International Conference on Mechanical, Industrial and Materials Engineering 2017 (ICMIME2017)
28-30 December, 2017, RUET, Rajshahi, Bangladesh.

Paper ID: MS-50

Tribological (Wear) Properties of Cu/Ni/Cu-Ni Content Al-Si Hypoeutectic Alloys under Dry Sliding Condition

A. Hossain[1], M. A. Gafur[2], F. Gulshan[3] and ASW. Kurny[3]

[1]Sylhet Gas Fields Limited (A company Petrobangla), Energy and Mineral Resources Division, Sylhet-3160
[2]Principal Scientific Officer, PP&PDC, BCSIR Laboratories, Dhaka, Bangladesh
[3]Department of Materials and Metallurgical Engineering, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh
E-mail: ah_buetmmesgfl@live.com

Abstract

The wear properties of heat treated Al-Si hypo-eutectic alloys containing Cu/Ni/Cu-Ni were studied under dry sliding conditions. The test specimens were machined to ASTM standards and were subjected to solution heat treatment and artificial ageing. Wear loss was calculated by measuring weight before and after test at room temperature. Dry sliding wear behavior depends on size and shape of the silicon particles, size distribution of α-Al grains, Mg_2Si, $CuAl_2$, Al_2CuMg, Al_3Ni, Al_7Cu_4Ni and other intermetallics in the interdendritic region. As heat treated condition, Cu/Cu-Ni content Al-6Si-0.5Mg alloys have better wear resistance all over the ageing conditions. The wear resistance of the alloys increased with increasing ageing temperature. A degree of improvement in wear resistance was observed in aged (200-250^{0}C) condition with all over heat treatment. After excessive ageing (overageing), an increase was observed in wear loss of all alloys.

Keywords: Al-Si alloys, heat treatment, wear.

1. Introduction

The literature survey is carried out to study and evaluate the wear properties of Al-Si alloys used in automotive applications. The various parameters such as Silicon content, applied load, sliding distance, effect of microstructure, etc have been studied. Wear tests on the Al-Si alloys were performed on a pin on disk type wear testing apparatus and parameters were size and shape of the pin, load, speed and the material pairs. Increase in the rotational speed of the disk leads to the increase in the mass loss of the as-cast and heat treated alloys. The wear rate is higher for as-cast samples. High speed leads to reduction in wear rate. The reduction is pronounced in heat treated samples. This is because during sliding, heat is developed and the material becomes softer and weaker. This heat might not affect the hardness of heat treated alloys due to their inherent characteristics [1-3].
Alloy composition, sliding distance, sliding speed and load effects on the wear rate of Al-Si alloys. The wear rate is strongly dependent on the applied load. It increases linearly with load in three distinct regions in all the alloys. Mild wear, Intermediate wear and Severe wear. Mild wear takes a longer duration and takes place under low loads. The intermediate wear and severe wear regions are distinguished from the mild region by higher rates of increase in the wear rate per unit weight [4].
Tribological properties of forged 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 it is observed that, addition of grain refiners to A356 alloy converts predominantly columnar dendritic structure into fine equiaxed dendritic structure and addition of modifier 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 depends on a number of 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 counter face [5-7].
There have been many attempts to study the effect that silicon content has on the wear behaviour of the Al-Si alloys, with a variety of conclusions particularly regarding to the effect of silicon content on the dry sliding wear

of Al-Si alloys as obtained in past studies [8]. The wear of Al-Si binary alloys containing 4, 8, 11, 16, and 20% silicon under dry sliding condition, and concluded that the mild wear rate (oxidative wear rate) was independent of the silicon content, silicon particle size and applied load as well. Only the transition from mild wear to severe wear increased when the silicon content increased [9]. It was found that increasing in the silicon content from 8.6 to 14.2% extended the load range, in which fine equiaxed particles were produced. [10]

