Analysis of wear properties of aluminium based journal bearing alloys with and without lubrication.

To cite this article: J Joy Mathavan and Amar Patnaik 2016 *IOP Conf. Ser.: Mater. Sci. Eng.* **149** 012052

IOP Conf. Series: Materials Science and Engineering **149** (2016) 012052 doi:10.1088/1757-899X/149/1/012052

Analysis of wear properties of aluminium based journal bearing alloys with and without lubrication.

J Joy Mathavan and Amar Patnaik

Mechanical Engineering Department, Malaviya National Institute of Technology, Jaipur, 302017, India

Email: joymathavan2013@gmail.com

Abstract Apart from classical bearing materials, Aluminium alloys are used as bearing materials these days because of their superior quality. In this analysis, new Aluminium based bearing materials, with filler metals Si, Ni, and Cr are prepared by metal mould casting in burnout furnace machine, and tribological properties of these alloys with and without lubrication were tested. The experiments for wear with lubrication are conducted on multiple specimen tester and experiments without lubrication is conducted on Pin on disk tribometer. The disc material used was SAE 1050 steel. Wear tests were conducted at a sliding speed of 0.785 m/s and at a normal load of 20 N. Coefficient of friction values, temperature changes and wear of the specimens were plotted on graph according to the above mentioned working conditions. Hardness and weight losses of the specimens were calculated. The obtained results demonstrate how the friction and wear properties of these samples have changed with the % addition of Silicon, Chromium and Nickel to the base metal aluminium.

1. Introduction

Wear resistance and fatigue strength of aluminium based bearing materials are higher than classical bearing materials and they can be used at elevated temperatures. The alloys based on aluminium have superior qualities like corrosion resistance, higher thermal conductivity, high fatigue strength, co-adaption with steel shafts, light in weight, low cost, and workability. But, beside from the advantages mentioned above, the engineering applications for some aluminium alloys are restricted because of their poor surface properties and low resistance to abrasion. However the required tribological and mechanical properties are developed by adding alloys and applying heat treatment.

The biggest consideration about bearing material is its wear resistance. Current developments in engine technology have seen the launch of advanced materials. So, aluminium-based alloys are introduced in bearing industry because of its high wear resistance. Aluminium based bearing materials are used in several applications like crank shaft bearings in automotive industry, internal combustion engines etc. Advancement in the efficiency of IC engines has caused growth in the consumption of aluminium alloys like Al–Si. The target of this analysis is to suggest new Aluminium based bearing materials that have higher grade qualities than classical bearing materials and to study the tribological properties of these alloys experimentally with and without lubrication. Accordingly, three different aluminium alloy based bearing materials were prepared, experimented and the results were analyzed.

2. Research background

Alloys made up of Aluminium–Silicon combination are considerably used in engineering implementations. They have fine mechanical and tribological behaviors like exceptional resistance for corrosion, higher thermal conductivity and high fatigue strength. Generally, the insertion of Silicon into aluminium advances the resistance to wear. The main reason to add Silicon particulates into aluminium is that they escalate the hardness. It was observed from the previous studies that wear resistance of Aluminium–Silicon alloys improves with the increase in Silicon content and their load carrying capacity also increases. The engines today, which are operating in elevated temperatures, need the utilization of materials which have high melting point instead of traditional bearing alloys like Al–Sn or Cu–Sn–Pb. This problem resolved by using Al–Pb alloys earlier. But in this study, the selected alloying materials are Chromium (melting point 1907^0C) and Nickel (melting point 1455^0C) with Silicon (melting point 1414^0C) which have higher melting points than Pb (melting point 328^0C).

3. Experimental procedure

In this study Al-Si, Al-Si-Cr, Al-Si-Ni bearing alloys were used as journal bearing material and the shaft used was SAE 1050. Table 1shows the chemical compositions of the bearing specimens used in the study. The sample castings were prepared by burnout furnace machine. As the melting point of aluminium is 660^0C, the machine was set up to 800^0C maximum limit. The percentage of Si was varied from 0 to 4% by weight of 2%, The percentage of Cr was varied from 0 to 4% by weight of 2% and the percentage of Ni was varied from 1% to 3% by weight of 1%. Si, Cr and Ni powder is introduced into the crucible which contains molten Aluminium and stirred well and placed again for some time in Burnout furnace machine for proper mix of materials. The alloy melt was stirred well and then poured into split-type moulds. The slag was removed before pouring it into the mould.

