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RESEARCH

A Comparative Study on Wear Properties of As Cast, Cast Aged and Forge Aged A356 Alloy with Addition of Grain Refiner and/or Modifier

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A B S T R A C T

In the present work, a comparative wear behavior study of three categories of materials viz, as cast, cast aged (casting followed by T6) and forge aged (forging followed by T6) has been investigated. Neither melt treatment nor solid state processing (like aging and forging) seems to be altering the wear behavior of the materials drastically. Cast aged A356 materials exhibit higher wear resistance compared to as cast and forge aged A356 materials. Further, it was observed that cast aged samples register lower coefficient of friction compared to other samples. It is also noted that the difference in wear behavior is revealed only at conditions of higher load, higher speed and longer sliding distance of testing. At lower regimes the difference is marginal. Among cast aged samples, ones treated with combined addition exhibit better wear resistance compared to other materials. Samples treated with combined addition register lowest coefficient of friction followed by samples treated with Sr, those with B, those with Ti and untreated ones. Abrasive wear mechanism is found to be operative in the regime of higher loading and higher velocity of sliding. Adhesive wear mechanism seems to be dominating the wear process at the lower regime of load and velocity of sliding.

1. INTRODUCTION AND BACKGROUND

Aluminium having an FCC crystal structure, with a relatively low density (2.7 g/cm^3) and low melting point (660 °C), is the second most plentiful metallic element on the earth. Aluminium-silicon alloys have received considerable attention for practical as well as fundamental reasons. Aluminium is one of the most important non-ferrous metals. Aluminium-based alloy are widely used in the automotive and aerospace industries of their low densities, attractive physical and mechanical properties [1-5]. Hypoeutectic Al-Si alloys have a large fraction of primary α-Al in their microstructure. The quality of the casting can be improved by grain refinement, which reduces the size of primary α-Al grains/dendritic structure in the casting. It provides number of technical and economic advantages, including improved feeding ability, reduced ingot cracking, better ingot homogeneity, uniform distribution of second phases and micro porosity, improved mechanical properties, machinability and excellent deep drawability of the products [6-8]. Tribological properties of A356 alloy mainly depend on the shape and size of the α-Al dendrites and the eutectic silicon morphology. The coarse silicon plates/needles of the unmodified acicular silicon structure act as internal stress raisers in the microstructure and provide easy paths for the fracture. From the literature survey it has been observed that, addition of grain refiners (Al-Ti and Al-B) to A356 alloy converts predominantly columnar dendritic structure into fine equiaxed dendritic structure and addition of modifier (Sr) changes plate like eutectic Si into fine particles, which leads to the improvements in tensile properties and wear behavior of the product. The wear behavior of Al-Si alloys depend on a number of material related mechanical properties (hardness, ductility and toughness) and microstructure (such as eutectic silicon morphology, dendrite arm spacing (DAS), grain size, composition, distribution of micro constituents) in addition to load, speed, temperature and counterface [9-13]. It is also confirmed from the literature review that, there is no much information available on the wear behavior of A356 alloy with the addition of grain refiner and modifier in both as cast and forged conditions.

For assessment of wear properties practically, the conditions at the sliding surfaces are very much complex and difficult to study. However, there is very little published information on wear mechanisms and the microstructural changes occurring during sliding wear of A356 alloy in as cast and forged conditions. The change in the microstructures and properties of a given material is reflected from the transition of one mechanism to another and due to the changes in normal pressure, sliding speed, sliding distance. The basic fundamental of wear involves the presence of small particles between the contacting surfaces. The ultimate break down of the surface in any material is probably due to the abrading particles first penetrating into the metal and then causing tearing of the surface [14].

2. EXPERIMENTAL DETAILS

2.1. Preparation of wear specimens

The wear specimens for tribological studies were prepared by melting A356 alloy with and without the addition of grain refiner and modifier in a resistance furnace by pouring the melt in to a square type graphite mould. The prepared wear samples from as cast, cast aged and forge aged coupons are rounded bars with a flat surface having dimensions of 32 mm length x 10 mm diameter (Fig. 1). After giving T6 treatment process (Table 1) the samples were tested by pin-on-disc type wear testing machine TR-201CL, DUCOM (Fig. 2).

