ISSN: 0975-833X

Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 8, Issue, 05, pp.31686-31692, May, 2016

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

RESEARCH ARTICLE

AMALGAMATION OF AL-SI ALLOYS AND STUDY OF THEIR MECHANICAL PROPERTIES

[1]Chandra Mouli, B., [2]Vijay Kumar, A., [3,*]SaiSandeep, N. V. and [4]Sai Vivek, T.

[1]Department of Mechanical Engineering, Raghu Engineering College, Visakhapatnam, India
[2,3,4] Department of Mechanical Engineering, Raghu Engineering College, Visakhapatnam, India

ARTICLE INFO

Article History:
Received 23rd February, 2016
Received in revised form
25th March, 2016
Accepted 14th April, 2016
Published online 31st May, 2016

Key words:

Al-Si alloy, Sand casting, Tensile testing, Hardness, Impact strength, Wear test, Wear micro structures.

ABSTRACT

In the last few years there been a swift increase in the utilization of aluminum-silicon alloys, particularly in the automobile and manufacturing industries, this is because due to their high strength to weight ratio, high wear resistance, low density and low coefficient of thermal expansion. The progressions in the field of application make the study of their wear and tensile behavior an utmost importance. In this present investigation, Aluminum Based Alloys containing 6%, 10%,13%, 16%, 20% and 23% weight of Silicon were synthesized using sand casting method. The tensile, hardness and impact tests are done on different samples of same composition where the results increased with increase in silicon percentage. Yield strength and ultimate tensile strength has increased with increase in silicon percentage. Wear behavior was studied by using computerized pin-on-disc wear testing machine. Resistance to wear has increased with increase in silicon amount and the worn surfaces were analyzed using optical microscope.

Citation: Chandra Mouli, B., Vijay Kumar, A., Sai Sandeep, N.V. and Sai Vivek, T., 2016. "Amalgamation of al-si alloys and study of their mechanical properties", *International Journal of Current Research*, 8, (05), 31686-31692.

INTRODUCTION

Alloy which is defined by metallic bonding character is a mixture of two or more metals or non- metals exhibiting different phases used to enhance the properties such as tensile strength and shear strength better than those of their parent metal. In this study we typically use Aluminum as a base alloy, the reason behind selecting this metal is due to its high strength to weight ratio, low density these properties as a function help the metal to incredibly use in manufacturing industries especially in aerospace and marine applications (Balamugundan and Karthikeyan, 2014) and when this metal is mixed with silicon as weight percentage there will be change in their physical properties like reduction in thermal expansion, magnetic susceptibility, mach inability (www.kettometals.com, 2001). The increase of Silicon content into the Aluminum mixture will increase the fluidic nature of the alloy which helps in casting applications. These properties of Al-Si alloy help them to use in manufacturing automobile parts like pistons, cylinder liners, cylinder heads. At high silicon levels, the alloy exhibits excellent dimensional stability, surface hardness and wear resistant properties (Jonathan, 2003). The main reason of Aluminum's weaknesses is its lack of strength is its pure form. To get around this and preserve Aluminum's low density and lightweight other elements are added to the metal to pin dislocations reducing ductility but increasing strength. By this method some aluminum alloys can be as strong as steel. Adding different elements achieves slightly different effect but almost all alloys are stronger than the original aluminum metal. Aluminum-Silicon system is a simple binary eutectic with limited solubility of aluminum in silicon and limited solubility of silicon in aluminum. Depending on Silicon content in weight percentage (wt%) the Al-Si alloy falls into three major categories namely Hypo eutectic (<12 wt% Si), Eutectic (12-13 wt% Si) and Hyper eutectic (14-25 wt% Si). These eutectic regions show diverse characteristic values for different engineering properties.In this work, different mechanical properties and wear behavior of Aluminum-Silicon alloy was studied by varying the weight percentage of silicon in the mixture by sand-casting process.

Corresponding author: Sai Sandeep, N.V.
Department of Mechanical Engineering, Raghu Engineering College, Visakhapatnam, India.

