Tribological Parametric Influence of Dry Sintered Iron Bearings

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Abstract : The friction and wear of sintered bearing materials were studied under dry condition using a dedicated test rig. The materials tested were Fe based alloy and additives added in it through sintering process. The performances of coefficient of friction and wear were evaluated against process and manufacturing parameters. Parametric influence on tribo-characteristics have been evaluated under varying condition of running. Effect of additive concentration have been shown in case of MoS_2 and Zn-stearate impregnated bearings. A comparison of specific wear rate of bearings have been reported. Finally SEM micrographs have been taken to study the mechanism of tribo-process.

Keywords: Sintered bearing, friction and wear, process and manufacturing parameter, SEM micrograph

I. INTRODUCTION

Sintered bearings made with different combination of metals have been studied for some years now and their properties are becoming increasingly well known. They have been developed widely for application in many industrial areas because they have good formability and excellent properties of materials.[1, 2].Amsallem et al.[3] demonstrated low wear of Fe alloy sintered material at low speed and Gopinath et al.[4] have derived equations for the friction and wear of Fe alloy material. Bekir Sadik [5] concluded that metal based materials with additives like MoS_2 may be used in the industry for wider range of operating condition due to better tribological and mechanical properties and he investigated that copper with zinc and tin based bearing materials were better than those of aluminium and combination of SnPbCuSb bearing materials, particularly at low loads. Self-lubricating bushing is one of the most attractive applications of porous powder metallurgy (P/M) parts. The most widely used materials for porous self lubricating bushes are bronze and iron–bronze, iron-based powders and nickel-based alloys [6, 7]. Elements like graphite, MoS_2 which have self- lubricating nature, are added to sintered materials to improve the wear characteristics [8,9.]. However, Fe based sintered alloy with parametric variation have not been studied extensively under different tribological conditions. But in order to meet the requirement of various applications, it is important to choose material with appropriate properties at specified condition of running. This may be achieved by choosing efficient alloying with desirable combinations of elements by varying curing temperature, hardness, compaction pressure and porosity etc. At present, no suitable data are available for commercial use from tribological point of view and it is important to have necessary performance data on such bearings.The aim of the present study is to investigate the tribological behaviour of Fe based sintered material using a dedicated test rig. The effect of manufacturing and process parameters on the tribo-responses, namely coefficient of friction and wear are reported. A comparison of specific wear rate among materials with additive has been shown. The morphological changes of the worn surfaces of samples are also examined through SEM.

II. Experimental procedure

2.1. Tribology test

The experiments were carried on a specially designed "Dry bearing test rig", having shaft as counter surface - size 50 mm made up of hardened steel (Rc-65) and surface roughness of 0.45μm (CLA). Test bearing is mounted on the shaft experiencing direct loading under a wide range of speed. Friction force was measured by a load sensor attached to the swinging arm connected to the motor and located in the frame (fig 1b). After running the samples for required duration of time on dry bearing test rig, wear was observed as dimensional changes of specimen and measured on 3D-coordinate measuring machine. Dimensional changes of specimen bore are measured before and after experiment and average wear are calculated by noting the difference in average diametral dimension of bearing bore size. The unit has got a control panel properly interfaced with the PC for data logging of process parameters. The test rig is shown in Figure 1(a) and 1(b). Tribological interface of mating surfaces has been depicted in figure 1(c). Operating test conditions are given below.

Table 1. Operating test conditions

Speed m/s	Specific pressure, N/mm^2	Time of running,
0.5-2	2-8	5-20 min for friction and 8 -16 hrs for wear

