SLIDING WEAR CHARACTERISTICS OF AL-SI-MG-FE ALLOYS

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ABSTRACT:

Sliding wear behaviour of Al alloys in T6 condition was tested using a pin-on-disc wear testing machine.In recent years Cast Al-alloys has been expanding widely in aeronautical, automobile and general industries. The tribological behaviour can be evaluated in terms of wear characteristics. The wear characteristics of these alloys depend upon the material morphology such as composition, size, shape and distribution of micro constituents and service conditions such as load, contact surface, contact time and sliding speed. In the present study, dry sliding wear characteristics of Al-Si-Mg-Fe alloy have been investigated. The influence of variables viz: contact time, sliding speed, and normal pressure on wear behaviour were studied. The wear loss increases with increase in normal pressure at constant contact time and at constant sliding speed. The wear loss increases with increasing contact time at constant normal pressure and at constant sliding speed. The wear loss decreases with increasing sliding speed at constant normal pressure and at constant contact time. Al-Si-Mg-Fe alloy exhibits abrasive, adhesive, slip, melt-wear and oxidative mechanisms.

*Keywords**:** : Sliding wear, tribology, Al-Si-Mg-Fe alloy, sliding speed, wear mechanisms*

1.INTRODUCTION

Aluminium alloys are attractive alternatives to ferrous materials for tribological applications due to their low density and high thermal conductivity.However, their uses hae been limited by their inferior strength, rigidity and wear resistance[1]. The wear of components made of Al-Si-Mg-Fe alloys depend on number of material related parameters, i.e. shape , size, composition and distribution of micro constituents in addition to the operating conditions such as load, sliding speed , temperature, environment and counter surface.Various researchers have been observed that increase in normal load increase the wear rate. The use of aluminium alloys in industry is increasing owing to their high strength/density ratios and other advantage properties. Applications requiring enhanced friction and wear performance include brake rotors, engine blocks and cylinder lines, connecting rods and pistons, gears, valves, pulleys, suspension components[2]. The effect of Al alloys composition on dry wear behavior against a ferrous counterface. In particular, the effect of alloy composition on work hardening behaviour has been investigated. The gratest wear resistance was exhibited by the A2124. This alloy showed the great initial hardness and the most surface hadening at all loads. The A6092 produced intermediate behaviour, with values of wear rates. As for the A5056, a lower specific wear rate at the highest load appeared to be associated with proportionality thinner surface damage accumulation. The A3004, being the softest alloy, exhibited the most aubstantial reduction in specific wear rate with load, being the highest at 23N of all alloys by some margin, but similar to the other materials at 140N[3]. The commercially important alloys contain copper as major addition and the phase reactions, which occur are thosebetween an aluminium solid solution and the intermetallic phases $CuAl2$ and $CuMgAl2$ [4,5].AA6061 Al alloy another commercial alloy has a few Cu. It was reported that it showed relatively smooth worn surface. The best wear resistance of 6061 Al alloy could be attributed to the highest hardeness and lowest coefficient of friction[6].

The most important reason for the damage and conquently failure of amchine parts is wear. Techically speaking according to DIN 50320 and ASTM G40-93 standards, wear is unwanted surface damage as a result of separation of small pieces from the material surface due to the interaction of other materials such as liquid, solid or gas.The mechanism of wear means the physical and chemical processes that occur during wear. The term of abrasive wear is the removal of pieces from one of the two rubbing bodies.The abrasive wear occurs in devicesmoving in touch with various abrasives[7]. A great deal of research on the two body abrasive wear behaviour of aluminum alloys, has been carried out experimentally. Recent studies have revealed that with hard particles dispersed in a relatively ductile matrix composites possess an ideal structure for wear resistant materials[8]. In wear mechanisms, some impartant factors are hardness, the shape and size of abrasive grit or roughness, attack angle, normal load, contact surface, contact time, sliding speed and the fracture toughness of material[9].