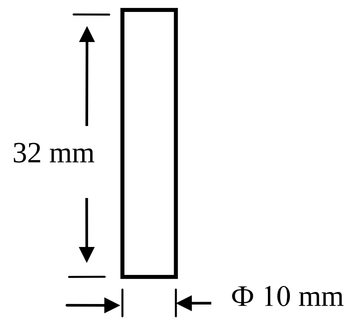
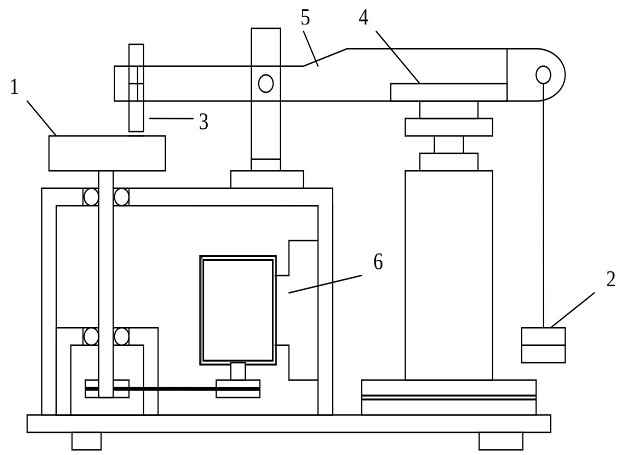


Fig. 1. Wear sample.



1. Disc
2. Load
3. Specimen (pin)
4. Friction force sensor
5. Load beam
6. Electric machine

Fig. 2. Schematic diagram of the wear and friction testing machine.

Table 1. Standard specification for T6 heat treatment process.

Process	Temperature	Time (hour)	Cooling condition
Solution treatment	535°C	8	Quenching in hot water about 75°C
Aging	160°C	4	Cooled in switched off furnace

Table 2. Parameters for wear study.

Composition of the alloys	Parameters	Variables	Constants
A356 alloy before and after the addition of master alloys (As cast, Cast aged and Forge aged conditions)	Normal pressure N/mm^2	0.13, 0.23, 0.38, 0.50 and 0.63	At constant sliding speed v = 1.88m/s and at constant sliding distance L = 3400 m of A356 Alloy
A356 alloy before and after the addition of master alloys (As cast, Cast aged and Forge aged conditions)	Sliding speed m/s	0.47, 0.94, 1.41, 1.88, 2.35 and 2.82	At constant normal pressure P = 0.63 N/mm^2 and at constant sliding distance L = 3400 m of A356 Alloy
A356 alloy before and after the addition of master alloys (As cast, Cast aged and Forge aged conditions)	Sliding distance m	850, 1700, 2540, 3400 and 4240	At constant normal pressure P = 0.63 N/mm^2 and at constant sliding speed v = 1.88m/s m of A356 Alloy

The machine is provided with friction and wear monitor to note down the wear and friction of the specimen. The device is provided with provision to conduct the wear test under different disc speeds, loads, track diameter and time. The machine is designed to apply loads upto 200 N, speeds upto 2000 rpm, track diameter upto 140 mm and ±2 mm. The sliding occurs between pin and rotating disc [14].

The surface roughness of the disc varies from 0.02 to 0.06 µm. A constant 90mm track diameter was used throughout the experimental work. The wear tests were carried out under varying normal pressures different sliding speeds and with different sliding distances. The weight loss measured in grams was continuously monitored and the frictional force generated on the specimen was measured in newtons by using a frictional force sensor. The worn surface studies were carried out on the prepared wear test specimens.

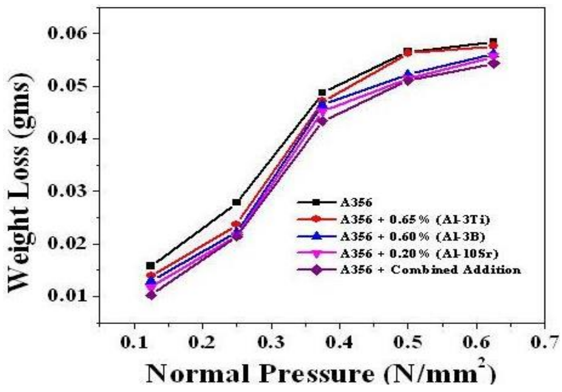
Three sets of experiments in all three conditions were conducted on each pin to study the friction and wear properties of the samples. The wear tests were carried out at room temperature. Table 2 shows the details of parameters studied in the present work.

