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Tribological Behavior of Sintered Iron Based Ternary Alloy under Unduplicated and Lubricated Condition

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Abstract: - Lubricated and unlubricated sliding wear tests were carried on sintered iron based ternary alloys produced by powder metallurgy technique. The detailed experiments were carried out on Fe20Al20Al, Fe15Al15Cu and Fe (without alloying elements). Friction and wear behavior of solid lubricant at four different sliding speeds (1, 1.5m/sec) has been compared with unlubricated sliding condition. Sintered iron based ternary alloy Fe20Al20Cu under lubricated condition shown reduction in mass loss compared Fe15Al15Cu and Fe(without alloying elements) at all sliding speeds. Friction coefficient reduces with increase in sliding speeds for all the conditions. This could also be due to sliding resistance offered by lubricant coated samples with predominant asperities interaction. Sintered iron based ternary alloy Fe20Al20Cu under lubricated condition samples also generated lowest frictional temperature compared to other conditions

I. INTRODUCTION

Powder metallurgy plays a major role in the modern technology world. The Development of the Powder Metallurgy industries during the past years is largely attributable to the cost savings associated with net (or near-net) shape processing compared to other metal working methods, such as casting or forging. The conversion of cast or wrought component to powder metal provides a cost savings of 40% or more than that higher. PM typically uses more than 97% of the starting raw material in the finished part and is especially suited to high volume components production requirements. The advantages of using a powder metallurgy product are (a) Cost savings compared with substitute processes, and (b) Exclusive properties attainable only by the Powder Metallurgy [1-4]. Many iron based powder metallurgy components are used in automotive industry for its excellent properties such as good thermal conductivity, good machine ability, vibration damping capacity along with good mechanical strength and wear resistance. Iron based components contains ferritic- pearlitic or fully pearlitic matrix with graphite flakes randomly dispersed in the matrix. Therefore, it is suitable for components in sliding system, bearing surfaces. Additions of alloying elements or heat treatments will improve their properties much beyond the conventional iron based components. Alloying elements would tend to strengthen the matrix, refine the microstructure or introduce hard phases in the matrix to impart suitable properties required for specific applications. By taking various advantages of the intermetallic alloys into account a series of works on their application to tribology have been performed by the various research group [1–4]. It has been found that addition of Al to iron showed good wear properties and the wear resistance was significantly improved by the addition of high amount of C. Kim et al. [5,6] investigated room temperature dry sliding wear behavior of iron aluminides of various composition ratios. They reported that the wear rate of the aluminides increased with the increase in applied load and sliding speed and the wear resistance decreased with the increase in aluminum contents. Hawk et al. [7] and Maupin et al. [8] reported that the addition of Ti to Fe3Al was very effective in improving the anti-abrasive properties. They have also identified adhesive wear as the predominant mode of wear of the alloy steel. Adding Cu and Mo to plain carbon steel is reported [6] to reduce the deformation level due to the formation of fused Cu particles and Mo particulates, which enhances the hardness of the steel [12-16]. The improved hardness could result in reduced wear of the steel. It has been experimentally found [19] that the addition of Mo to plain carbon steel appreciably improves its hardness and tensile strength of alloy steel due to the possible formation of carbides and particulates of alloying element. Unlike hydrodynamic lubrication where the lubricant film completely separates the mating surface, boundary lubrication is characterized by the absence of lubricants at the contact where surface interaction leads to severe form of wear. The lubricant film thickness goes below the roughness peaks in boundary lubrication regime leading to dry sliding behavior. The main wear modes predominant during boundary regime are adhesive, abrasive, surface fatigue and chemical wear. The fragment that is generated from dry sliding also further aggravates the wear of parts. The presence of oil additives can possibly provide some reduction in friction and wear of sliding contact. Every grade of industrial lubricants normally comes with several additive components which would physically or chemically absorb on the surface to prevent aggressive wear condition in boundary lubrication regime. Solid lubricants in sufficient thickness can effectively work under extreme conditions of temperature, loads and speeds. Layered solid lubricants reduce friction by the mode of easy shear between their layers. They can be applied through buffing, sputter coating or as composite films on the sliding surfaces.

Molybdenum-di-Sulphide (MoS_2) is a good example of layered solids with friction coefficient less than 0.05 in dry condition [8]. Fullerene structures can withstand very high loads and speed [9]. But they also oxidize beyond 450◦C and become ineffective. Coated films are reported to greatly improve the scuffing resistance [10]. Relative humidity is known to affect the friction and wear behavior of MoS2 [11]. In the present research the tribological behavior of the iron based sintered alloy Fe20Al20Cu, Fe15Al15Cu and Fe (without alloying elements) are analyzed. Influence of Al, Cu as alloying element and MoS_2 as lubricant on wear and frictional properties is discussed and analyzed by conducting the sliding wear tests using pin-on-disk wear testing machine. A relationship has been established between friction and wear with load and sliding speed.