Figure 1(a). Dry bearing test rig

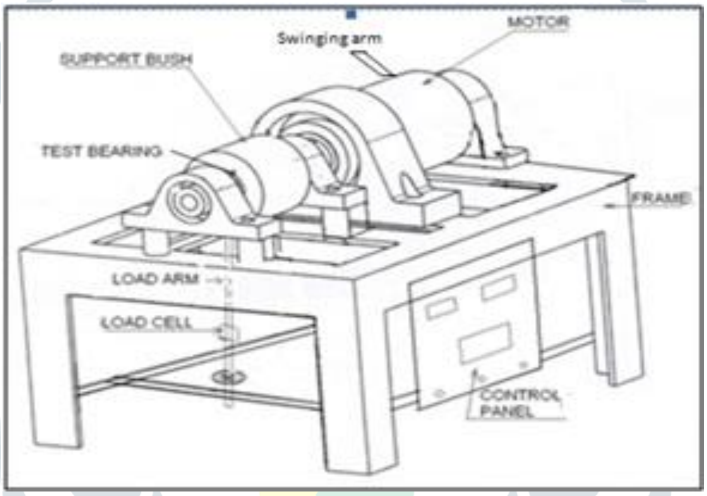

Figure 1(b). Schematic of the test rig

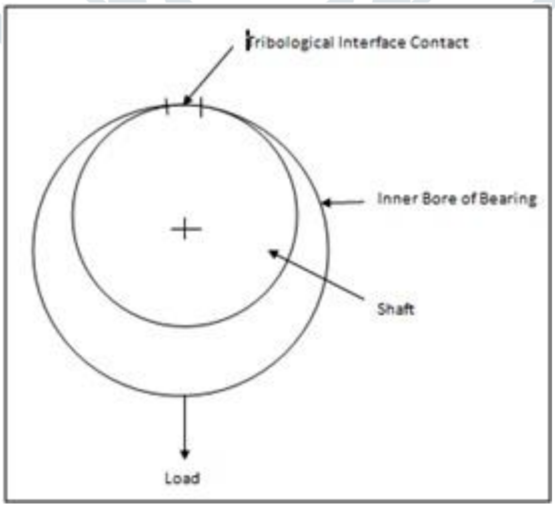

Figure 1(c). Tribological interface contact

III MATERIALS

Dimensions of bearing specimen were as follows: inner diameter 50mm, outer diameter 70mm and length 60mm. The bearings were manufactured by sintering under curing temperature ranging from 800°C to 1100ºC and compaction pressure ranging from 500 MPa to 800 MPa. The chemical composition of iron based sintered bearing was Fe-99%, Cu-1% and density ranging from 6.30-6.40 g/cm^3. Porosity was found to be between 16% to 25%.

IV RESULTS

There are several parameters which change the properties of material during manufacturing i.e. sintering. Among them, compaction pressure, curing temperature, hardness, porosity etc change the properties which in turn affect tribological properties of material. The experimental studies conducted on the mentioned test rig on plain sintered iron bearing within experimental limits (P = 2 N/mm^2 to 8 N/mm^2, v = 0.5 m/s to 2 m/s, T = 5 min to 20 min for friction, 8 hrs to 16 hrs for wear) to see the variation of friction with manufacturing parameters (refer fig.2 to fig.5) as mentioned. Effect of process parameters on coefficient of friction have been analyzed from fig 6 to fig 8. Effect of additive concentration on frictional values has been shown in fig 9.

4.1. Discussion on friction

Figure 2 shows coefficient of friction increases slightly as the compaction pressure increased. This is due to the fact that under high compaction pressure, powder materials have strong bonding and high surface asperity number resulting more resistance to movement. Since curing temperature increase leads to possibly removal of soft surface layers composed of Fe-Cu-S, thus exposing brittle subsurface layers consisting of hard phases such as Fe-Cu with high shear strength, coefficient of friction increases with curing temperature as cited in figure 3.

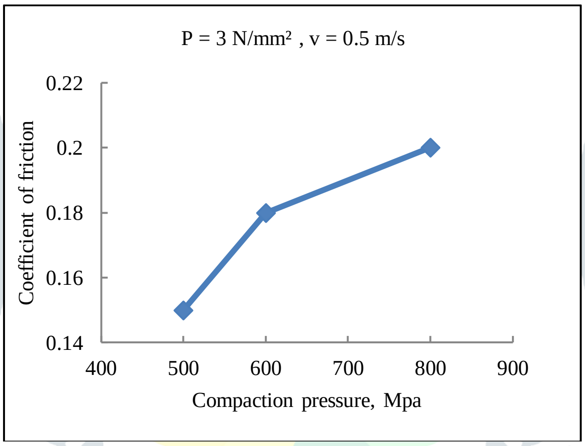

Figure 2. Effect of compaction pressure on coefficient of friction

As evident in figure 4, coefficient of friction increases with hardness and this is due to the fact that hard formation of Cu_2Fe creates high shear strength resulting more resistance in movement.