3. RESULTS AND DISCUSSION

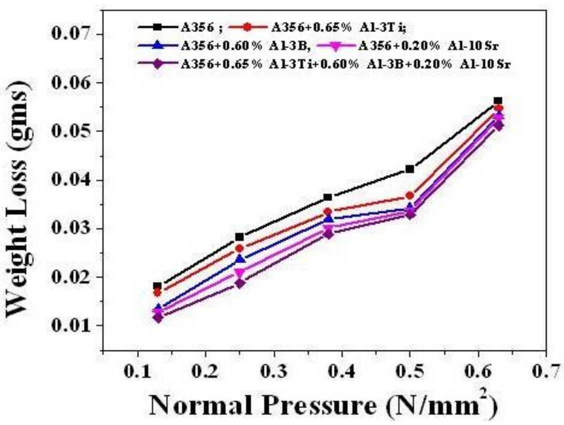
The wear behaviour of as cast, cast aged and forge aged A356 alloy without and with the addition of grain refiner and modifier under various normal pressures, sliding speeds and sliding distances have been studied. Wear properties viz weight loss, frictional force (force exerted by a surface as an object moves across it or makes an effort to move across it. There are at least two types of friction force - sliding and static friction) and coefficient of friction (ratio of the force of friction between two bodies and the force pressing them together) of as cast, cast aged and forge aged A356 materials are evaluated.

3.1. Effect of normal pressure

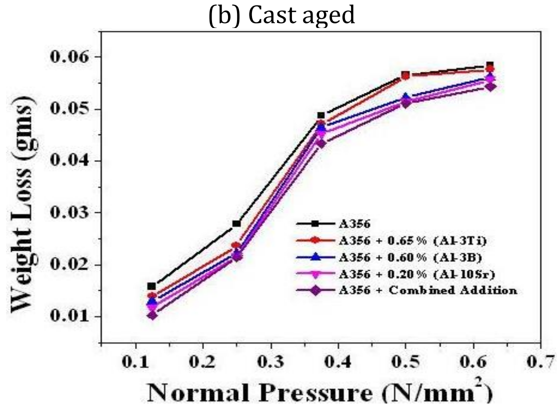
The effect of normal pressure and frictional force on weight loss of as cast, cast aged and forge aged A356 alloy under different normal pressures with constant sliding distance (3400 m) and at constant sliding speed (1.88 m/s) is shown in Figs. 3(a-c) and 4(a-c). From these figures it is clear that, weight loss of forged A356 alloy increases with increase in normal pressure in all the cases studied.



