Experimental Study of Hardness and Sliding Wear Rate of Aluminum Alloy by Horizontal Centrifugal Casting

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***Abstract*— Aluminum alloys are in demand for several structural devices because of their high strength to weight ratio. The enhancements in properties are further observed when suitably alloyed with the different elements. Al-Si alloy find their application mostly in automobile engineering. Alloys of eutectic composition are used as piston alloys as Si exhibit good wear properties.**

This study was designed to investigate the effect of rotational speed on the wear rate and mechanical properties of aluminum-silicon eutectic alloy, keeping other factors such as melt treatments, physical and thermal properties of the mould, and alloy composition constant. After casting process, the samples were machined and prepared for hardness testing. Wear tests were conducted using a pin-on-disc type wear testing machine.

Keywords*— Design, Production, HCC, BHN, HRB, ASTM, Al. Si, Mg, Wear rate.

I-INTRODUCTION

This study is significant because of the vital position of Al-Si alloys in today's industry and manufacturing technology. Apart from light weight, the special advantages of aluminum alloys for castings are the relatively low melting temperatures, negligible solubility for all gases except hydrogen and the good surface finish that is usually achieved with final products.

Undoubtedly the most widely used alloys in this class are those containing between 9 and 13% silicon, with occasionally small amounts of copper. These alloys are of approximately eutectic composition, a fact that makes them eminently suitable as die-casting alloys, since their freezing range will be small. They are also used in the form of general purpose sand castings and die-castings and can be used in the "as-cast" condition, i.e. no heat-treatment is required. Important requirement for cylinder material is its coefficient of friction. Friction between the cylinder block surface and the piston rings has a major impact on the efficiency of an automobile's power train. Friction accounts for a loss of over 40% of the total vehicle power.[1] Over half of that power loss can be attributed to the frictional loss between piston rings and cylinder bores as shown in Figure below. Therefore in order for the alternative to be a viable option for replacing cast iron liners the more it can reduce the frictional loss between the cylinder liner and the piston ring.

II-DESIGN OF HCC APPARTUS

Generally for casting of cylinder liners, Centrifugal Casting Technique is recognized more advantageous.

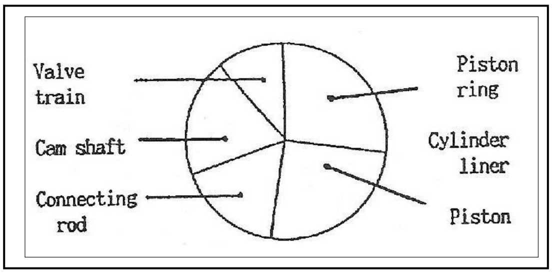

Fig. 1. *Breakdown of engine components due to friction loss*[1]

A) Assumptions & Input Parameters for design of HCCM:

- In this horizontal centrifugal casting machine set-up, diameter of motor pulley and diameter of shaft pulley is taken same.
- The speed of the driven pulley is speed of driver pulley say maximum 1000 rpm.
- The mould is made of cast-iron and having density (ρ) = 6800 kg/m^3.[4]
- d_o = outer diameter of mould = 160mm, d_i= inner diameter of mould = 100 mm, L = length of mould = 195 mm.

[1] "Replacing the Cast Iron Liners for Aluminum Engine Cylinder Blocks: A Comparative Assessment of Potential Candidates", by john lenny jr, Rensselaer Polytechnic Institute, April 2011.

- EN-8 material was chosen as shaft material of caster having yield strength 138 N/mm^2 and ultimate tensile strength 126 N/mm^2.

B) Output Parameters of design of HCCM:[5]

- The speed of the belt is determined to be 188.49 m/min.
- The length of the belt is determined to be 908 mm.
- The angular velocity of the driven pulley is found as 125.66 radians per second.
- The centrifugal force of the machine is determined to be 2500 N.
- The maximum Torque for the shaft is found to be as 13.52 N·mm.
- The maximum Bending Moment for the shaft is found to be as 34200 N·mm.
- The shaft diameter is determined to be as 40 mm.

C) Specifications of HCCM:

Fig. 2. *Horizontal Centrifugal Casting Experiment Appartus*

- *Mould:*

  Size : O.D =160 mm.
  : I.D = 100 mm.
  : Thickness = 30 mm.
  : Length =150 mm.
  Material : Cast-Iron.

- *Shaft:*

  Diameter = 40 mm
  Material for shaft : EN8

- *Motor drive:*

  1.5 KW, 1500 RPM, 3- phase AC supply.

The motor is used to rotate the mould at required speed of rotation. The speed of mould rotation can be controlled by using Variable Frequency Drive (VFD).