Silicon particles play an important role in an Al-Si alloy the wear resistance. The general mechanism responsible for an increase in the wear resistance of an Al-Si alloy is that silicon can increase the overall hardness of the alloy, making it more resistant to wear. This does not always mean, however, that the higher the fraction of silicon in the alloy, the greater the alloy‘s wear resistance. Due to its high brittleness, impact load can break silicon and thus may increase the overall wear of the alloy, so the optimal fraction and morphology of silicon in an Al-Si alloy is a vital key to improving its wear performance. The addition of magnesium up to 1 % is also useful in reducing wear. It is added to provide strengthening through precipitation of Mg_2Si in the matrix [11]. Copper increases the strength and wear resistance of aluminum alloys through a mechanism of precipitation hardening. The wear and seizure resistance of Al-Cu alloys were found to increase up to Cu contents of about 4%, after which it levels off [9]. The highest wear resistance is obtained with the peak aged precipitates [12].

The wear behaviors of 2Cu/2Ni/2Cu-2Ni content Al-6Si-0.5Mg alloys, using pin-on-disc test apparatus were explored here.

2. Experimental procedure

The experimental alloys were prepared by melting Al-7Si-0.3Mg (A356) alloys and adding Al, Cu and/or Ni into the melt. Table1 shows the chemical compositions of the castings. The cast samples were first ground properly to remove the oxide layer from the surface. The Homogenization, solutionization and ageing of the cast alloys were evaluated using an electrical heating furnace in the heat treatment laboratory (Lenton, Model: AWF 13/42) of Pilot Plant and Process Developed Centre (PP & PDC), BCSIR, Dhaka, Bangladesh. In this study homogenizing was carried out at 500ºC for 24 hrs. A set of wear samples from the four alloys were cut from each homogenized samples. The samples were subjected to solution treatment at 540ºC for 2hr and rapidly quenched in ice salt water solution. The solutionized and quenched samples were artificially aged at room temperature for 1 day prior to artificial ageing. Artificial ageing was conducted in the electrical furnace .The wear samples of the four alloys were aged at 150, 200, 225, 250 & 300ºC for 1 hr. The samples were taken out of the furnace and cooled in still air. The quenched and aged samples were used for the wear testing and metallography studies.

Wear testing was performed on an exploratory manner. The procedure given in ASTM G99 standard was followed to conduct the tests. The testing was performed on three specimens for each alloy in six tempers. Dry sliding wear tests were performed using a pin-on-disk type machine (Fig.1).