II. EXPERIMENTAL PROCEDURE

For the preparation of the iron based ternary alloy, electrolytic iron powder, electrolytic aluminum powder and electrolytic copper powder were used as the starting materials. The chemical characterization of the experimental powders are carried out in accordance with standards for analysis of melted and casting and alloys is as shown in Table 1.Also, the physical characteristics and the technological characteristics are shown Table 2. The morphology of raw powders was determined using Environmental Scanning Electron Microscopy, FEI XL-30 type (Philips)is shown in Figure 1.

Table 1: chemical analysis of Aluminium, Copper and Iron powder

Particle Size (□ m) (Approximately)	**Iron**	**Aluminium**	**Copper**
	100	**100**	**100**

Table 2: Physical and Technological Properties

Powder Type	**Physical and Technological Properties**			
	Apparent Density (g/cm^3)	**Tap Density (g/cm^3)**	**Flow Rate (s/50g)**	**Area Surface (m^2/cm^3)**
Fe	2.68	3.16	40	0.52
Al	1.29	1.374	13	0.12
Cu	2.35	2.84	38	0.41

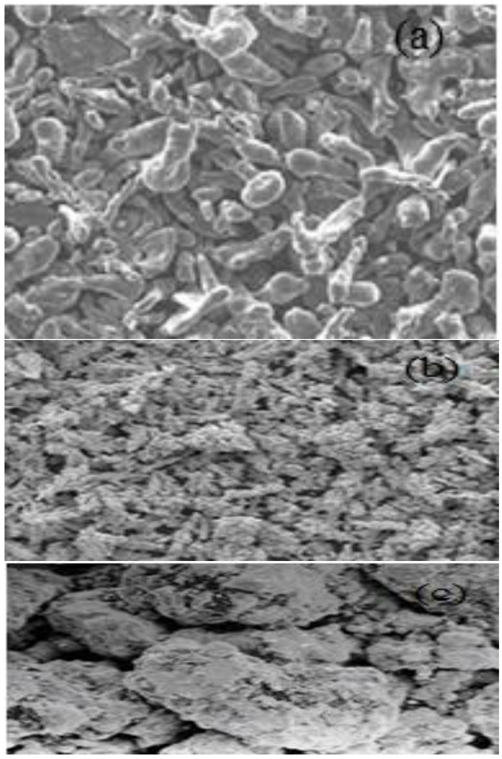

Fig 1: The morphology of elemental powders used as experimental powders :(a) Aluminium powder; (b) electrolytic Copper powder and (c) Iron Powder

Preparation of iron based ternary alloy specimens

The iron based ternary alloy test specimens was prepared by using electrolytic iron powder, electrolytic aluminum powder and electrolytic copper powder. Before manufacturing the test specimen's elementary powders were reduced in a furnace (Siemens-Plania type) in the presence of the hydrogen gas at 285^oC for 1 hour and the iron powder was heated for 410^oC holding for 2 hours to eliminate absorbed gases, moisture and any other contaminates. The mixing was carried out in the double cone blender of 5 kg capacity at a speed of 30rpm for 3 hours to produce a homogeneous mixture containing powders of the ternary alloy. The obtained mixtures were homogeny at the macroscopic level. The composition, characteristics is as shown in Table3.

Table3: Composition of the test specimens

Test specimen	**Aluminium Wt. %**	**Copper Wt. %**	**Iron Wt. %**
TS1	20	20	Balance
TS2	15	15	Balance
TS3	-	-	Balance

III. POWDER COMPACTION AND SINTERING

Ternary alloy which was obtained as powder was uni-axially compacted at 450 MPa to produce test specimen samples of diameter 6 mm and length 15

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mm. The green compacts were sintered at 850°C for 40 min in a gas mixture containing 85% nitrogen and 15% hydrogen. The density of the component was maintained at 6.8 g/cm^3. The sintered ternary alloy compacts were studied under an optical microscope for ensuring uniform distribution of Fe, Al and Cu particles. Commercially available solid lubricants (Molybdenum di Sulphate – MoS_2– used as lubricant) with average particle size of 0.65µm were procured. The surface of the disc was cleaned with acetone and the lubricants were burnished with a cloth on to the surface. The lubricant particles fill within the roughness valleys on the surface and simulate the layer that forms during oil starved condition. Wear test was performed at 10 kg normal load for a fixed sliding distances of 5000 m. Wear loss is a measurement of difference between initial and final weight after sliding for a specific fixed distance. Wear loss was measured for different sliding speeds. Two experiments were conducted at each of the sliding speeds and the average was recorded as wear loss.