D) Specifications of Induction Melting Furnace:

Fig. 3. Indusction Melting Furnace

- Input volts :415 V
- Output Power :25 kW
- Frequency :10000 Hz

III- EXPERIMENTAL PROCEDURE

First of all, the inner diameter of the mould was pre-heated by oxy-acetylene flame with slow rotation of the mould. The mould temperature was maintained between 250 to 350 °C. The mould temperature can be critical for the coating adhesion to the mould, coating strength, as well as casting surface quality. Once the mould is heated sufficiently, zircon water based ceramic slurry is applied on the mould inside diameter by spraying. The mould wash thickness is usually between 0.5 and 3 mm (0.02 and 0.12 in.), depending on the application. The spraying method is preferred for most processes because it gives more uniform coating thickness, smoother coating finish and more consistent coating quality.

Al–Si alloys with 12.4 % Si contents were selected in this study. Materials were melted in an induction furnace at temperatures above their melting temperature and then poured into a cast iron mould. The permanent mould was preheated at 250° C for all castings. [3] The charge was melted at 700˚C in an induction furnace. Then melt was degassed with 1% hexachloroethane tablet. After fluxing and proper degassing, 1% Al-3Ti-1B wrapped in aluminum foil, was added to the molten alloy with stirring of the melt at pouring temperature. This was followed (after 10 minute of addition of grain refiner) by addition of 1% of strontium in the form of Al-10%Sr master alloy to the melt. After the holding for 10 minute, dross was removed and temperature is measured using "MICRO TEMP DETECTOR"(fig 5.5), subsequently molten alloy was poured in rotating mould of horizontal centrifugal casting machine. On horizontal centrifugal castings the mould was rotating around the central axis of the casting machine at different rpm and the molten Al-Si alloy was poured into the mould cavity by centrifugal force. The rotational speed of mould is varied by using VFD (Variable Frequency Drive). Summary of experimental details are mentioned below in table.

Table 1: Experiment readings

Casting Method	**Pouring Temp (°C)**	**Weight (gms)**	**Speed (RPM)**	**Furnace**	**Symbol**
HCC	715	1550	850	Pit furnace	A
HCC	785	1550	950	Induction furnace	B
HCC	714	1550	1050	Induction furnace	C

As shown above casting samples were extracted using this caster has following specifications

Fig. 4. Casting Samples

Casting weight was 1.62 kg, OD = 100 mm, ID = 80 mm & Thickness= 10 mm.

For wear test [6], Pin-on-disc test apparatus was used in experiment condition stated below:

Table 2: Wear Test Specifications

Comonent/Parameter	Specification
Disc	EN-31 steel, Dia. 140 mm
Sliding velocity	0.43 m/s
External Contact force	10 N
Duration	600 Sec.

The tests have been carried out under the following steps[7][8]:

1. Initially pin and disc material was cleaned with acetone.
2. Marking the radial sliding track to EN31 steel disc
3. Marking the six pin of aluminum-silicon alloy A-I, A-O, B-I, B-O and C-I, C-O as for radial wear track 40 mm respectively as shown in figure below.

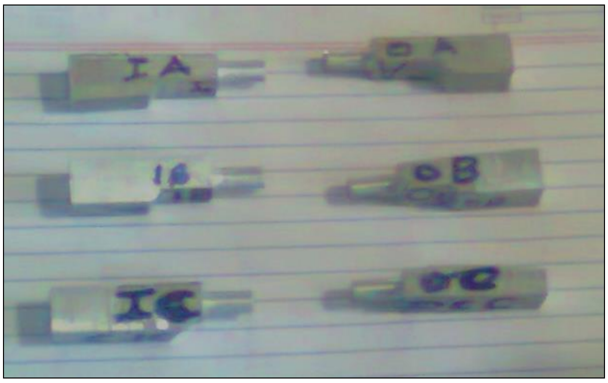

Fig. 5. Testing speciment for wear test

4. Pin and disc attached on the lathe machine.
5. Lathe tool dynamometer attached with the A.C supply and set zero reading.
6. Take a stop watch for experimentation time duration initially set zero reading.
7. Switched on the lathe machine.