Hardness testing of the specimens was conducted in Wolpert hardness tester with 10 mm diameter indenture steel ball and 500N load because it is the standard for aluminium alloys.

Weights of the specimens were measured by a Precisa 125 A precision balance. It has a least count of 1 mg and a maximum of 450 g can be measured on it.

Table 1. Percentage addition of filler materials to base metal aluminium

Designation	Sample Name	Aluminium	Silicon	Chromium	Nickel
Al-1	Pure Al	100			
AlS-2	Al2Si	98	2		
AlS-3	Al4Si	96	4		
AlSC-4	Al2Si2Cr	96	2	2	
AlSC-5	Al2Si4Cr	94	2	4	
AlSN-6	Al2Si1Ni	97	2		1
AlSN-7	Al2Si2Ni	96	2		2
AlSN-8	Al2Si3Ni	95	2		3

The samples were given with a designation name and it is being used throughout the paper because the names given as sample names are not the standard names of the tested samples and it cannot be written in usual chemical symbols. It is given to show the addition of filler material with base material.

In this experiment the samples were tested in Pin on Disk Friction and Wear Test Rig without lubricant and in Multi specimen tester with lubricant. The samples were tested at 20 N load and 0.785 m/s sliding velocity. The experiments were carried out at 34^0C and in 60% RH humidity. The disc was cleaned well before the test to remove any worn out particles and other impurities on the surface. Before and after the experiments the specimens were cleaned and weighed using a balance of least count ± 0.001 g. The weight loss measurements were used to calculate the wear loss. The ratio of weight loss to density was used to compute the wear loss volume. Wear rate was obtained using wear volume, sliding distance and applied force. Usage of these parameters to calculate the wear loss is common and has already been used by some researchers like Rohatgi et al, S.C. Sharma, B.M. Girish, Rathnakar Kamath, and B.M. Satish [7]. The data for the wear analysis were obtained from the average of two tests. Before the measurement of weight, the worn out surfaces of the samples were cleaned to remove any possible wear debris and to remove the oil layer present on the surface in case of the test with lubrication. The wear behaviors of the rotating steel disc is not analyzed in this paper because the hardness of the rotating steel disc was much higher than that of the samples and its wear volume is negligible.

4. Description of the test device

4.1 Pin-on-disc wear and friction test rig

It is unique equipment established to analyze frictional behavior and sliding wear properties of materials. Here, the sliding occurs between a rotating disc and a stationary pin. The load applied to the pin can be up to 200 N. The wear track radius variation is from 10 to 65 mm. The disc speed can be vary from 200 to 2000 rpm. The sliding speed can be vary from 0.26 to 12m/s. LVDT (Linear Variable Displacement Transducer) and digital displacement monitor are used to measure the wear. Settings were made to fix the sample tightly and also to apply the required force on the sample. The test specimen was fastened by screws in the specimen holder and kept against the rotating steel disc. Load of 20 N and rotational speed of 150 rpm is used in the current experiment. In other words a linear speed of 0.785m/s is obtained by setting the distance of pin to 50 mm from the center. A standard experimental procedure was followed. Dimensions of the samples used in the experiment were 10*10*25mm. The duration of each test was 1275 seconds to achieve 1km sliding distance.

4.2 Multiple Specimen tester

Here the test was conducted according to the test procedure ASTM G-99. In this experiment the sliding occurs between a stationary specimen and a rotating steel disc. The variation of load can be from 5 to 100 N according to the test requirement. The diameter of wear track can be varied from 0 to 40 mm. The speed of disk can be set between 20 to 1400 rpm. The oil flow rate can be varied from 50 to 750ml/min. LVDT (Linear Variable Displacement Transducer) and digital displacement monitor occupied to measure the wear. Arrangements were made to hold the sample. The test specimen was fixed in the specimen holder by screws and kept against the rotating steel disc. Load of 20 N and rotational speed of 500 rpm is possessed in the current study. That is, at a distance of 15mm from the center ensures a linear speed of 0.785m/s. Dimensions of the samples used in the experiment were 9*9*13mm. The duration of each test was 2550 seconds to achieve 2km sliding distance.