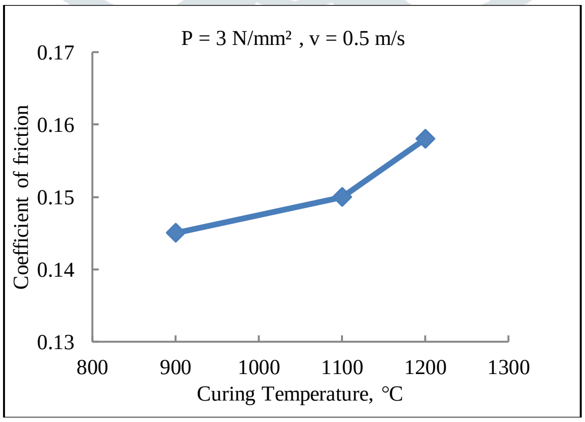

Figure 3. Effect of curing temperature on coefficient of friction

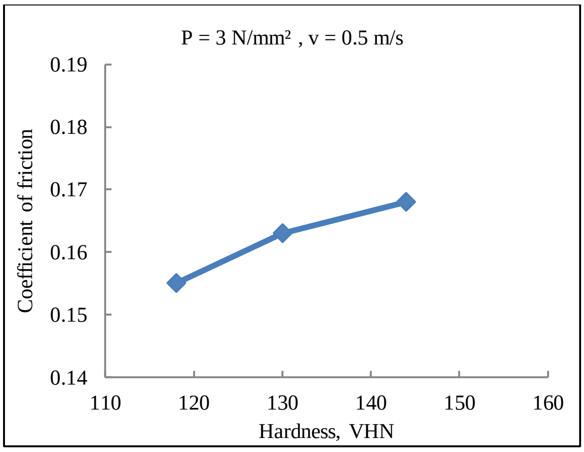

Figure 4. Effect of hardness on coefficient of friction

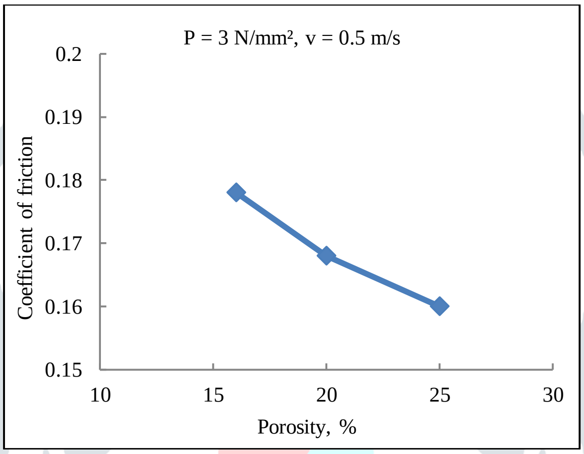

Figure 5. Effect of porosity on coefficient of friction

Figure 5 depicts that increase in porosity leads to less resistance in traversing due to lesser number of metal asperities under contact. Moreover, particles are susceptible to loosen out from the main bond and plastic deformation is rather easy. This phenomenon helps to reduce the friction.

The variation of coefficient of friction with sliding speed is shown in figure 6. It has been seen that with the increase in speed, coefficient of friction also increased. Increase in speed results in removal of oxidation surface layer and also powder particles peel off as a discrete material and act as some sort of hindrances in the movement showing abrasion of the surface.

Figure 7 depicts that as the load increases on bearing, coefficient of friction decreases. This is due to the fact that under load, bulk powder material gets sheared off creating a situation of plastic flow having less resistance. But at very high load, softening of particles tend to increase friction slightly leading to enhanced mechanism of adhesion, abrasion and oxidation thus creating a situation of stiction and agglomeration of particles by emitting coarse particle debris on surface (as evident in SEM analysis- fig 19(b)). Figure 8 represents the effect of running time on coefficient of friction. With time, coefficient of friction does not show much variation. Variation only can be attributed due to the compatibility of the system at the beginning. In general, time of running would not immediately make substantial changes in coefficient of friction until deterioration of surface takes place.

