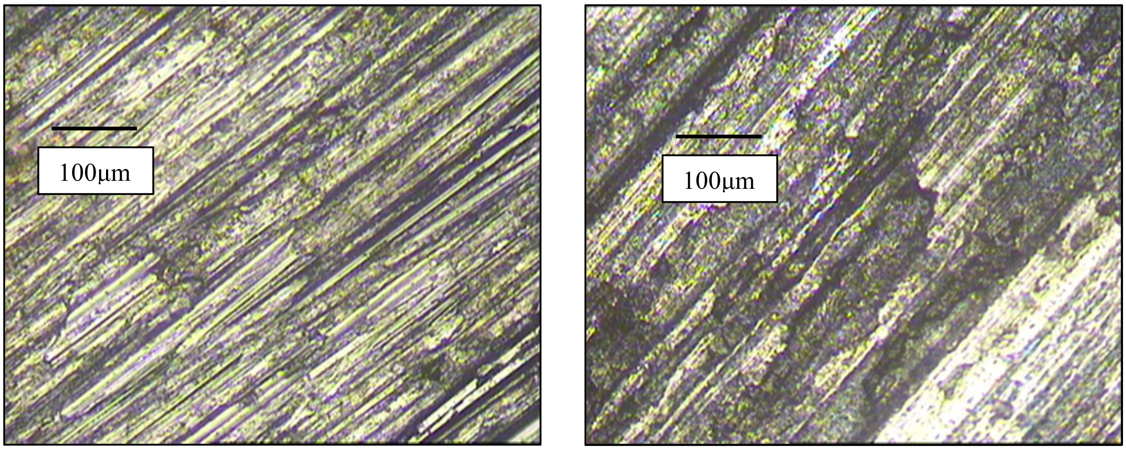


(a) Fe-1C-1W-85%- 400x; (b) Fe-1C-1W-90%- 400x; (c) Fe-1C-1W-95% - 400x

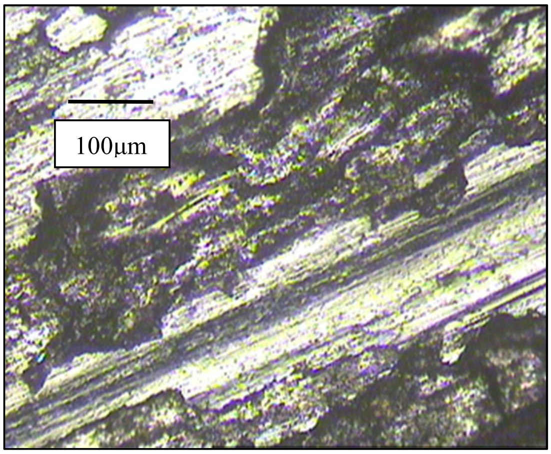
Fig. 4. Optical micrographs of the as-sintered P/M alloy steels

3.4. Wear pattern

Figure 5 illustrates the morphological observations of wear pattern of maximum worn out pin surfaces of P/M alloy steels. Non-uniform wear pattern was observed from Figure 5(c) due to the presence of high dense tungsten carbides because of the addition of alloying element. Tungsten is known carbide former. At higher load and higher density (95%) extent of grooves, craters formed at the worn surface of the preforms indicate that delamination is a main mechanism responsible for removal of material. Failure by a delamination process is clearly indicated by the shape of the debris particles. The wear debris mechanism of wear may include oxidative wear, micro-cutting and delamination wear because of some oxide particles, microchips, delamination flakes. Heat generated at high load causes more oxidation but that is counteracted by continuous fracture under those conditions (1994).



(a) (b)

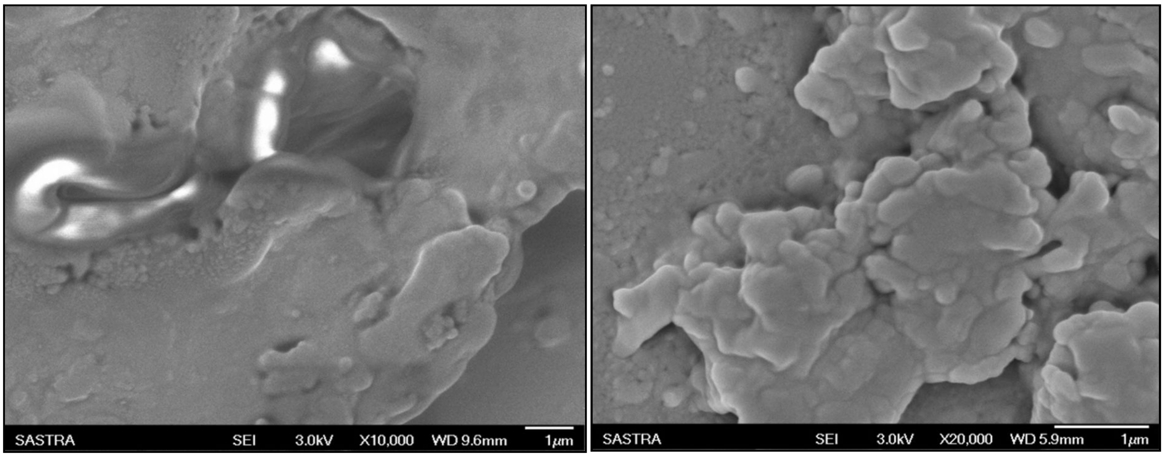


(c)