5. Results and discussion

5.1. *Wear behaviors*

The graphs below show the wear loss, friction coefficient and bearing temperature variations with time. The graphs drawn separately because 8 samples neither be compared in Pin on disk tribometer nor be compared in Multi specimen tester. Maximum of only 4 samples can be compared in Pin on disk wear and test rig and 6 samples can be compared on Multi specimen tester.

The wear rate values of bearings are mentioned in table 2 and 3. Wear rate was estimated by Equation $Ws = V/FL$ where Ws is the wear rate, V is the lost volume, F is the applied load, and L is the sliding distance.

Table 2. Weight loss, Coefficient of friction, Mean temperature and Wear results of tests conducted without lubrication

Material	Weight loss (mg)	Coefficient of friction	Mean temperature (^0C)	Wear (mm^3/Nm) ($*10^{-4}$)
Al-1	16	0.32	38.4	2.962
AlS-2	13	0.32	38.9	2.414
AlS-3	11	0.31	39.1	2.048
AlSC-4	12	0.34	36	2.157
AlSC-5	11	0.31	36.8	1.916
AlSN-6	13	0.32	37.2	2.36
AlSN-7	10	0.32	37	1.775
AlSN-8	15	0.37	37.1	2.605

Table 3. Weight loss, Coefficient of friction, Mean temperature and Wear results of tests conducted with lubrication

Material	Weight loss (mg)	Coefficient of friction	Wear (mm^3/Nm) ($*10^{-5}$)
Al-1	4.5	0.136	4.166
AlS-2	4	0.135	3.724
AlS-3	4	0.133	3.714
AlSC-4	3	0.134	2.696
AlSC-5	1	0.132	0.871
AlSN-6	4.5	0.135	4.084
AlSN-7	2.5	0.133	2.21
AlSN-8	3	0.137	2.605

5.2 Graphs obtained in the tests without lubrication in Pin on Disk Wear Test Rig

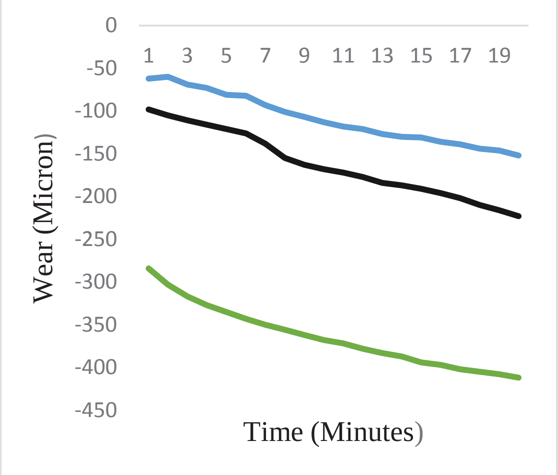

Figure 1. Comparison of wear rate of Al-1 (Blue), AlS-2 (Black) and AlS-3 (Green).

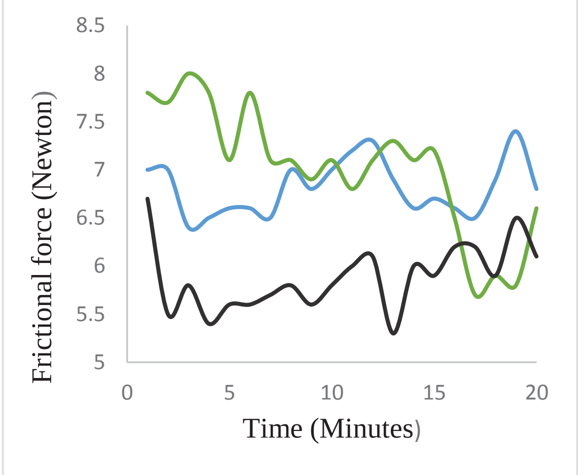

Figure 2. Comparison of rate of change of Frictional force in Al-1 (Blue), AlS-2 (Black) and AlS-3 (Green).