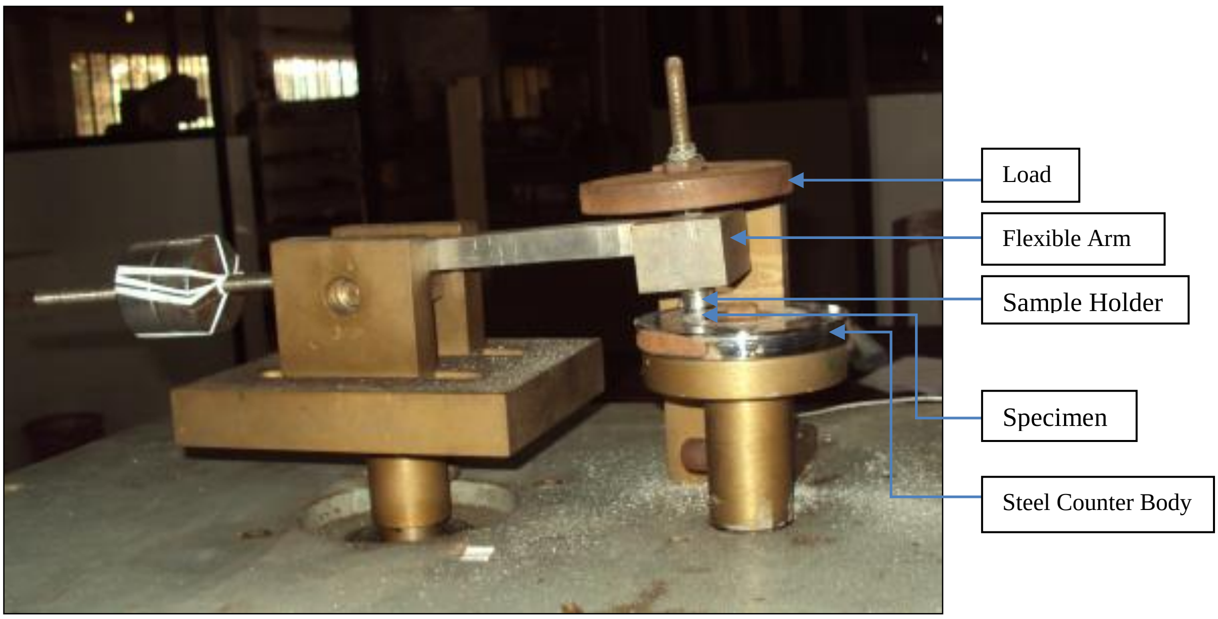

Fig.1. Pin-on-Disk type friction and wear test machine

The rotating disc, 45 mm in diameter, was made of carbon steel and the hardness of the disc was 30 HRC. The experimental samples were held stationary and a required normal load was applied through a lever mechanism. Wear tests were carried out under dry sliding conditions under a normal load of 5.4N at a constant sliding speed of 900 rpm and the sliding distance per second is (900 x 2 x 3.14 x 0.0225 m)/60 s =2.12 m/s. The wear loss was measured directly as the weight loss of the specimen. The tests were carried out for 10 minutes. No lubricant was used during the test. Care has been taken that the specimens under test are continuously cleaned with woollen cloth to avoid the entrapment of wear debris and to achieve uniformity in experimental procedure. The overall experimental steps are shown in Fig.2.

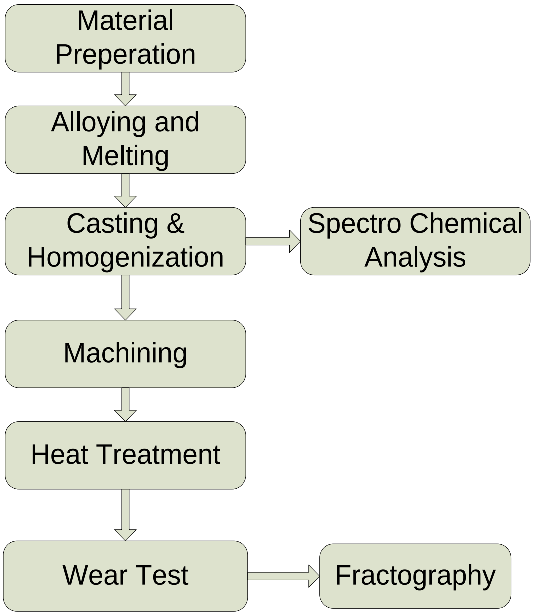

Fig.2. The alloy synthesis and experimental steps for wear studies

The alloy codes and compositions are given in Table 1.

Table 1. Chemical compositions of the alloys

Alloy Code	Alloy Compositions (wt %)
Alloy-1	Al-6Si-0.5Mg
Alloy-2	Al-6Si-0.5Mg-2Cu
Alloy-3	Al-6Si-0.5Mg-2Ni
Alloy-4	Al-6Si-0.5Mg-2Cu-2Ni