IV. RESULTS AND DISCUSSION

The microstructures of iron based ternary alloy used for test sample of composition Fe20Al20Cuis as shown in figure 2. The microstructure consists of complete pearlite. The distinct white regions are hard carbide particles along the eutectic cell boundaries which also imparts wear resistance to the material.

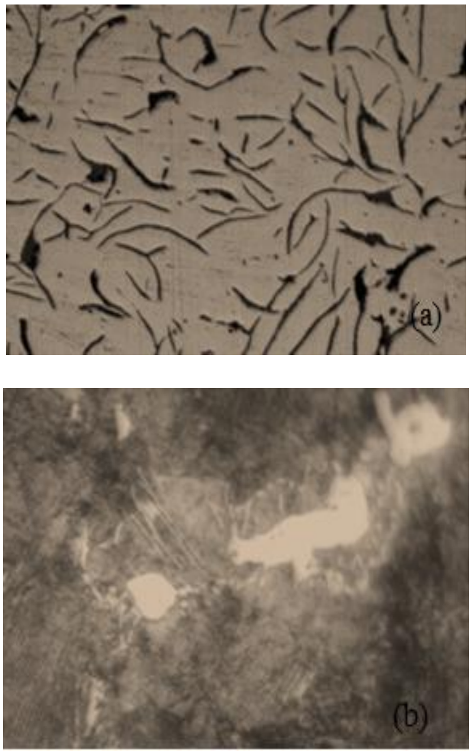

Fig 2: (a) Un-etched microstructure and (b) etched microstructure of sintered iron based alloy of composition Fe20Al20Cu

Mass loss at various sliding speeds for the lubricated and unlubricated condition is shown in figure 3. In general, the mass loss shows a slight decreasing trend for all the conditions except test specimen 3 under dry condition. Test specimen 1 and 2 have shown slightly reduced wear compared to test specimen 3 in both dry and lubricated condition. It is about 30 to 50% less than others with few exceptions. The two important selection parameters are purity and crystallite size. It is reported that the wear rate decreases with increase in crystallite size and increases with increase in impurity content. Synthetic grades show lower wear rate compared to natural grades.

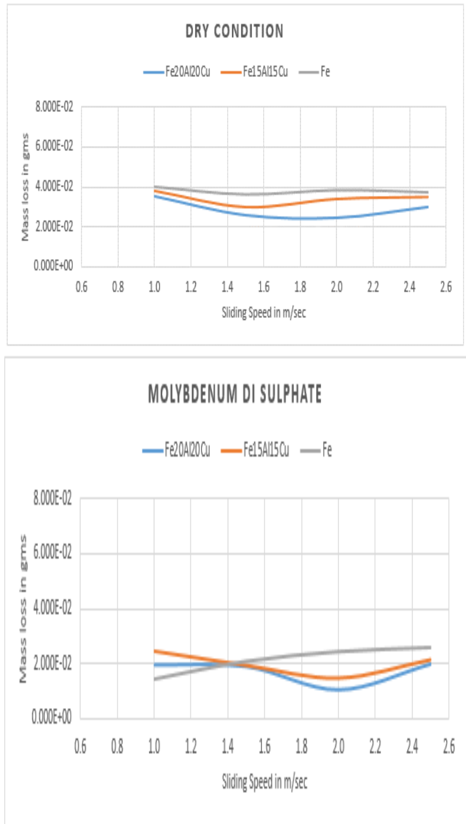

Fig 3: Mass loss at various sliding speeds for different lubricants.

Test specimens 1 and 2 under lubricated condition (MoS2) have also shown the reduction in wear rate. The effect is more pronounced at higher loads. It is reported that a composite coating on phosphated steel consisting of graphite (25%), zirconia (8%) and MoS_2 has significantly improved the wear resistance (72%) and decreased COF from 0.11 to 0.06[22-28]. The trend of friction coefficient with respect to sliding speed for different solid lubricants has been shown in figure 4. Generally, friction reduces with increase in sliding speed (from 0.4–0.55 to 0.25–0.35) possibly from temperature-induced softening and reorientation of lubricant layers parallel to substrate. The lubricant film containing lumps of particles may disintegrate from the influence of higher temperature and shear force and reorients itself along the sliding plane to reduce friction. Friction values are way higher compared to literature values because the lubricants are stored below the roughness peaks and solid surface interactions do take place under this condition. In the oil starved conditions, the solid additives within the oil come into operation and reduces friction and wear. But it is not as effective as solid low friction films coated through different process such as PVD or spray coatings. This work simulates the natural process of operation in the lubricated sliding parts of a typical machine.