Use of solution treated Al-Si-Mg-Fe alloys as a tribological component in recent years, has been expanding widely in aeronautical, automobile and general industries. Depending upon the applications, these alloys may be sand cast, investment cast and die cast. The conventional melting and casting procedures for Al-Si-Mg-Fe alloys result in massive nonmetallic precipitates and consequent casting defects causing detoriation of strength and toughness.The tribological behaviour can be evaluated in terms of wear characteristics.

In the recent years, abrasive wear behaviours of aged aluminium alloys are investigated. Song et al. Investigated abrasive wear behaviour of aluminium alloys. They explained that mechanical propertiesdecreased because of ovaage at 200^0 C. Different wear test methods have been improved so that wear have

defined. Wear tests of aluminium alloys usually were carried out by pin-o disc method[10-12].In this study, evaluation of wear characteristics of Al-Si-Mg-Fe alloys that was aged at different temperatures on pin-on disc under dry sliding system.

MATERIAL AND EXPERIMENTAL STUDY

The Following raw materials were used to evaluate the wear and machining characteristics Al-Si-Mg-Fe alloy samples:

Al-Si alloy
Pure magnesium
Pure aluminum
Pure iron
Sand mould, investment shell, and cast iron mould (die)
Fluxing agent
Degasifier

The alloy was prepared and chemical analysis of their ingredients was done. The chemical composition of alloy is given in Table 1. The sand mould, investment shell, and cast iron mould were employed to prepare the samples for wear tests. The melts were degasified with tetrachlorethane tablets.

Alloy	Composition determined spectrographically, %						
Element	Al	Si	Mg	Fe	Cu	Mn	Cr
%	85.22	9.0	2.0	3.5	0.01	0.25	0.02

Table-1: Chemical composition of alloys

An Al-Si-Mg-Fe alloys were melted in an oil-fired furnace. The melting losses of aluminum and magnesium were taken into account while preparing the charge. During melting, the charge was fluxed with coveral-11 (a Foseco company product) to prevent dressing. The molten metal was then degasified by tetrachlorethane (in solid form) using a plunger ending in a small inverted crucible. The melt was also modified with sodium and refined with Al-Ti master alloy in the crucible before pouring. The crucibles were made of graphite. The dross removed melt was finally gravity poured into the preheated sand mould, investment shell, and metal die. The cavity shape is cylindrical in all the methods of casting. The pin specimens were prepared from Al-Si-Mg-Fe alloys. The dimensions of the specimens was 6 mm diameter and 20mm length.

A pin on disc type friction and wear monitor (ASTM G99) was used to evaluate the wear behaviour of Al-Si-Mg-Fe alloys against hardened ground steel (En32) disc having hardness of RC 62 and surface roughness (R_a) 0.6 µm(Fig.1). Load was applied on pin by dead weight through pulley string arrangement. Al the test samples were solution heat treated under T6 conditions. The mechanical behavior of the Al-Si-Mg-Fe alloy specimens was evaluated in terms of tensile strength, ductility (in terms of tensile elongation), and hardness. The microstructural examination of the test samples was carried out to reveal and study the grain structure, the interfaces, and the formation of intermetallics in the test samples. The sliding behavior of the specimens under the dry frictional conditions was evaluated (fig.1).