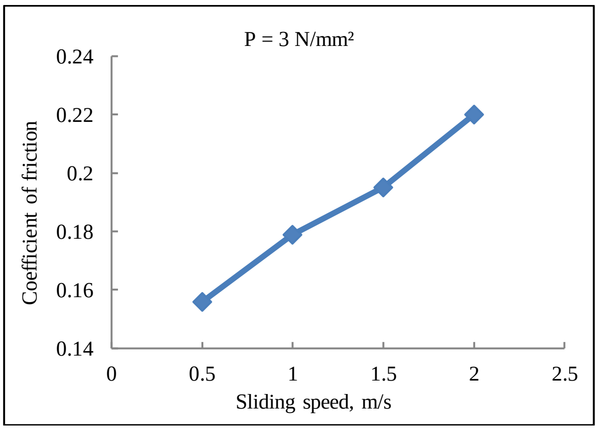

Figure 6. Effect of sliding speed on coefficient of friction

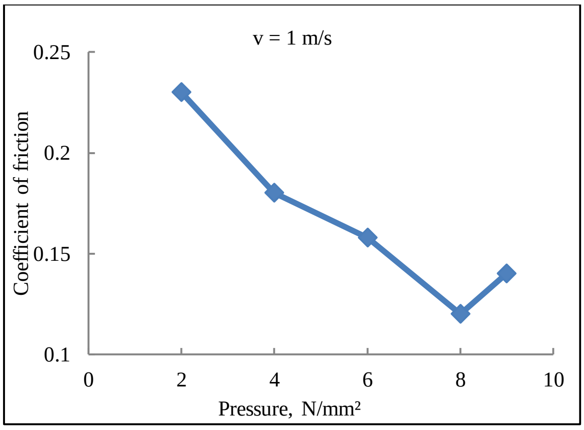

Figure 7. Effect of pressure on coefficient of friction

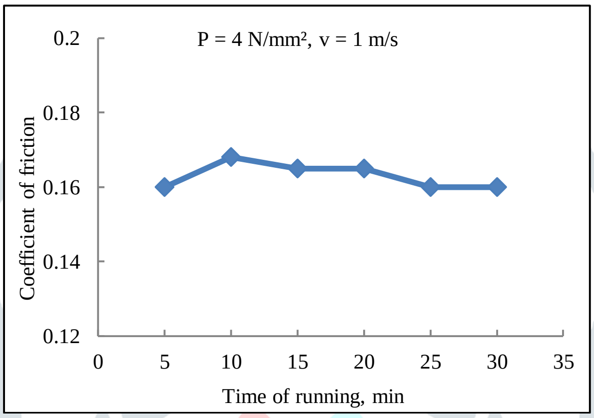

Figure 8. Effect of time on coefficient of friction

In case of bearing with solid lubricant, the author used MoS_2 and Zn stearate for imparting special properties for improvement in tribological condition as demanded. Inclusion of MoS_2 results in little lubricity due to presence of sulphur having lamellar structure and overall reduction of wear due to wear resistant property of Mo additive. Zn stearate provides effective bonding of powder even with increased porosity plus little lubricity effect. This additive is cheaper in cost and hence finds many industrial applications. From figure 9, it has been found that MoS_2 helps to reduce the coefficient of friction to some extent but more addition may not be helpful. Reason behind it lies with the fact that sulphur having lamellar structure influences the friction process and more sulphur may add to the stiction process and hence may not prove to be beneficial.

Addition of Zn stearate basically helps in keeping the bond strength good. More addition makes the material weak in strength but helps the binding of material to be strong so that loose particles could not come out easily making smooth movement of surface. It has been noticed that addition helps to reduce friction to some extent as seen in the case of MoS_2. Zn stearate is comparatively cheap and could be good substitute for MoS_2 but has lower strength and hardness. It has been noticed that addition of 2-3% of Zn stearate is good enough to reduce the coefficient of friction. It is anticipated that more addition of Zn stearate may not be significantly helpful for practical considerations.

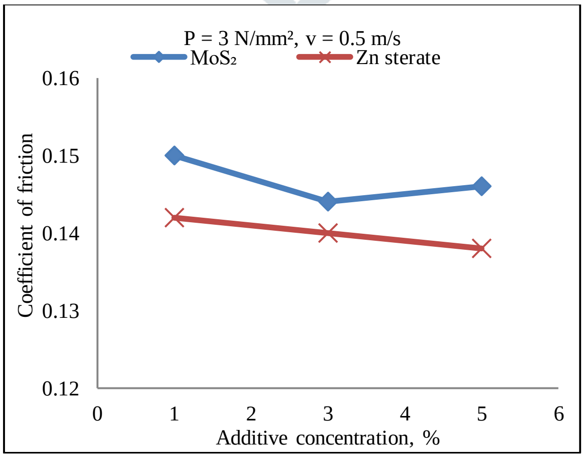

Figure 9. Effect of additives concentration on coefficient of friction

V DISCUSSION ON WEAR

Several graphs were plotted to see the effect variation of wear with manufacturing parameters for bearing (porosity 16%, hardness 144 VHN and curing temperature 1100°C, compaction pressure 600 N/mm^2) within experimental limits. Figure 10, depicts that as compaction pressure increases the wear decreases. This is due to the fact that compaction pressure imparts very close structure of powder material and behaves like solid material; this enhances wear resistant property. In figure 11, it has been observed that as curing temperature increases the wear decreases. This is because as sintering temperature increases the densification and fraction of Fe-Cu phase increases, their hardness increases leading to lower wear rate. Figure 12 depicts that as the hardness increases the wear decreases. This is due to the formation of Fe-Cu phase with a more stable and smooth layer which may have a strong bond in the particles and increases wear resistant property of the material.