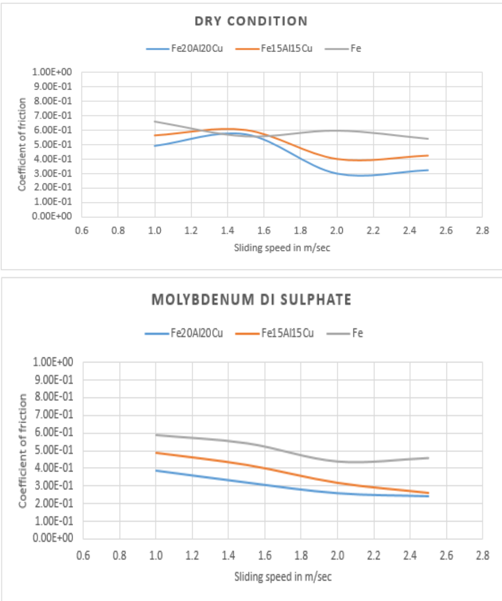

Fig 4: Friction coefficient at various sliding speeds for different lubricants.

The friction coefficient with respect to incremental loading steps for different lubricants is shown in figure 5. In general, frictional force remains steady within a specific range for a specific sliding speed. But it decreases with sliding speed as observed earlier (figure 4). The scatter is higher at lower loads (less than 30 N) possibly due to lubricant retained as coarse particles rather than re-oriented layers parallel to the sliding direction. However, there are few exceptions. The scatter slowly reduces due to reorientation of lubricants parallel to substrate as said earlier with incremental load steps. Higher loads possibly help break up the particulate like lubricants to finer parallel layers. Slight differences in friction coefficient values are observed even at higher loads indicating the effectiveness of lubricants possessing higher load carrying ability. Even here, it is observed that the friction coefficient values lie within a specific range for all the lubricants. Lowest sliding speed (1 m/sec) shows the highest value due to impediments from coarse particulate-like lubricant layer. The friction coefficient values gradually reduce with increase in sliding speeds from the lubricant particle disintegration and re-orientation as described earlier. A mild decreasing trend is observed in case of dry lubricated condition although by and large the values are within a specific range.

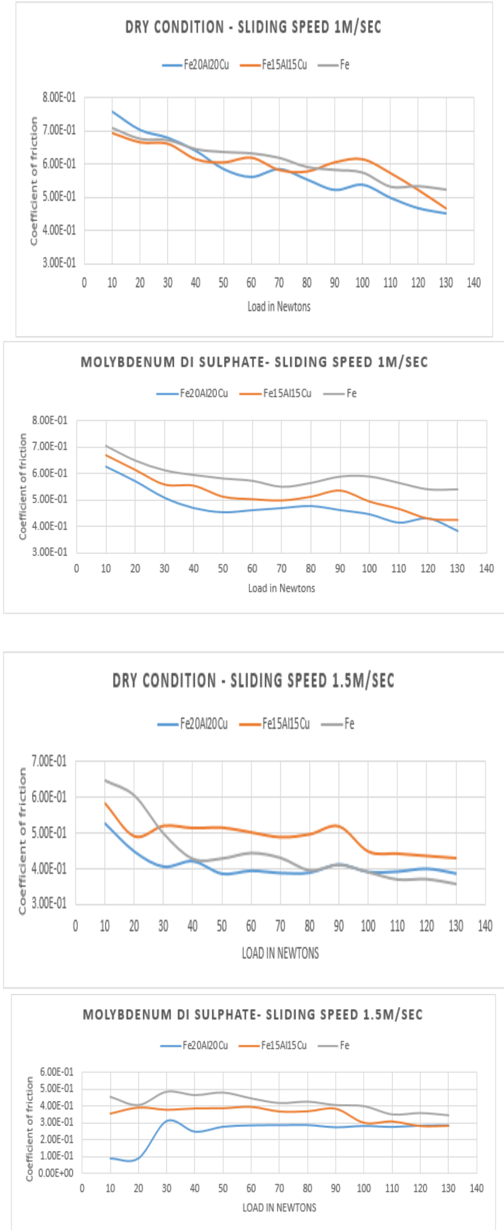

Fig 4. Variation of coefficient of friction at incremental load for various lubricants and sliding speeds.

V. CONCLUSION

The effect of sliding speeds on friction and wear behavior of lubricated has been compared with dry condition. Results indicate that test specimen with composition Fe20Al20Cu show 30 to 50% reduction in mass loss compared to other composition at all sliding speeds. The friction coefficient reduces with increase in sliding speed for all the condition possibly due to higher temperature and shear force causing reorientation of lubricant layers. Higher wear and friction coefficient values experienced by test specimen 1 possibly due to adherence of the iron particles. Test specimen 2 showed

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similar friction and wear trends as dry condition. Sliding interface temperature increases with increase in sliding speed.

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