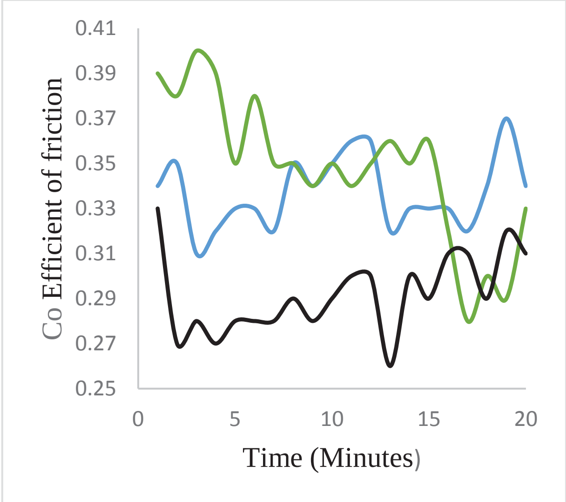

Figure 3. Comparison of change of co efficient of friction of Al-1 (Blue), AlS-2 (Black) and AlS-3 (Green) with time.

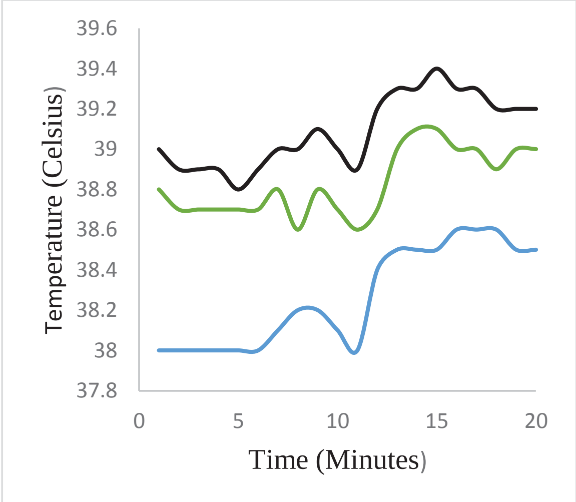

Figure 4. Comparison of rate of change of temperature in Al-1 (Blue), AlS-2 (Black) and AlS-3 (Green).

Figure 1-4 describes the variation of different parameters. The Frictional force is varying in small range of 5 to 9 Newton for all the samples and co efficient of friction values also varying in a small range from 0.3 to 0.4 for all the samples. But the wear and temperature variations show a significant pattern. Wear varies through 350 microns and temperature varies through 2 degrees while comparing 3 samples.

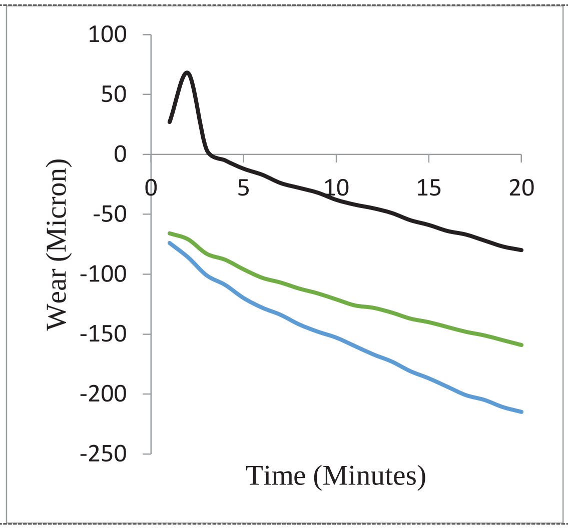

Figure 5. Comparison of wear rate of AlS-2 (Green), AlSC-4 (Black) and AlSC-5 (Blue).

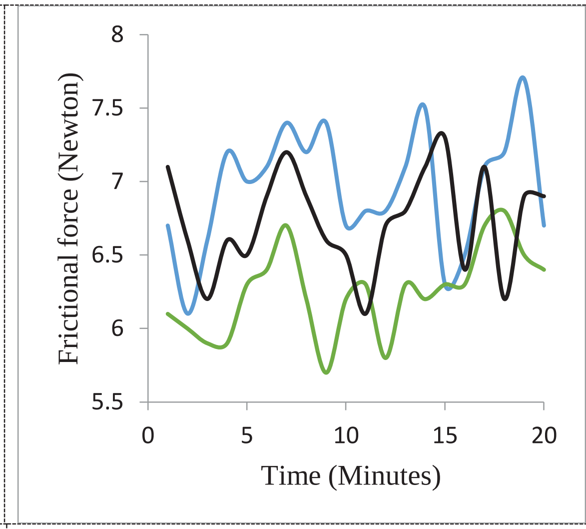

Figure 6. Comparison of rate of change of frictional force in AlS-2 (Green), AlSC-4 (Black) and AlSC-5 (Blue).