(a) As cast

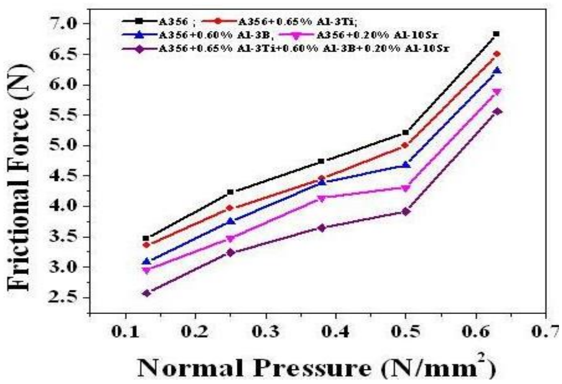


(b) Cast aged

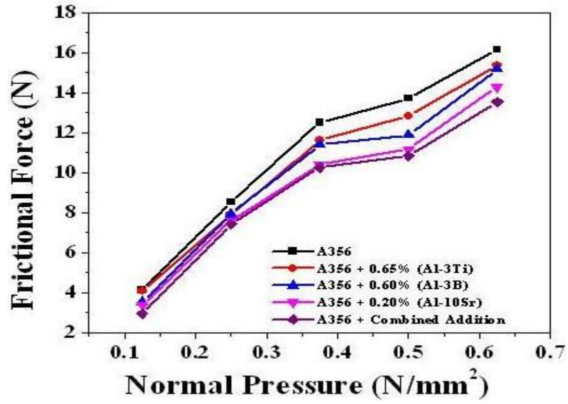


(c) Forge aged

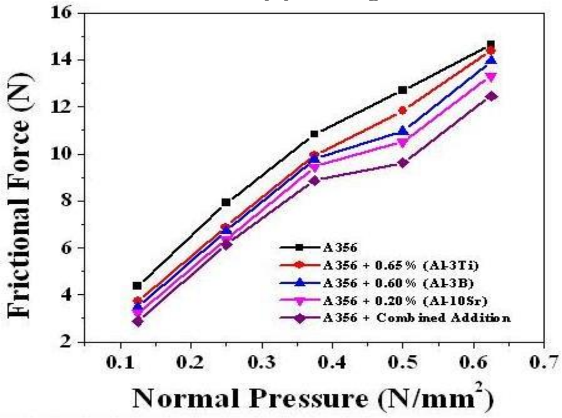
Fig. 3(a-c). Effect of normal pressure on the weight loss of A356 alloy.



(a) As cast



(b) Cast aged



(c) Forge aged

Fig. 4(a-c). Effect of normal pressure on the frictional force of A356 alloy.

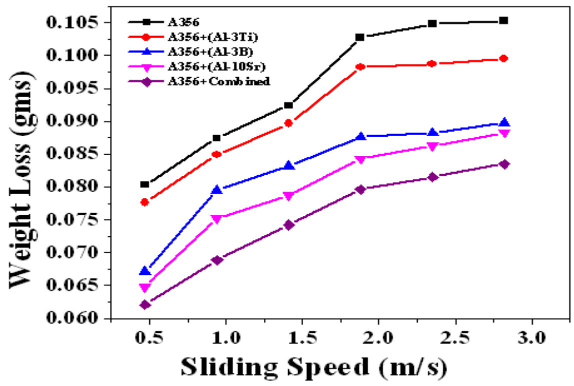
- Weight loss profiles with respect to normal pressure for all the three materials, i.e. as cast, cast aged and forge aged are qualitatively similar.
- Neither melt treatment nor solid state processing (like aging and forging) seems to be altering the wear behaviour of the materials drastically with respect to normal pressure.
- In all the cases, linearity in the curve is disrupted twice with sudden change in the slope which results in 3 regimes in the profile. These 3 regimes could be correlated to the three mechanisms operative under different pressure conditions. In the low pressure regime loss of metal could be attributed to abrasion wear which is caused by the hard silicon particles scuffed away from the matrix. At higher normal pressure, debris of silicon particles gets embedded into the soft Al matrix leading to a situation where adhesive wear becomes dominant. At intermediate levels of normal pressure a mixed mode of mechanism prevails.

- Almost a similar trend is seen by the profiles of the frictional forces with respect to normal pressure as clearly observed in Fig. 4(a-c).

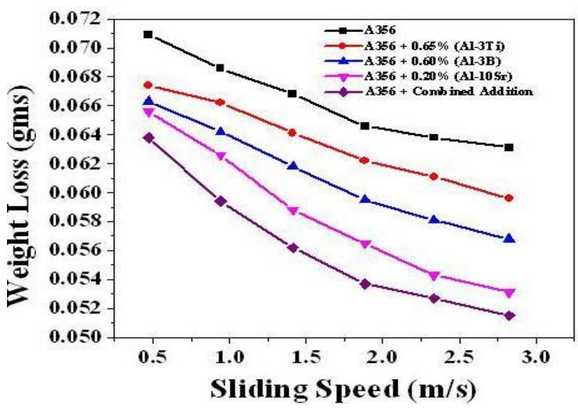
3.2. Effect of sliding speed

The effect of sliding speed of on the weight loss and frictional force of as cast, cast aged and forge aged A356 alloy under different sliding speeds, with constant normal pressures (0.63 N/mm^2) and at constant sliding distance (3400 m) is shown in Figs. 5(a-c) and 6(a-c). Following observations can be made on these profiles:

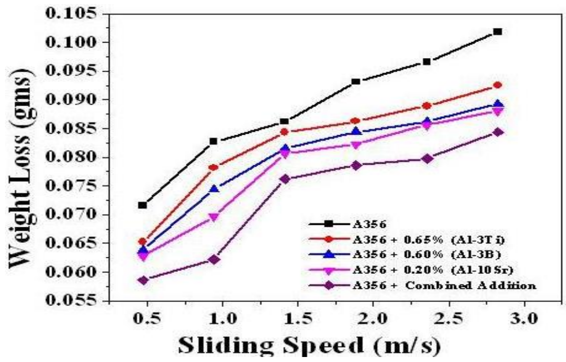
- Weight loss decreases with an increasing sliding speed for as cast materials whereas, it increases with increasing sliding speed for cast aged and forge aged materials.
- Frictional force is almost independent of sliding speed for as cast and forge aged materials.
- In the case of as cast and forge aged materials, the samples treated with modifier register considerably lower frictional force as compared to those without the addition of modifier. Grouping of these two categories of materials is obvious from Fig. 6a and 6c.



(a) As cast

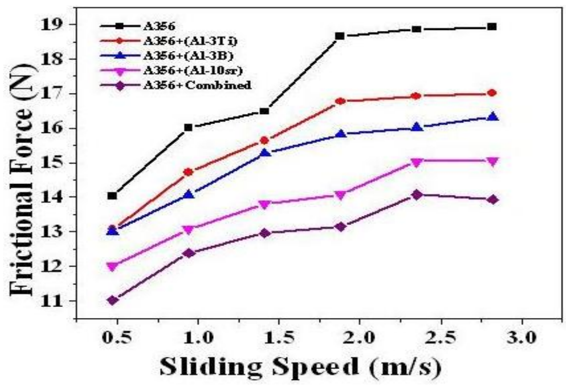


(b) Cast aged

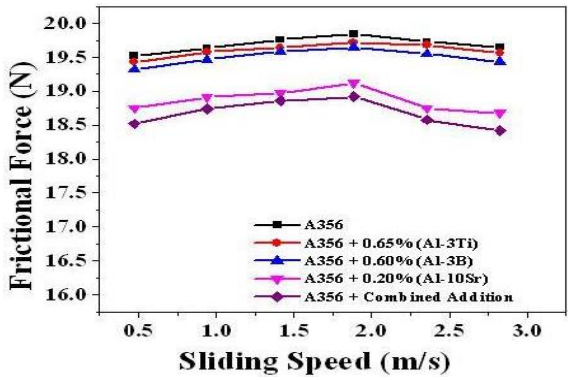


(c) Forge aged

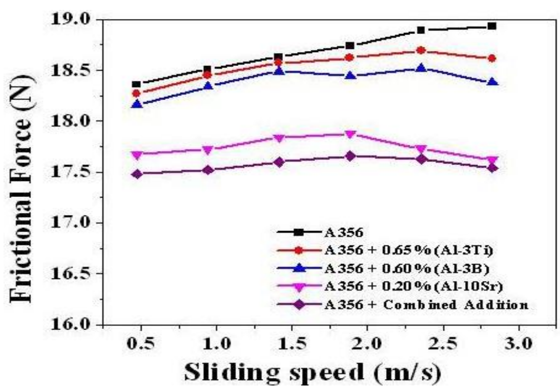
Fig. 5(a-c). Effect of sliding speed on the weight loss of A356 alloy.