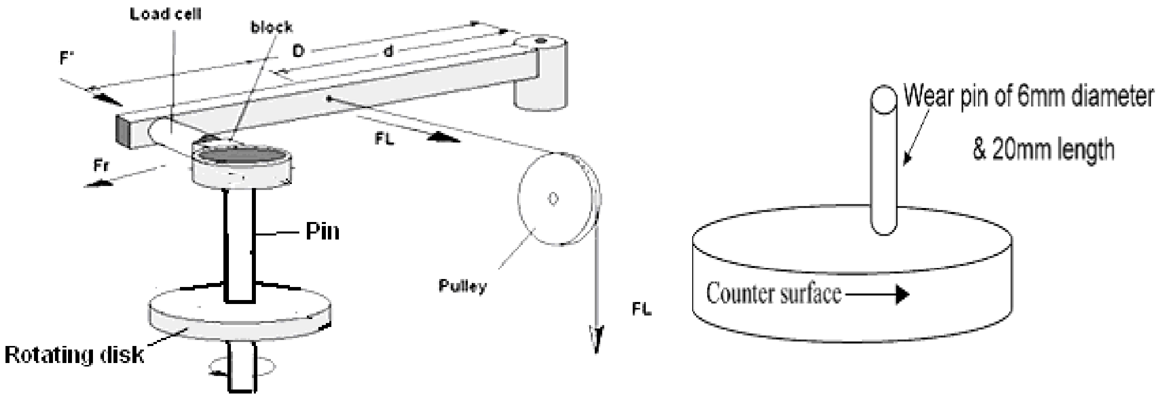


Fig.1. Schematic representation of the sliding wear experiment

Wear tests include the measurement of:

Weight loss using electronic weighing balance with accuracy up to 0.1 mg,

Temperature of pin using thermocouple, and

Friction force with data acquisition system

An investigation has been carried out to study the effects of sliding speed, contact time, normal pressure, and casting procedure of Al-Si-Mg-Fe alloys on the wear characteristics. The mechanical properties and metallurgical morphology were investigated to evaluate the wear behaviour of these alloys. Temperature measurements of wear pin during the sliding were carried out with chromel-alumel thermocouple.Thermocoulpes were placed into a hole of 2 mm diameter at 1.5 mm away from sliding surface. Tempertature was recorded with the help of digital temperature indicator. EDX analysis was also carried out to find the major elements present in the worn surface of the wear specimens. Each experiment was repeated twice and the average values of wear characteristics were plotted against the process variables.

3. RESULTS AND DISCUSSION

3.1 MECHANICAL PROPERTIES

The mechanical properties of Al-Si-Mg-Fe alloys are given in Table-2. The mechanical properties of die cast alloy are superior to investment cast and sand alloys. The reason could be the fine grain structure in the die cast alloys. The grain structure in the casting is influenced by the solidification process. The solidification time was short for the die castings whereas it was long for the sand casting and intermediate for the investment castings. The prolonged solidification retards the nucleation and promotes the growth of crystals. The grain refiner Al-Ti and sodium modifier together with fast solidification in the die cast specimens convert large elongated α-Al dendrites into fine α-Al equiaxed dendrites and plate-like silicon into fine particles resulting in the improved mechanical properties. The sand casting resulted with coarse grain structure in the castings due to slow solidification process. The castings produced by the investment casting have intermediate grain size having the lower limit of sand castings and the upper limit of die castings.

Mechanical properties	Sand cast	Investment cast	Die cast
Tensile strength, N/mm^2	199.52	213.64	234.11
% Elongation	9.1	9.8	10.2
Hardness (surface), BHN	71	75	87

Table-2: Mechanical Properties of Al-Si-Mg-Fe alloys

The solubility of Mn in aluminium is reduced by the presence of Fe and Si leading the formation of intermetallic compounds. Fig.2 shows the EDX analysis of the Al-Si-Mg-Fe alloy castings.The EDX analysis of worn surfaces of Al-Si-Mg-Fe alloy. EDX analysis showed that the worn surfaces contain Al, Si, Mg, Fe, O, and indicating the presence of Fe_2O_3, Al_2O_3, and MgO. This confirms that the wear mechanism also consists of oxidative phenomena.