IV- RESULTS & DISCUSSION

[A] Results of Hardness Test:

The hardness values of the sample were determined using the Rockwell hardness tester on "B" scale with 1/16" Steel ball indenter, minor load of 10 kg, and major load of 100 kg. The results obtained are shown in below table

Table 3 Hardness Test Results

Sample Code	Speed (in rpm)	Hardness(HRB)		
		Inner	Middle	Outer
A	850	35.33	31.89	30.67
B	950	33.55	31.22	26.78
C	1050	30.55	28	28

It is clear from above chart that the value of hardness is maximum for the sample which was extracted at the moderate

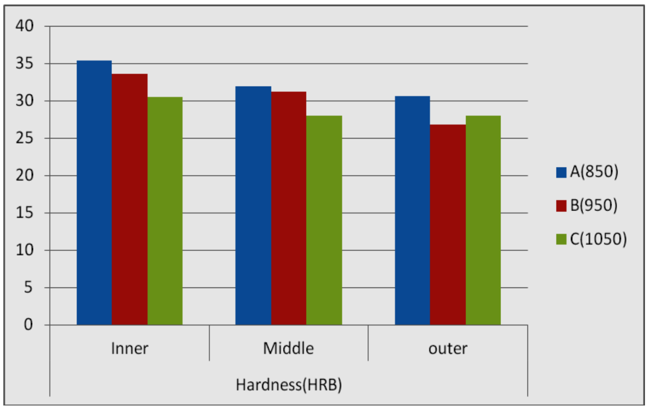

Fig. 6. Hardness test results

speed of 850 rpm in all sections. For each sample the hardness value is decreasing gradually form inner to outer section. In literature[9], it is stated that due to centrifugal force, primary silicon density is increased at inside diameter of cylinder so corresponding hardness value is high. From inner to outer, density of silicon decreases gradually so hardness value is also decreased.

[B] Results of Wear Test:

The sliding wear experiments were conducted with the influence of rotational speed (N), with constant radial contacting surface area or wear track (R) and time duration (T) with up to 1 kg load on Aluminium-Silicon alloys. On conducting the experiments, the dry sliding wear results for various combinations of parameters were obtained and shown in table shown below.

Table 4: Wear test results for Inner section of specimens

Sample	Initial weight(mg)	Final weight(mg)	Wear loss(mg)	Volumetric wear rate $mm^{3*}10^{-4}$ /(N.m)
A	11567.30	11565.27	2.03	2.99
B	12714.45	12707.38	7.07	10.42
C	14441.29	14430.66	8.27	12.63

Table 5: Wear test results for Outer section of specimens

Sample	Initial weight(mg)	Final weight(mg)	Wear loss(mg)	Volumetric wear rate $mm^{3*}10^{-4}$ /(N.m)
A	11252.43	11249.90	2.53	3.73
B	12318.18	12309.85	8.32	12.3
C	10556.81	10539.37	17.43	17.44

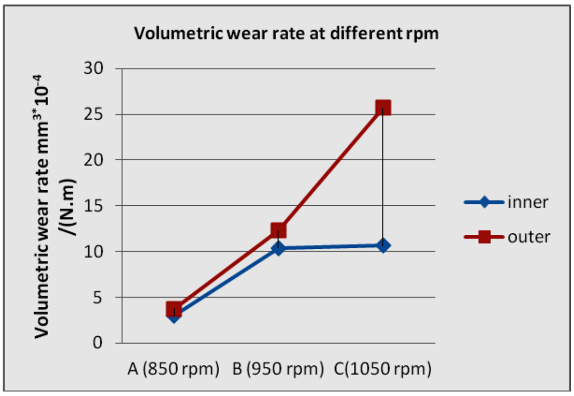

Fig. 7. Wear test results

V- CONCLUSION

Cylinder liners of Al-Si eutectic alloys have been prepared by horizontal centrifugal casting technique using the different mould rotational speed. The effects of different rotational speed on rate of solidification and thus on Hardness and wear have been studied. Moreover, for analytical data the wear rate of each sample have been taken. After analyzing the results, following conclusions can be drawn.

1. There exists an optimum speed of rotation of mould (850 rpm in our case) under given experimental conditions which result in higher hardness and wear resistance.
2. Rotational speed of the mould has been found to play an important role in the rate of cooling (solidification) of the casting. At moderate speed (850rpm), the flow of the metal will be turbulent hence cooling rate becomes faster[10]. This is due to the fact that as the rotational speed is increased; the centrifugal force is also increased, which create a strong convection in the liquid pool. At rotational speeds above the optimum speed, the cooling rate is slower due to negligible relative movement between the rotating cylinder and the hot liquid. Also the absence of chilling effect of mould is also responsible for slower solidification at outer surface. At higher speed stage, the fluid forms a uniform layer concentric to the mould profile. Presence of primary silicon in the casting produced at the speed above optimum speed (850rpm) shows the slower cooling rate due to absence of relative movement of molten metal and the rotating mould.
3. The influence of rotational speed on the wear behavior of the eutectic Al-Si alloy was investigated and in this set of experiment, the wear behavior is having linear relation with Hardness value.
4. Under given experimental conditions, the value of hardness goes on decreasing from inner to outer surface of the casting, with increase in rotational speed and corresponding value of wear-rate goes on decreasing.
5. Hardness can't be thought as the wear controlling property, it is the hardness of the contacting asperities and not the bulk hardness that will control the wear.

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