3. Result and discussions

Fig.3 shows the wear test results i.e. weight loss (mass loss) vs. ageing temperature of the alloys. Dry sliding wear behavior of Cu/Ni/Cu-Ni Content Al-Si Hypoeutectic alloys depends on size and shape of the silicon particles, size distribution of α-Al grains, Mg_2Si, $CuAl_2$, Al_2CuMg, Al_3Ni, Al_7Cu_4Ni etc and other intermetallic and precipitate particles in the interdendritic region. Thermal modification converts large α-Al grains into fine equiaxed α-Al grains and forms fine fibrous silicon particles and fine Mg_2Si, $CuAl_2$, Al_2CuMg precipitate particles in the interdendritic region. These $CuAl_2$, Al_2CuMg precipitates are fully coherent but Mg_2Si precipitates are semi-coherent with the α-aluminium matrix. Ni content intermetallics are partially modified during solution treatment. These affect the mechanical properties and wear properties of the alloys.

As quenched condition, Alloy-3 shows the highest mass loss and Alloy-1 shows slightly lower than. Addition of Cu/Ni/Cu-Ni into Al-6Si-0.5Mg alloy increases the wear resistance. The wear resistance of the experimental alloys increases with ageing temperatures and maximum found aged at 200-225ºC. Alloy-1 and Alloy-3 show very similar wear behavior all over the ageing conditions. Addition of 2wt% Ni into Al-6Si-0.5Mg (Alloy-3) increases the wear loss. This is due to the formation of new hard intermetallic phases (Al_3Ni, Al_7Cu_4Ni etc.) along the grain boundaries and enhances crack formation and increase wear loss of the alloy. Alloy-3 shows higher wear loss i.e. lower wear resistance among the investigated alloys at allover ageing conditions (except aged at 200ºC).

Additions of Cu and Cu-Ni into Al-Si hypoeutectic alloys increase the hardness [13]. This is due to the formation of new hard intermetallics or precipitates during thermal treatment in the presence of Cu/Cu-Ni atoms. During solution treatment the Cu/Ni atoms go to solution and the Si particles are modified. After thermal modification, the Cu (Alloy-2) and Cu-Ni (Alloy-4) content alloys show better wear resistance. During ageing, precipitates form and increase the hardness and wear resistance. At peakaged condition (1hr at 225^{o}C), the wear loss of the Cu content alloy (Alloy-2) are slightly higher than when aged at 200^{o}C and 250^{o}C but lower than all other ageing conditions. After excessive ageing, an increase was observed in wear loss of the Cu content alloy. As-solutionized and quenched condition, Cu-Ni content alloy (Alloy-4) has better wear resistance than other alloys. The wear resistance of the alloys increases up to peakaged condition. Alloy-4 shows the maximum wear resistance when aged at 225^{o}C whereas Alloy-2 shows maximum wear resistance aged at 200^{o}C. The higher mass loss was obtained in the alloys which were aged at 300^{o}C. There was an increase in the mass loss with increasing the ageing temperature. This is due to the effect of overageing.