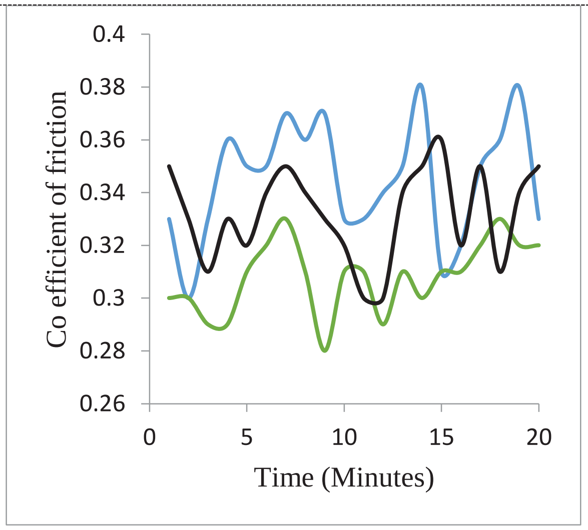

Figure 7. Comparison of change of co efficient of friction of AlS-2 (Green), AlSC-4 (Black) and AlSC-5 (Blue) with time.

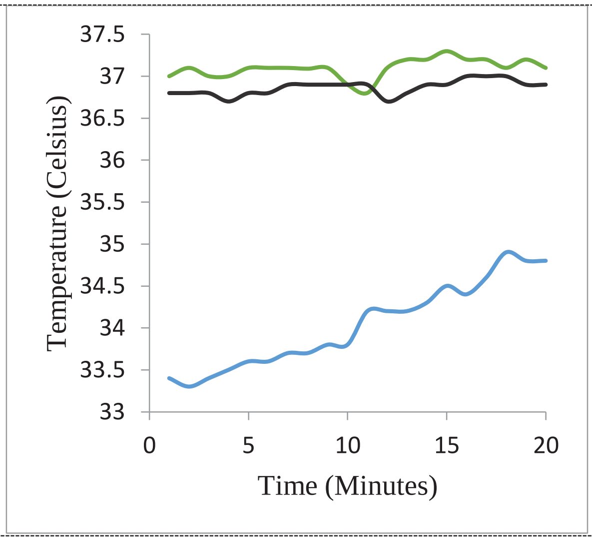

Figure 8. Comparison of rate of change of temperature in AlS-2 (Green), AlSC-4 (Black) and AlSC-5 (Blue).

Coefficient of friction and frictional force changes are not very significant here and it can be observed through the graphs. The Frictional force is varying in small range of 5 to 8 Newton for all the samples and co efficient of friction values also varying in a small range from 0.3 to 0.4 for all the samples. Wear varying through 300 micron and temperature varying through 4 degrees when comparing all the samples.

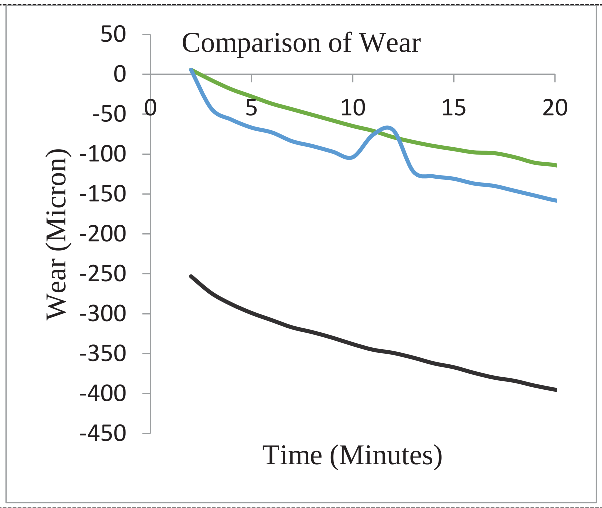

Figure 9. Comparison of wear rate of AlSN-6 (Blue), AlSN-7 (Black) and AlSN-8 (Green).