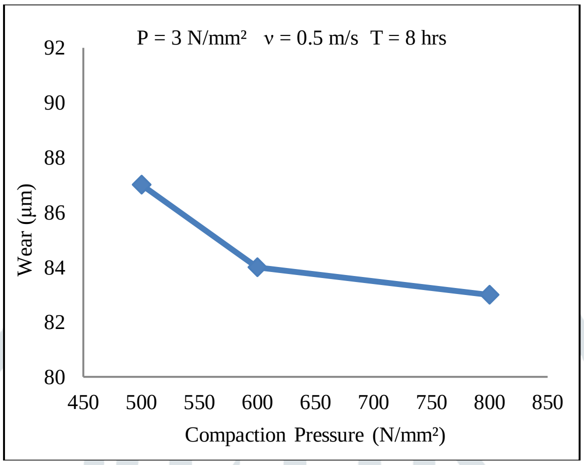

Figure 10. Effect of compaction pressure on wear

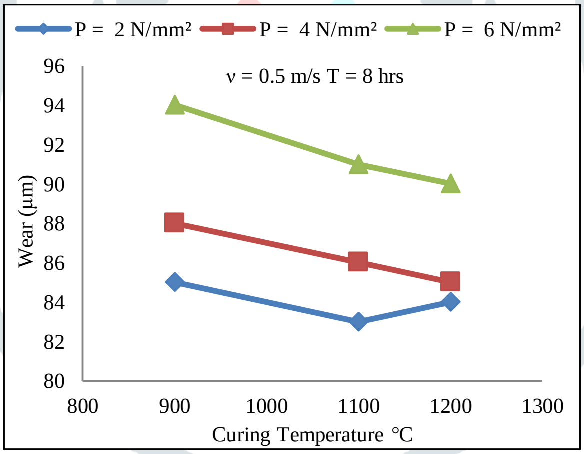

Figure 11. Effect of curing temperature on wear

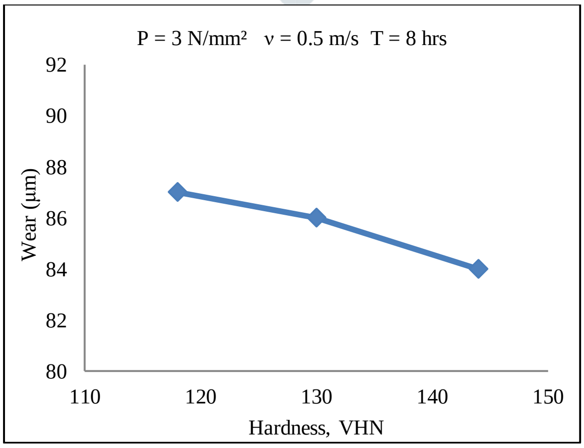

Figure 12. Effect of hardness on wear

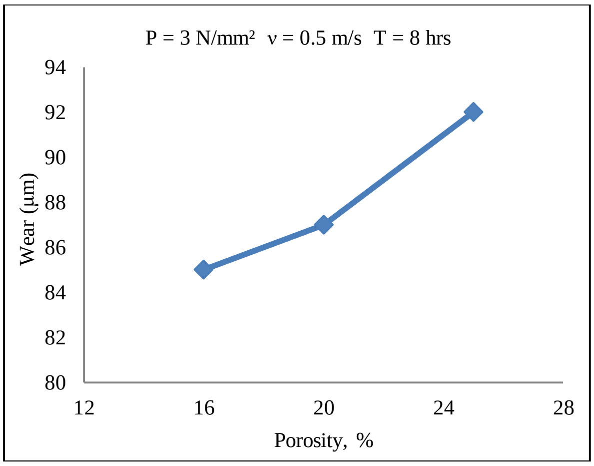

Figure 13. Effect of porosity on wear

In figure 13, wear increases as the porosity increases because wear debris particles get trapped inside the pores. At low porosity level, the possibility of particle agglomeration during sliding and formation of large abrasive agglomerates is diminished by plastic deformation. This explains why abrasion lines on specimen surface are more intense for low porosity levels. As porosity increases the pores are filled by metallic debris particles and oxide debris during sliding. The plastic deformation mechanism resulting in metallic particle detachment is expected to dominate and thereby decreasing wear resistance with increasing porosity.

From figure 14 (a) & (b), it is evident that as sliding distance increases, specific wear rate decreases. This is due to the fact that as distance increases, surface temperature and oxidation rate increase, resulting in reduction of metal to metal contact and material transfer rate. It has been observed that with increase in speed wear volume increases but specific wear rate decreases and shows a tendency to stabilize. Upto speed of 1 m/s, wear volume gradually increases and above 1.5 m/s there is a rapid increase in that value. It is because of the greater plasticity due to higher frictional heating and formation of mechanically mixed layer with the removal of oxidized surface layer. At higher velocities, the layer becomes unstable and fresh materials get peeled off and exposed to the counter surface leading more wear. From figure 15, it has been observed that as pressure increases wear also increases. This is due to the fact that oxide layer is formed at low load and thus the wear is less but as the pressure increases the temperature increases and detachment of film takes place which may cause metallic contact and thereby more wear. Upto pressure of 4 N/mm^2, there is gradual increase in wear due to surface softening and afterwards there is rapid increase due to detachment of surface layer and direct metal contact with mating specimen.