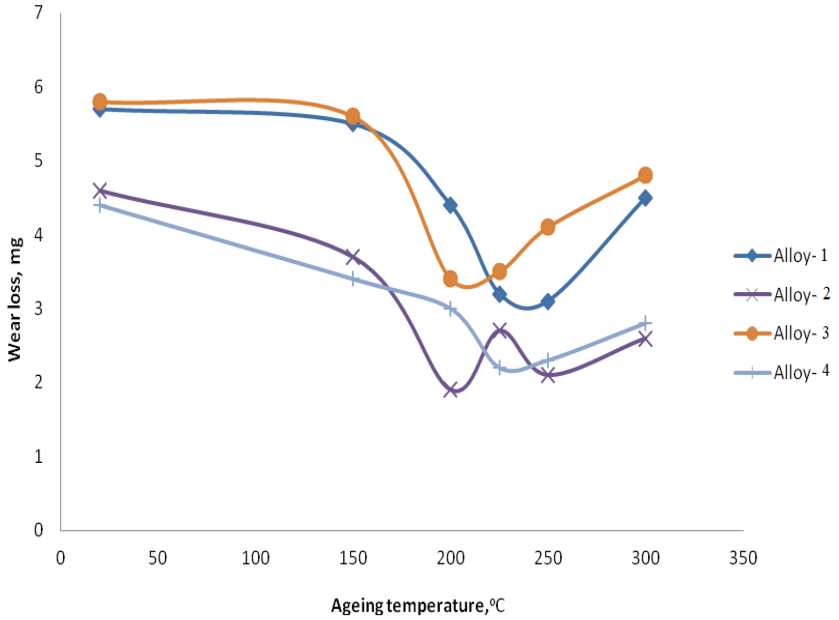

Fig.3. Wear behaviour of Alloys 1- 4

4. Conclusions

In solution treated condition reference alloy (Alloy-1) and Ni content alloy (Alloy-3) showed lower wear resistance. These alloys are also showed slightly improved wear resistance aged at 200-250^{o}C. So no significant changed of wear properties due to Ni addition into Al-Si hypoeutectic alloy. Cu content Alloy-2 and Cu-Ni content Alloy-4 wear resistances were higher at solutionized, quenched and allover heat treated conditions. Their (Alloy -2 & Alloy-4) wear resistances were modified and improved with the ageing temperatures.

5. References

[1] H. Torabian, J. Pathak, & S. Tiwari, “Wear characteristics of Al-Si alloys”, *Wear*, vol.172, No. 1, pp.49-58, 1994.

[2] T. Yasmin, A. Khalid Asad, M. M. Haque, “Tribological (wear) properties of aluminum–silicon eutectic base alloy under dry sliding condition”, *Journal of Materials Processing Technology*, Vol.153–154 pp.833-838, 2004.

[3] S. A. Kori, T. M. Chandrashekharaiah, “Studies on the dry sliding wear behaviour of hypoeutectic and eutectic Al–Si alloys”, *Wear*, Vol.263 pp.745-755, 2007.

[4] H. Torabian, J. P. Pathak, and S. N. Tiwari, “Wear characteristics of Al-Si alloys”, *Wear*, vol.172, pp.49-58, 1994.

[5] G. Rajaram, T. Rao, Srinivas, “High temperature tensile and wear behaviour of aluminum silicon alloy”, *Materials Science and Engineering A*, Vol.528 pp.247-253, 2010.

[6] T. M. Chandrashekharaiah, “Studies on sliding wear behaviour of grain refined and modified hypoeutectic, eutectic and hypereutectic Al-Si alloys”, PhD Thesis, VTU Belgaum, 2007.

[7] ASTM G99-17, Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus, *ASTM International*, West Conshohocken, PA, 2017, www.astm.org.

[8] A. S. Reddy, B. N. Pramila Bai, K. S. S. Murthy, and S. K. Biswas, "Wear and seizure of binary Al-Si alloys", *Wear*, Vol.171, pp.115-127, 1994.

[9] R. Shivanath, P. K. Sengupta, and T. S. Eyre, "Wear of aluminum-silicon alloy", *British Foundrymen*, Vol.79, pp.349-356, 1977.

[10] R. Antoniou, and D. W. Borland, "Mild wear of Al-Si binary alloys during unlubricated sliding", *Materials Science and Engineering*, Vol.93, pp.57-72, 1987.

[11] J.R. Davis "ASM Specialty Handbook, Aluminum and Aluminum Alloys," *ASM International*, Materials Park, OH, 1993.

[12] C. Subramanian, "Some Considerations towards the Design of a Wear Resistant Aluminum Alloy," *Wear*, vol.155, pp.193-205, 1992.

[13] A. Hossain, M. S. Kaiser, and A. S. W. Kurny, "Influence of Copper and Nickel Addition on Microstructure and Artificial Ageing of Al-6Si-0.5Mg Alloys", *International Conference on Mechanical, Industrial and Materials Engineering 2013 (ICMIME 2013)*, pp.648-654, 1-3 November, 2013, RUET, Rajshahi, Bangladesh.