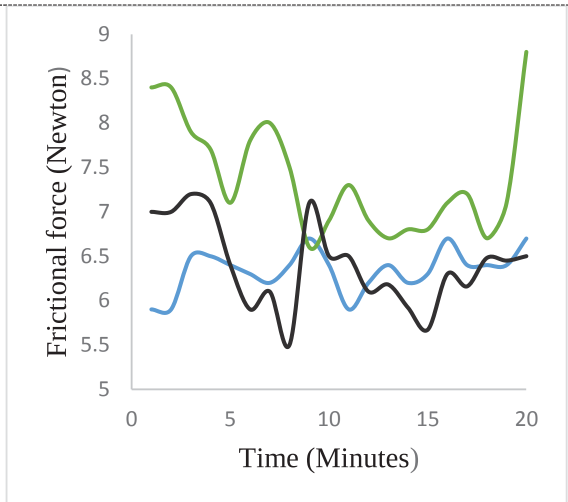

Figure 10. Comparison of rate of change of frictional force in AlSN-6 (Blue), AlSN-7 (Black) and AlSN-8 (Green).

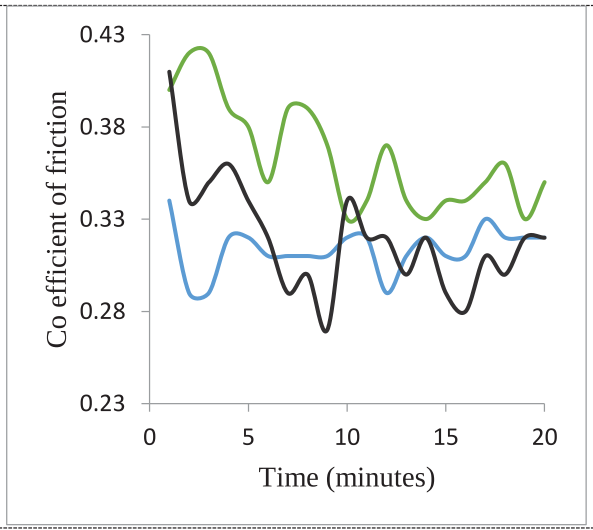

Figure 11. Comparison of change of co efficient of friction of AlSN-6 (Blue), AlSN-7 (Black) and AlSN-8 (Green) with time.

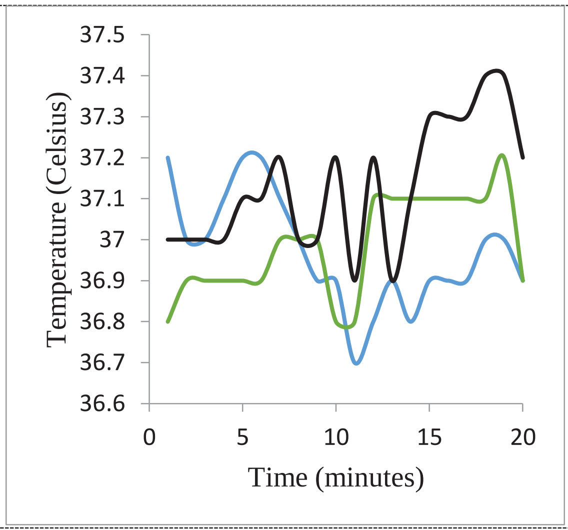

Figure 12. Comparison of rate of change of temperature in AlSN-6 (Blue), AlSN-7 (Black) and AlSN-8 (Green).

The Frictional force and co efficient of friction are varying in small range for all the 3 samples. The Frictional force is varying in the range of 5.5 to 9 Newton and co efficient of friction values are varying from 0.3 to 0.4. In these graphs temperature change shows a significant pattern and through 1 degree throughout the graph and wear variation range is around 500 micron while comparing the samples.