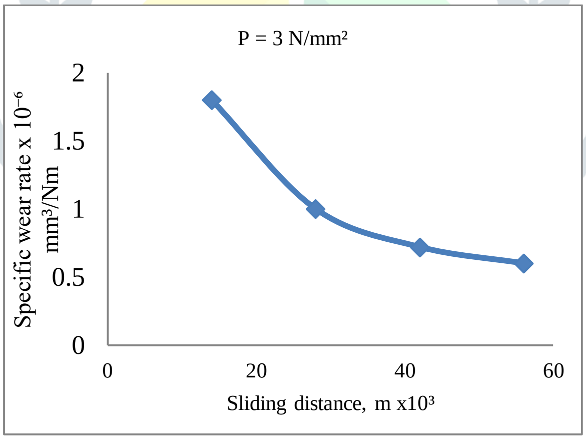

Figure 14 (a). Effect of sliding distance on sp. wear rate

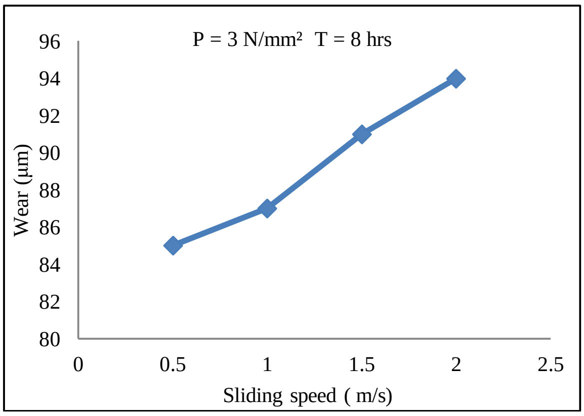

Figure 14 (b). Effect of sliding speed on wear volume

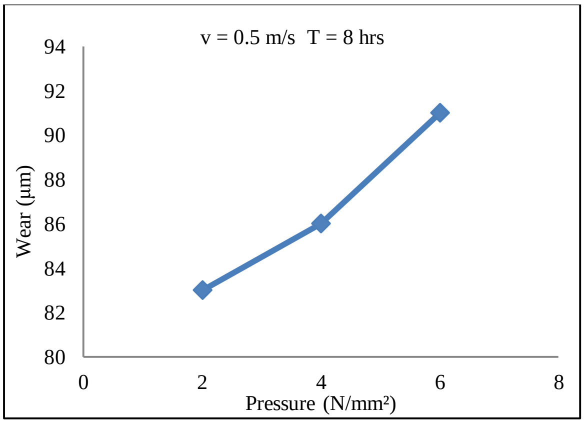

Figure 15. Effect of pressure on wear

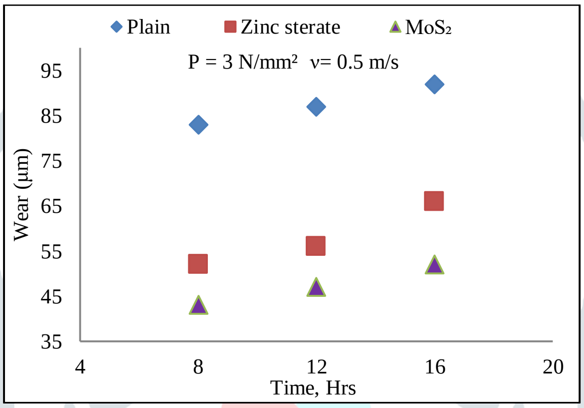

Figure 16. Effect of time on wear

Figure 16 represents comparison in wear with plain and solid lubricants added Fe based bearing. The graph depicts that wear is more for plain compared with reinforced bearings and MoS_2 added bearing shows much less wear even when compared with Zn stearate. Addition of MoS_2 increases the strength and toughness of the specimen and thus the material loss is observed to be less compared with the base material. Zn stearate also shows the same property but when compared with MoS_2 it shows more wear loss. From the graph it is evident that as time increases wear also increases for all specimen and this is due to temperature generation between the mating parts and detachment of mechanically mixed surface layer under prolonged contact. Figure 17 shows the graph between wear variations with additives concentration. It has been noticed that addition of solid lubricants to a certain percentage helps to reduce wear initially. But addition beyond approximately 3% , wear rate increases exhibiting a higher mass loss compared to 1%-3% MoS_2 and same with Zn stearate. The strength of 5% MoS_2 is comparatively lower than 1%-3% MoS_2 addition creating presence of brittle $CuMo_2S_3$ compound in the sintered composites. If the specimen carries too much MoS_2 (i.e. more than 3%), it may have low shear strength. However, severe spalling of the lubricating film may occur and self lubricating property drops remarkably. Similarly Zn stearate shows the same results. Addition of Zn stearate (more than 3%) mixed with base Cu alloy forms brittle compound which in turn lowers the strength resulting more wear loss. Figure 18 may act as a general comparison of specific wear rate values for materials with additives.