(a) As cast



(b) Cast aged

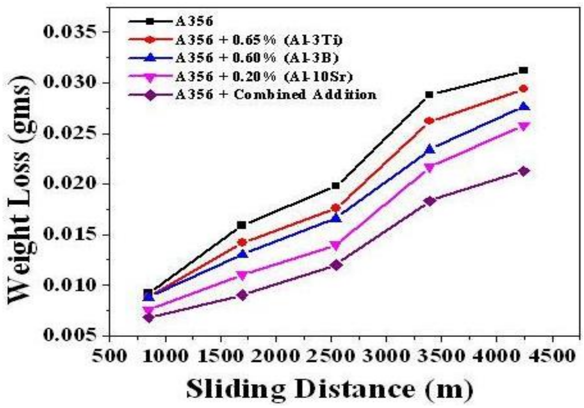


(c) Forge aged

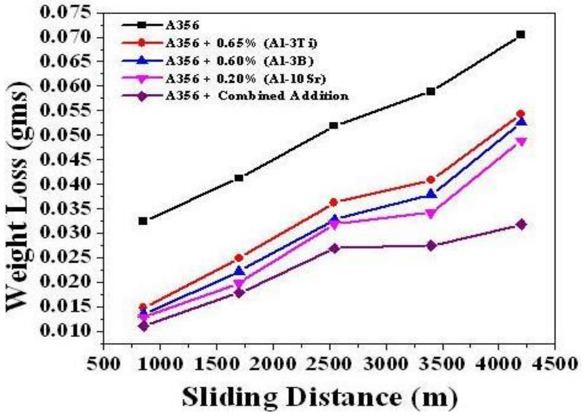
Fig. 6(a-c). Effect of sliding speed on the frictional force of A356 alloy.

3.3. Effect of sliding distance

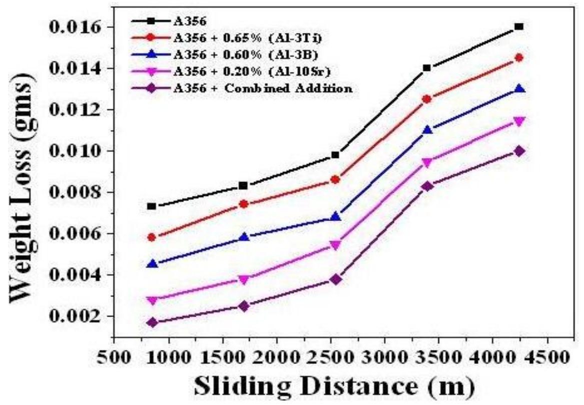
The effect of sliding distance on the weight loss and frictional force under different sliding distances with constant normal pressure (0.63 N/mm^2) and at constant sliding speed (1.88 m/s) is observed in Figs. 7(a-c) and 8(a-c). The following observations can be made on these profiles:



(a) As cast

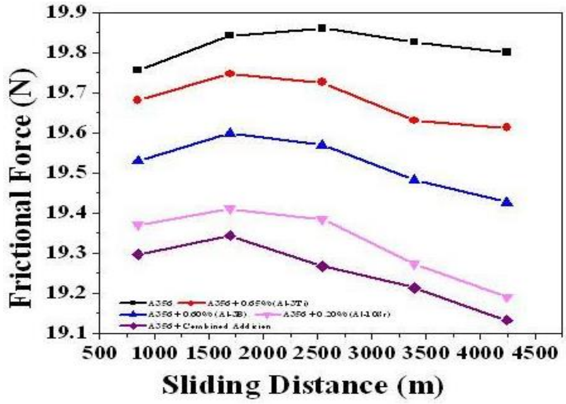


(b) Cast aged

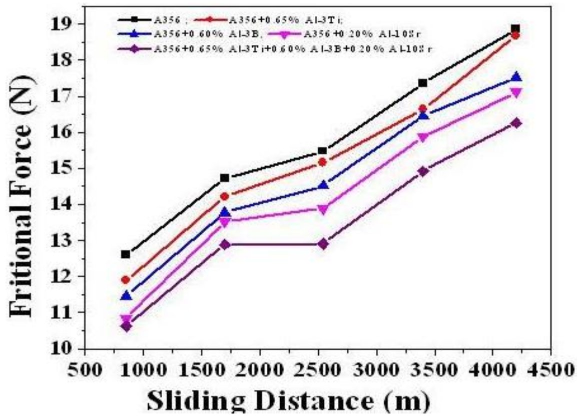


(c) Forge aged

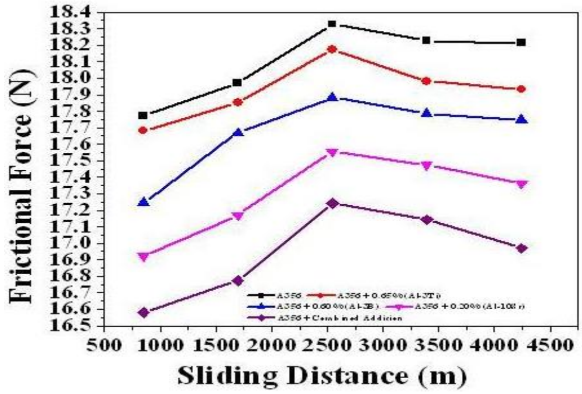
Fig. 7(a-c). Effect of sliding distance on the weight loss of A356 alloy.