5.3 Graphs obtained in the tests with lubrication on Multi Specimen Tester

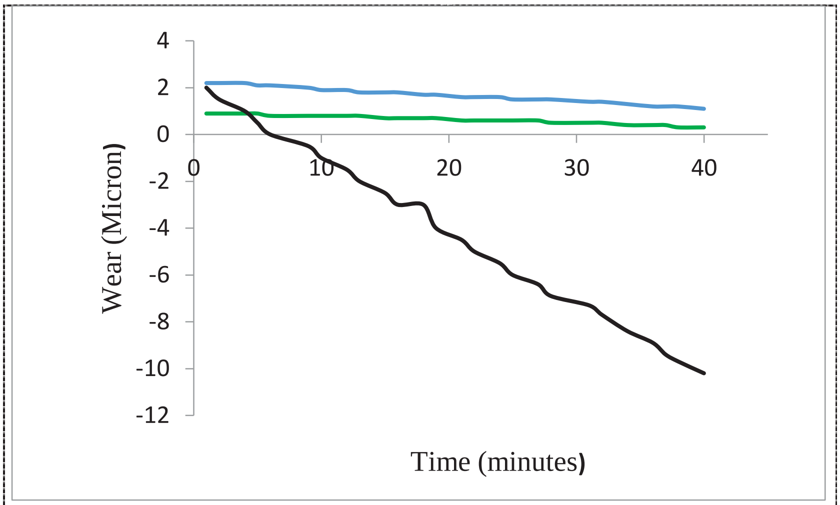

Figure 13. Comparison of wear rate of Al-1 (Green), AlS-2(Blue) and AlS-3 (Black) with time.

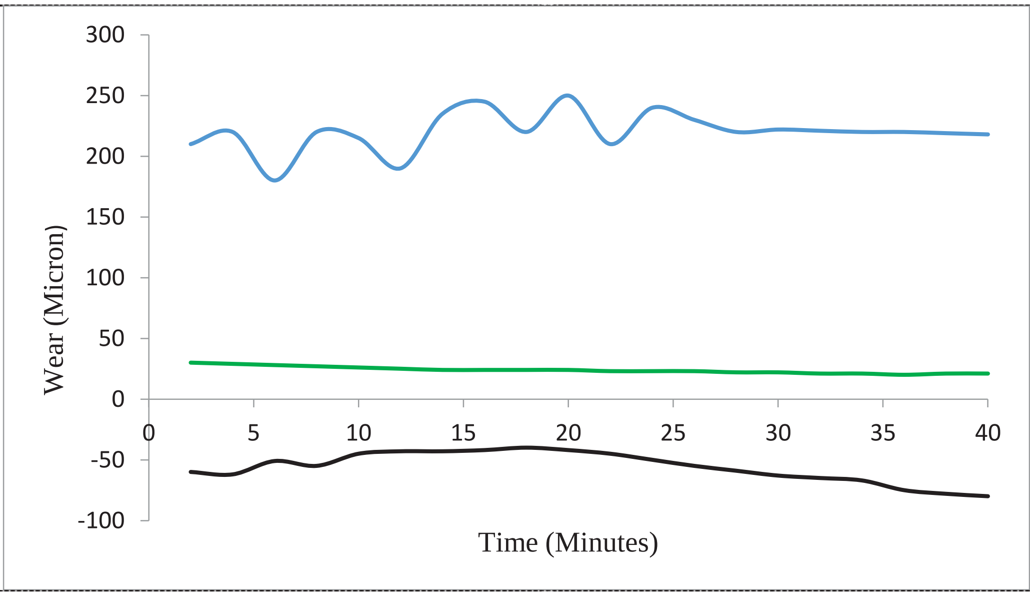

Figure 14. Comparison of wear rate of Al-2 (Green), AlSC-4(Blue) and AlSC-5 (Black)

It can be noticed through the graphs (figure 13-15) that the variation of wear of all samples can be observed clearly and in a range of few microns while comparing. Only wear rate is taken here because temperature, co efficient of friction and frictional force did not change to a mentionable extent because of application of lubrication.