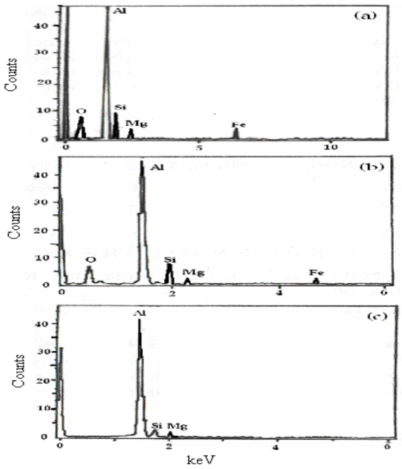
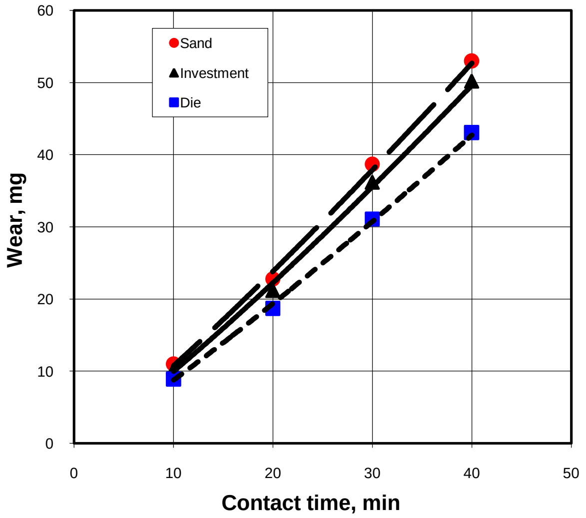


Fig.2: EDX analysis of Al-Si-Mg-Fe alloy worn surfaces (a) sand cast, (b) investment cast, and (c) die cast

Effect of Contact Time, Sliding Speed, And Normal Pressure on Wear

The influence of contact time is shown in figure 3. It can be seen that the specimens produced by the sand and investment casting methods, wear out faster than those produced by the die casting method. The wear resistance of specimens produced by the investment casting method is slightly better than those obtained by the sand casting method. It is also observed that a general trend of increase in wear is with increase in contact time. The major wear mechanisms are abrasive and adhesive in nature. The abrasion and adhesion are cumulative with prolonged contact time of wear specimen with the abrasive disc (for the purpose of wear test, the disc surface was abraded against 800 grade silicon carbide polishing paper and cleaned with acetone and dried before each test)

Fig.3. Influence of contact time on wear. The normal pressure and sliding speed are respectively, 0.75MPa and 2m/sec



The influence of sliding speed is illustrated in fig.4. It can be seen that the wear loss decreases with increase in the sliding speed in all the specimens. Initially, the seizure is dominant resulting high wear. As the sliding speed progresses the detachment of metal is

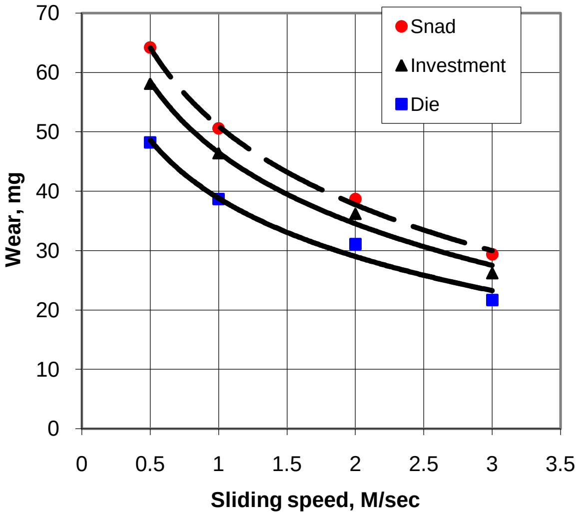


Fig.4 Influence of sliding speed on wear. The normal pressure and contact time are respectively, 0.75Mpa and 30min.

decelerated. At slow speeds the wear mechanism is abrasive in nature. The adhesive mechanism does not play significant role in the wear mechanism. As the sliding speed increases, the slip phenomena also appears. At high sliding speeds the slip phenomena dominates the abrasive mechanism consequently resulting low wear. The wear curves are parallel. The relative distance between the curves is on account of grain size, microstructural constituents, and mechanical properties. The die cast specimens have better wear resistance than the sand cast and investment specimens. In the die casting method, the solidification process was fat due to fast removal of heat from the metal die.