(a) As cast



(b) Cast aged



(c) Forge aged

Fig. 8(a-c). Effect of sliding distance on the frictional force of A356 alloy.

- Weight loss increases with an increasing sliding distance. However, linearity in the profile is not observed and for as cast and forge aged materials frictional force increases to a maximum before decreasing with an increasing sliding distance. This maximum occurs at a sliding distance of 2000-2500 m. However, such a maxima is not noted for cast aged materials.

4. CONCLUSIONS

- Cast aged A356 material possess higher wear resistance as compared to as cast and forge aged materials. Further, cast aged material is associated with lower frictional forces and coefficient of friction
- Standard T6 aging treatment carried out on A356 casting causes change in the morphology of modified and unmodified Si. Unmodified needle like Si is fragmented into near spherical goblet whereas modified fine Si particles of submicron size are agglomerated to near spherical goblets
- Forging improves both strength and ductility of the materials over as cast ones. However, the improvement in ductility is perceptible only for properly grain refined and modified A356 materials. Ones refined with 0.65 % Al-3Ti shows highest improvement in ductility while the ones treated with 0.20 % Al-10Sr exhibits less improvement in ductility when forged and
- Abrasive wear mechanism is found to be operative in the regime of higher loading and higher velocity of sliding. Adhesive wear mechanism seems to be dominating the wear process at the lower regime of load and velocity of sliding.

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REFERENCES

[1] H. Torbian, J.P. Pathak and S.N. Tiwari, 'Wear characteristics of Al-Si alloys', *Wear*, vol. 172, no. 1, pp. 49-58, 1994.

[2] M.K. Surappa, 'Aluminium matrix composites: challenges and opportunities', *Sadhana*, vol. 28, no. 1&2, pp. 319-334, 2003.

[3] S.V. Prasad and R. Asthana, 'Aluminium metal-matrix composite for automotive applications: tribological considerations', *Tribology Letters*, vol. 17, no. 3, pp. 445-453, 2004.

[4] D.B. Miracle and W.H. Hunt, *Automotive applications of metal-matrix composites*, ASM Handbook, Volume 21: Composites, ASM International, Materials Park, 2001.

[5] A. Vencl, A. Rac and I. Bobic, 'Tribological behavior of Al-based MMCs and their application on automotive industry', Tribology in Industry, vol. 26, no. 3&4, pp. 31-38, 2004.

[6] T. Sagstad and N. Dahle, 'Grain refining of hypoeutectic aluminium-silicon alloys with TiBloy', in *Proceedings of the Fifth International AFS Conference on Molten Aluminium Processing*, American Foundry men's Society, Orlando, pp. 100-116, 1998.

[7] S.A. Kori, B.S. Murty and M. Charkraborty, 'Development of an efficient grain refiner for Al-7Si alloy', *Material Science and Engineering: A*, vol. 280, no. 1, pp. 58-61, 2000.

[8] S.A. Kori, *Studies on the grain refinement and modification of some hypoeutectic and eutectic Al-Si alloys*, Ph. D. Thesis, Indian Institute of Technology, Kharagpur, 2000.

[9] A.D. Sarkar, 'Wear of aluminium-silicon alloys', *Wear*, vol. 31, no. 2, pp. 331-343, 1975.

[10] A.D. Sarkar, *Wear of metals*, Pergaman Press, England, 1976.

[11] Clarke and A.D. Sarkar, 'Wear characteristics of as-cast binary aluminium-silicon alloys', *Wear*, vol. 54, no. 1, pp. 7-16, 1979.

[12] C. Subramanian, 'Some consideration towards the design of a wear resistant aluminium alloy', *Wear*, vol. 155, no. 1, pp. 193-205, 1992.

[13] D.K. Dwivedi, 'Wear behaviour of cast hypereutectic aluminium silicon alloys', *Materials and Design*, vol. 27, no. 7, pp. 610-616, 2006.

[14] D.G. Mallapur, *Studies on the influence of grain refining and modification on mechanical and tribological properties of cast, forged and heat treated A356 alloy*, Ph.D. thesis, NITK, Surathkal, 2011.