Fig. 5.Wear pattern of maximum worn out surface of P/M alloy steels (a) 85%; (b) 90%; (c) 95%

3.5.Scanning Electron Microscope (SEM) images

SEM images of as-sintered Fe-1%C-1%W of 95% density preforms is shown in the **Fig 6(**a). The W particle embedded in between the ferritic grains matrix is evident from the SEM micrograph. **Fig 6(**b) shows the SEM image of the wear debris during the wear test of 95% density specimen. Physical metallic failure was observed because of long metallic debris generated at high loads for higher density indicating the occurrences of severe metallic wear. Metallic wear increases because of increases in the hardness of matrix and makes it more coherent which increases thermal softening of the materials owing to temperature rise.



(a) (b)

Fig. 6.SEM images of 95 % density preforms: (a) Fe-1%C-1%W as-sintered; (b) Fe-1%C-1%W wear debris

4. Conclusions

- The wear rate gradually increases with increase in applied load for all the density P/M low alloy steels and in higher load wear rate increases abruptly due to delaminative wear.
- In high density preforms (95%) due to hard phase of the tungsten carbide results in high hardness leads to higher wear loss during the test. Heat generated at high load causes more oxidation and the continuous fracture of oxide film formed the metal to metal contact results in delamination wear.
- The uniform wear loss was observed in 85% density preforms irrespective of loads compared with other density preforms. But the frictional coefficient slightly increases due to oxide layer formed.
- The basic microstructure of all density Fe-C-W P/M alloy steel is ferritic-pearlite. Distribution of the tungsten particles embedded in Fe-C matrix is uniform in the 85% density sintered P/M steel preforms results in uniform wear and also observed the least wear loss. So the density plays the vital role in the P/M alloy steels to enhance the wear resistance.

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References

Danninger, H., Jangg, G., Weiss, B., and Stickler, R., 1993.Microstructure and Mechanical Properties of Sintered Iron Part I-Basic Considerations and Review of literature.Powder Metallurgy International, Vol. 25, No.3, 111-116.

R.Haynes, 1989.Development of sintered low alloy steels. Powder Metallurgy, Vol.32, No. 2, 140-146.

Simchi, A., Danninger, 2004. H. Effect of porosity on delamination wear of sintered plain iron. Powder Metall J 44, 73–80.

Straffelini, G., Molinari, A., 2001.Dry sliding wear of ferrous PM materials. Powder Metall J 44, 48–52.

Engstrom,U., Lindberg, C., and Tengzeius, J., 1992.Powders and processes for high performance PM steels”. Powder Metallurgy International, Vol. 35, No. 1, 67-72.

Youseffi, M., Mitchell, S.C., Wronski, A.S., and Cias, A, 2000.Sintering, microstructure, and mechanical properties of PM manganese – molybdenum steels. PowderMetallurgy, Vol.43, No. 4, 353-358.

Wang, M.C, 1994. Properties of high density powder forged iron based alloy. Powder Metallurgy, Vol. 37, No.3, 201-205.

Philips, R.A, King, J.E., and Moon, J.R., 2000.Fracture toughness of some high density PMsteels. Powder Metallurgy, Vol.43, No. 1, 43-48.

Zuomin, Liu.,Childs, T.H.C.,2004.The study of wear characteristics of sintered high speed steels containing CaF_2, MnS, TiC additives at elevated temperature. Wear 257, 435-440.

Fodor, M., Wood, J.V,1995.Effect of carbon on microstructure of mixed powder system cooled at moderate rates after sintering. Powder Metallurgy, Vol. 38, No. 2, 141-146.

Molinari, A., Straffelini, G., and Campestrini, P, 1999.Influence of microstructure on impact and wear behaviour of sintered Cr and Mo steel.
PowderMetallurgy , Vol.42, No.3, 235-241.

Bose, A., Sadangi, R., German, R.M., 2012.A review on alloying in tungsten heavy alloys.TMS annual meeting and Exhibition, Volume-1, 455-465.

S. Senthur prabu, T.K. Kandavel, P. Karthikeyan, Influence of Tungsten on dry sliding wear behaviour of sintered plain carbon steel (Fe-1%C) Proceedings of Second International Conference on Advances in Materials Processing and Characterization, 2013, Volume-2, 905-913.

Dhanasekaran, S., Gnanamoorthy, R, 2007.Dry sliding friction and wear characteristics of Fe–C–Cu alloy containing molybdenum di sulphide, Materials and Design 28, 1135–1141.

Davis, F.A, Eyre, T.S, 1994. The effect of silicon content and morphology on wear of aluminium–silicon under dry and lubricated sliding conditions, Tribol. Int. Vol. 27, No. 3.171–181.