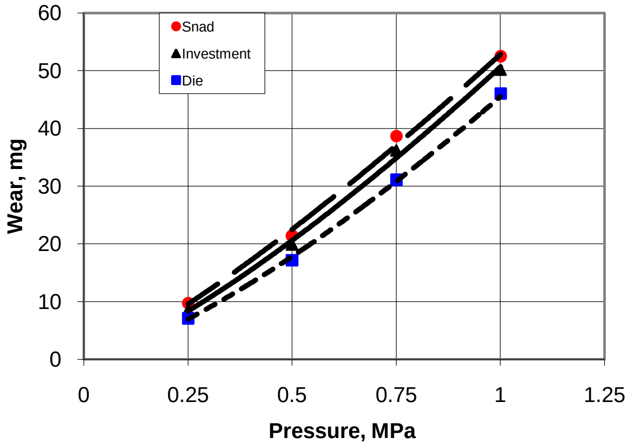
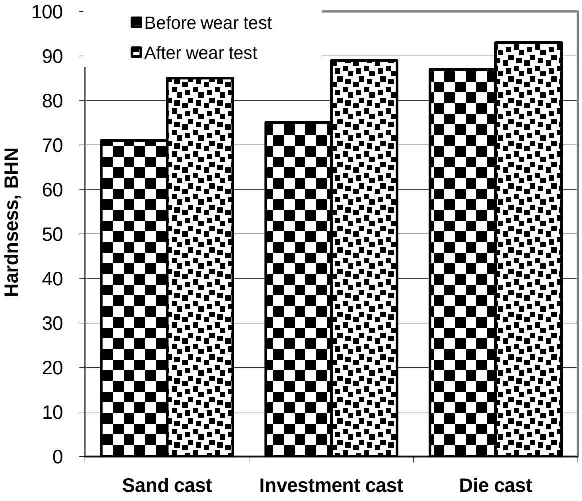


Fig.5 Influence of normal pressure on wear. The contact time and sliding speed are respectively, 30min and 2m/sec**.**

sand casting method, the solidification process was delayed because the heat removal from the sand mould takes long duration than the metal die used for die casting process. In the investment casting method, the investment shell was prepared from the slurry prepared from the colloidal silica binder and zirconia filler material and each layer of slurry was stuccoed with fine silica sand. The shell thickness was 15mm. The distance of heat travel from the center of the casting in the investing casting method was shorter than the in the sand casting method. Therefore, the resulting microstructure in the investment cast specimens is relatively finer than that in the sand cast specimens and is coarser than that in die cast specimens. The fine grain structure in the specimens results in better mechanical properties.

The intermetallic compounds are small in size and randomly distributed in the die cast specimens whereas the intermetallic compounds are large in size and clustered in the sand cast and investment cast specimens. The intermetallic compound is brittle in nature. The wear loss is countable for the amount of intermetallic compounds detached from the specimens during the test. The influence of normal pressure on the wear is shown in fig.4. At low normal pressure, the wear mechanism is abrasive and adhesive in nature. As the normal pressure increases the wear mechanism also includes melt wear because of the rise in temperature on the localized wear surface, resulting rapid metal loss from the specimens.

The worn specimens are not length enough for tensile testing to evaluate tensile strength and %elongation. Therefore, the worn specimens were tested for hardness only. The change in hardness of the worn specimens is shown in figure 6. It can be seen that the hardness values increase after wear test. The increase in hardness in the



worn specimens may be attributed to the work (strain) hardening and the frictional temperature.

Fig.6. **Hardness values of worn specimens.**

The microstructures of worn specimens are revealed in figure 7. The grains become finer owing to the work hardening. There is also diffusion across the grain boundaries due to the frictional temperatures and strain hardening. The frictional temperatures rise in the worn specimens on account of increased conversion of frictional energy into heat energy. The frictional temperatures and plastic deformations of the wearing surface result in the movement of dislocation in the wearing layers. The frictional temperatures also result in tempering which in turn soften the structure. The increase in hardness values of worn specimens indicates that the work hardening effect dominates the softening effect. The softening of structure in the wearing specimens aids in the diffusion across the grain boundaries.