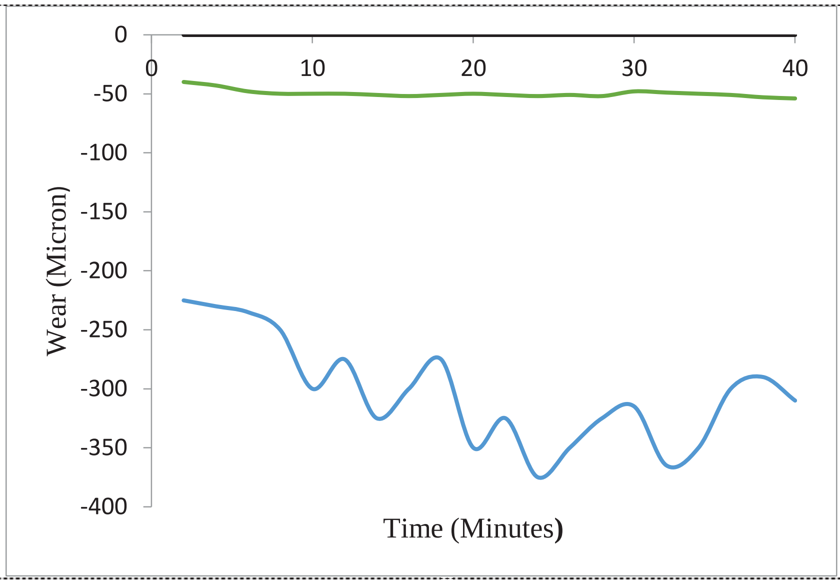

Figure 15. Comparison of change of co efficient of friction of AlSN-6 (Green), AlSN-7 (Black) and AlSN-8 (Blue) with time.

5.4 *Hardness of the samples*

The hardness of samples is shown in Table 4. As shown in the table, AlSN-7 and AlSC-5 alloys were hardest sample while the commercial Al found to be the softest. So according to this, the hardness increasing with the addition of Si and Cr up to 4%; but decreasing in case of Ni after 2%.

Table 4. Brinell Hardness values of samples

Material	Hardness (BHN)
Al-1	46.9
AlS-2	49.1
AlS-3	53.7
AlSC-4	60.5
AlSC-5	62.5
AlSN-6	50.2
AlSN-7	64.1
AlSN-8	52.4

IOP Conf. Series: Materials Science and Engineering **149** (2016) 012052 doi:10.1088/1757-899X/149/1/012052

6. Conclusions

In this study, mechanical and tribological behaviors of journal bearings prepared by aluminium based pure Al-1, AlS-2, AlS-3, AlSC-4, AlSC-5, AlSN-6, AlSN-7, AlSN-8 were studied. The following results were obtained:

1. The highest values of friction coefficients observed in AlSN-8 bearing while the lowest values of friction coefficients noticed in AlSC-5 and AlS-3 bearings in both the cases with and without lubrication.

2. The maximum values of bearing temperatures obtained in AlS-2 and AlS-3 bearings while the minimum values of bearing temperatures obtained in AlSC-4 and AlSC-5 bearings. And also it is observed that it is not varying for a wide range.

3. When we consider bearing wear rate, maximum values resulted in AlSC-4 and AlSN-8 bearings, and the minimum values resulted in AlSC-4 and AlSN-6 bearings for the experiments conducted without lubrication while maximum values resulted in AlSC-4 and AlSN-8 bearings, and the minimum values resulted in AlS-2 and AlS-3 bearings for the experiments conducted with lubrication.

4. The highest values of hardness were seen in AlSC-5 and AlSN-6 bearing materials while the lowest values of hardness were seen in Al-1 and AlS-2 bearing materials.

5. When we consider frictional loss with and without lubrication, it is observed that the loss occurred in the experiment with lubrication has decreased by almost 20 folds while comparing it with the experiment conducted without lubrication.

References

[1] Erol Feyzullahog lu and Nehir S akirog lu 2010 *Mat. And Design* **31** 2532-39.
[2] Bekir Sadık Ünlü and Enver Atik 2010 *J. Alloys and Comp* **489** 262-268.
[3] Seong Su Kim, Ha Na Yu, In Uk Hwang and Dai Gil Lee 2008 *Compo. Str* **86** 279-84.
[4] Bekir Sadık Ünlü, Hülya Durmus, and Selda Akgün 2009 *J. Alloys and Comp* **487** 225-30.
[5] Bekir Sadık Ünlü 2009 *Bull. Mat. Sci* **32** 451-57.
[6] Seong Su Kim, Dong Chang Park and Dai Gil Lee 2004 *Compo. Str* **66** 359-66.
[7] Sharma S C, Girish B M, Rathnakar Kamath and Satish B M 1998 *Wear* **219** 162-68.
[8] Rameshkumar T, Rajendran I, and Latha A D 2010 *Tribology in Industry* **32** No. 2.
[9] Sharma S C, Girish B M, Rathnakar Kamath and Satish B M 1997 *Wear* **213** 33-40.
[10] Hong-ling Qin, Xin cong Zhou, Xin ze Zhao, Jing tang Xing and Zhi ming Yan 2015 *Wear* **328** 257-261.
[11] Miyajima T, Tanaka Y, Iwai Y, Kagohara Y, Haneda S, Takayanagi S and Katsuki H 2013, *Trib. Inter* **59** 17-22.