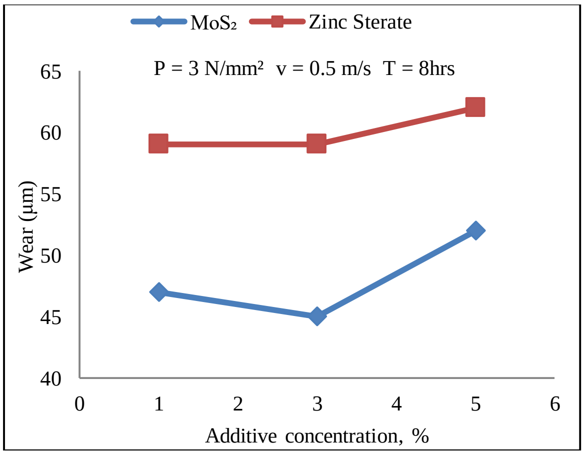

Figure 17. Effect of additives concentration on wear

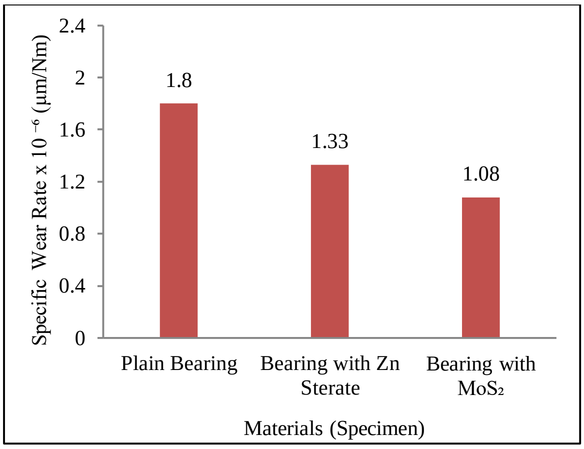

Figure 18. Comparison of specific wear rate for different material

VI SEM MICROGRAPH OF BEARINGS

Figure 19 (a-e) show morphological changes on the worn surface of plain bearing. Figure 19(a) shows severe abrasion where as figure 19(b) reflects production of wear flakes under abrasion, adhesion and oxidation due to high Pv value resulting in stiction and emission of coarse debris particles. Figure 19(c) represents good tribo-layer with addition of MoS_2 which helps in the reduction of coefficient of friction and wear. Figure 19(d) depicts formation of brittle structure of $CuMoS_3$ which leads to increase in specific wear rate at addition of MoS_2 more than 5%. Finally figure 19(e) shows the beneficial layer of added Zn-stearate reducing frictional value.

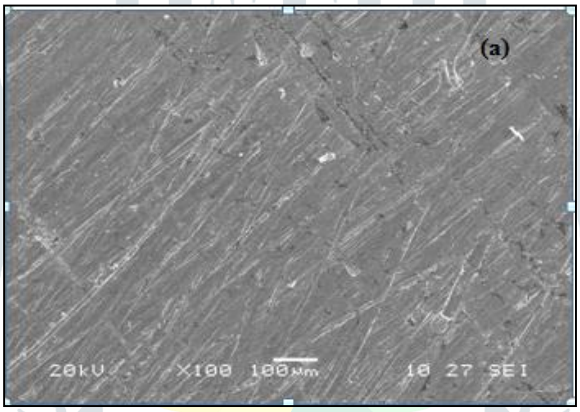

Figure 19(a). SEM of plain bearing

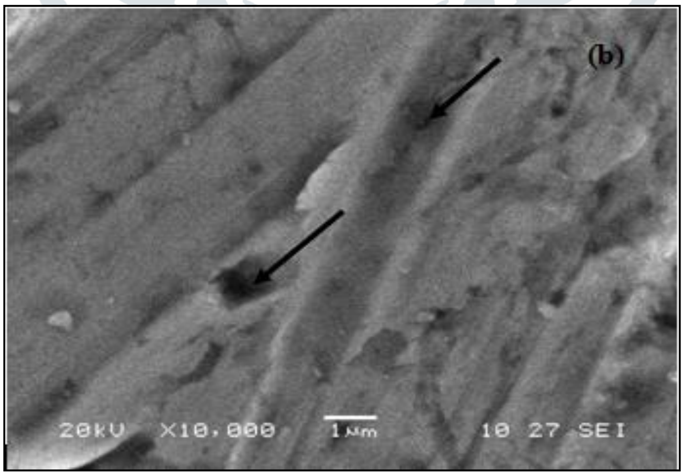

Figure 19(b). SEM at high Pv value (5.8N/mm². m/s)