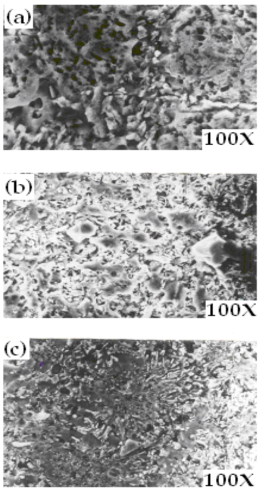


Fig. 7. TEM photomicrographs of worn surfaces (a) sand cast, (b) investment cast, and (c) die cast.

Figure 7 shows TEM photomicrographs of worn surfaces of Al-Si-Mg-Fe alloy exhibiting different wear morphologies. It is clearly seen that the wear particles are detached from the severely deformed material. Figure 7(a) and 7(b) show that the formation of abrasive grooves and particle detachment. Figure 7(c) shows the absence of large grains in die cast specimens.

4. CONCLUSIONS

The following conclusions can be drawn fron the test results:

1. The wear loss increases with increase in normal pressure at constant contact time and sliding speed.
2. The wear loss increases with increasing contact time at constant normal pressure and sliding speed.
3. The wear loss decreases with increasing sliding speed at constant normal pressure and contact time.
4. Al-Si-Mg-Fe alloy exhibits abrasive, adhesive, melt-wear and oxidative mechanisms.

REFERENCES

1. Odani.Y, Aluminium alloys. Metal Powder Report 49, pp.36-40, 1994.
2. Noguchi .M, and Fukizawa.K, Aluminium composite lines, cylinders, Advances in Materials and Processes, Vol. 143, No.6, pp.19-21, 1993.
3. Ghazali M.J, Wear characteristics of several commercial wrought Al-alloys against tool steel, Jurnal kejuruteraan, Vol.10, pp.49-56, 2006.
4. Kaçar H, Atik E and Meriç C, The effect of precipitation-hardening conditions on wear behaviours at 2024 aluminium wrought alloy, Journal of Materials Processing Technology, Vol. 142, pp.762–766, 2003.
5. Wouters P, Verlinden B, Mcqueen H.J, Aernoudt E, Delael L, and, Cauwenberg S, Effect of homogenisation and precipitation treatment on the hot workability of aluminium alloy AA2024, Material Science Engineering, Vol. A 23, pp. 239–245, 1990.
6. Song W.Q, P. Krauklis, A.P. Mouritz, S.Bandyopadhyay, The effect of thermal ageing on the abrasive wear behavior of age hardening 2014 Al/SiC and 6061 Al/SiC composites, Wear, Vol. 185, pp. 125–130, 1995.
7. William A.G, L.E. Fitzpatrick, Characterzation of tribological Materials, Butterworths, London, 1993.
8. Atik E, Mechanical properties and wear strength in aluminium alumina composites, Mater.Struct. 31 (1998) 418-422.
9. Odabas D, S.Su, A comparison of the reciprocating and continuous two-body abasive wear behaviour of solution-trated and age hardened 2014 Al alloy, Wear 208 (1997) 25-35.
10. Gore G.J, J.D. Gates, Effect of hardness on three very different forms of wear , Wear 203-204 (1997), 544-563.
11. Dwivedi D.K, T.S. Arjun, P.Thakur, H.Vaidya, K.Singh, Sliding wear and friction behaviour of Al-18% Si-0.5% Mg alloy, Journal of materials processing technology, 152 (204) 323-328.
12. Somi Reddy A, Pramila Bai B N, Murthy K S S, and Biswas S K, Wear, Vol. 171, pp.115-127, 1994.