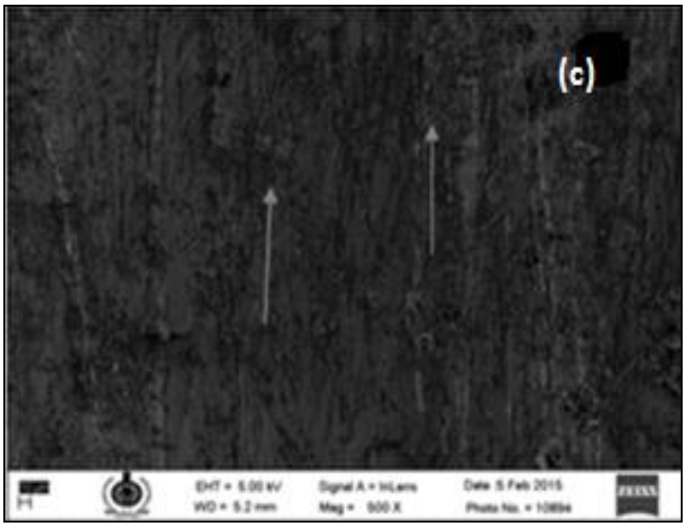

Figure 19(c). SEM of MoS_2 added bearing

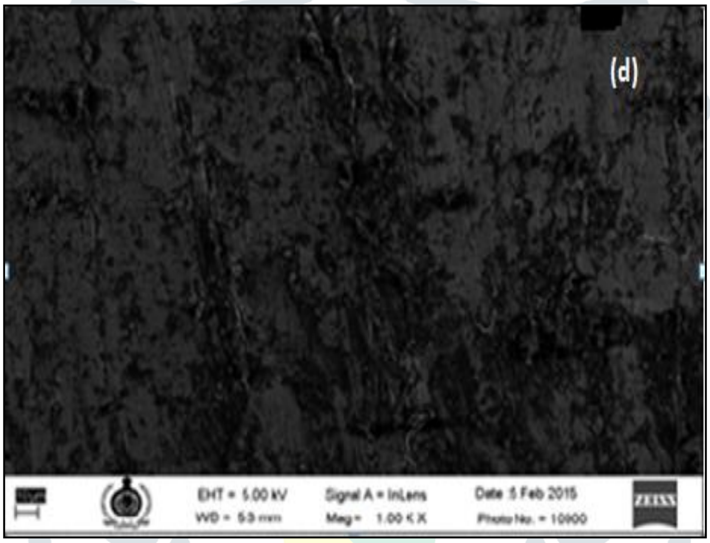

Figure 19(d). SEM at > 5% MoS_2 added bearing

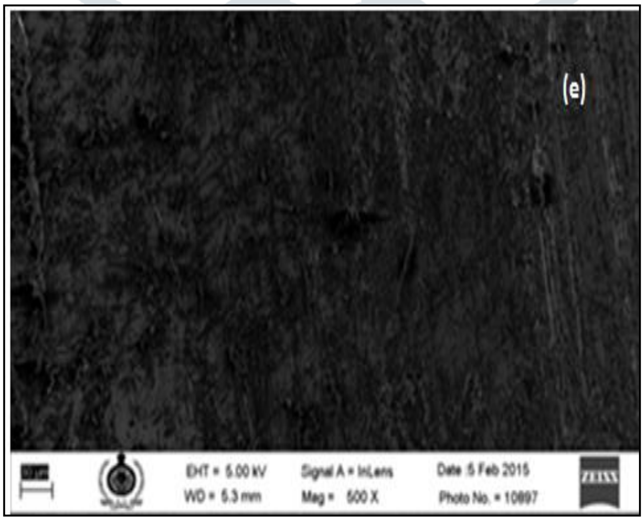

Figure 19(e). SEM of Zn stearate added bearing

VII CONCLUSION

From this study it can be concluded that:

1. Coefficient of friction increases with compaction pressure, curing temperature and hardness of the material under experimental condition. However increase in porosity leads to decrement in coefficient of friction. These manufacturing parameters are to be judiciously considered for limiting coefficient of friction.
2. Process parameters have got significant effect on coefficient of friction. Sliding speed and pressure have got opposing effect on coefficient of friction. Time of running does not vary coefficient of friction significantly until surface deterioration.
3. Manufacturing parameters affect wear process. High compaction pressure, curing temperature and hardness help to reduce wear. However porosity has got detrimental effect.
4. High sliding speed and pressure lead to rise in wear volume and specific wear rate gradually stabilizes with respect to time.
5. Comparison shows addition of solid lubricants to a certain level approximately 3% help to reduce friction and wear. Beyond that level they may not prove to be beneficial.
6. SEM micrographs depict mechanism of tribological process involved under different process parameters. At high Pv value stiction takes place. Addition of MoS_2 and Zn stearate to a certain level help in improvement of tribo properties of material.

VIII REFERENCES

[1]. Handbook of Friction Lubrication and Wear. 18; ASM International, USA, 1992.

[2]. JK Lancaster. Dry bearings: a survey of materials and factors affecting their performance. *Tribology 1973;* 219-245.

[3]. Amsallem C, Gaucher A and Guilhot G. Unlubricated frictional behaviour of sintered iron. *Wear* 1973; 23: 97-112.

[4]. Gopinath K, GVN Rayudu and RG Narayanmurthi. Friction and wear of sinter ed iron. *Wear* 1997; 42: 245-250.

[5]. Bekir S U. Investigation of tribological and mechanical properties of metal bearings. *Bulletin Material Science* 2009; 32: 451-457.

[6]. Suckchoon Kang. A study of friction and wear characteristics of copper and iron based sintered materials. *Wear* 1993; 162: 1123-1128.

[7]. Jun'an Wang and Herbert Danninger. Dry sliding wear behaviour of molybdenum alloyed sintered steels. *Wear* 1998; 222: 49-56.

[8]. Jianliang Li and Dangsheng Xiong. Tribological behavior of graphite-containing nickel-based composite as function of temperature, load and counter face. *Wear* 2009; 266: 360–367.

[9]. Gajjal P S, Lathkar G S, Bagchi H. Tribological relationship for sintered bearing using taguchi technique. *International journal of surface engineering and interdisciplinary materials science* 2015; 3(1): 48-57.

[10]. B.K. Prasad., (2004), "Sliding wear behaviour of bronzes under varying material composition, microstructure and test conditions", *Wear, Vol-257*, pp. 110-123.

[11] H. So.,(1996), "Characteristics of wear results tested by pin -on-disc at moderate to high speeds", *Tribology International, Vo1.29, No.5*, pp.415-423.

[12] Molesh, N.Saka, N.P.Suh., (2002), "A mechanism of high friction in dry sliding bearings*," Wear, Vol-252*, pp. 1-8.

[13] B.Sadik., (2009,) "Investigation of tribological and mechanical properties of metal bearings", *Bull. Material Sciences, Vol-32, No-4* August, pp 451-457.

[14] J.Paulo Davin,(2000), " An experimental study of the tribological behaviour of the brass/steel pair", *Journal of material processing technology, Vol- 100* pp. 273-277.

[15] Ranjit.K. Roy, (1996), "A *premier on the Taguchi Method"*, Van Nostrand Reinhold, New York.