Experimental procedure

Material Preparation

The pure Aluminum (99.9%) ingot is produced by molten salt electrolysis method using alumina and cryolite is mixed with commercially pure silicon (99.5%) by varying the silicon percentage. These two elements are melted in a graphite crucible by high frequency charcoal furnace and the melt was held at 720 ^{0}C to 740 ^{0}C in order to attain homogeneous composition. After degassing (RitizoYonagawa,1965) with 1%

sodium carbonate", drossing flux called "Potassium Aluminum Fluoride" is added to the melt, 0.1% Al–Ti master alloy was added to the melt for modification of microstructure. Each melt was stirred for 30s after the addition of the modifier, held for 2 min and then poured into a sand mold surrounded by green clay. The cast samples were of 200 mm length with 20 mm diameter and 10 mm rods. Aluminum and silicon are mixed in perfect proportions to get the compositions of 6%, 10%, 13%, 16%, 20% and 23% Al-Si alloys. The photographic images of the casting process of Al-Si alloy are shown in figure 1-4. The chemical composition of different cast Al-Si alloys were tested using spectrometer and the results are reported in Table 1.

Table 1. Alloy Composition

Elements Composition	Aluminum	Silicon	Other Elements
Al- 6%Si	92.81	7.08	Balance
Al-10%Si	89.62	10.18	Balance
Al-13%Si	86.71	13.18	Balance
Al-16%Si	83.65	16.24	Balance
Al-20%Si	79.87	20.02	Balance
Al-23%Si	76.14	23.15	Balance

Fig. 1. Pure Aluminum

Fig. 2. Charcoal Furnace

Fig. 3. Heating Aluminum Alloy

Fig. 4. Molten Al-Si Alloy pouring into Sand Mold

Tensile Testing

The tensile test was conducted to predict the yield strength (YS), ultimate tensile strength (UTS) of the material as well as to find the total elongation of the alloy. The test specimens were prepared according to ASTM – B557 standard. Tensile tests were carried out with a crosshead speed of 1mm/min, which corresponds to nominal strain rate of 0.001 per second. During the tests, the load elongation data is captured by induced software, whose data is used for further analysis. Figure 5 and 6 shows the drawing and the photographic image of the specimen. The specimens were tested under computerised universal testing machine (Model- TUE-C-600). The experimental set up is shown as shown in the figure 7.

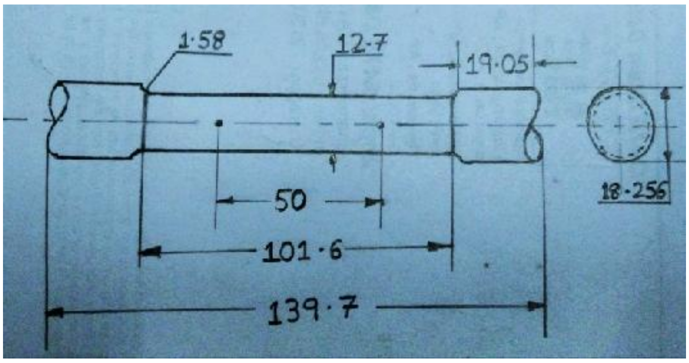

Fig. 5. Drawing of Tensile Test Specimen

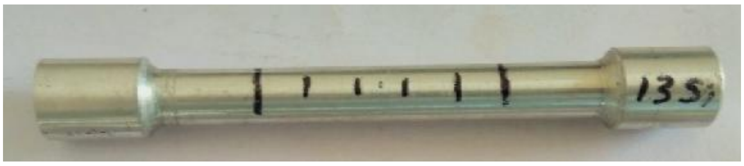

Fig. 6. Photograph image of Tensile Test Specimen

Hardness Testing

To assess the effect of silicon in different weight percentages, the hardness of the entire specimens were measured using Rockwell Hardness testing machine which is shown in the figure 8.A number of readings were taken at different location for each specimen and an average value was calculated. The specimens were prepared and tested as per ASTM- E384 standard (Ilangovan, 2014). Parameters used in this test were:

applying the load of 60 kgf, 100 kgf and150 kgf with a dwell time of 20 sec. Two different indenters are used to calculate the hardness of these samples i.e; 1/16th inch stainless steel ball indenter and diamond cone shape indenter which is of 120^{0}. The variations in the hardness values are shown by line graphs.

Fig. 7. Universal Tensile Testing Machine

Fig. 8. Rockwell Hardness Testing Machine

Impact Testing

The toughness of the specimens were determined by using the Charpy Impact testing machine. In this test the specimen should be under ASTM E23 standard (55mm*10mm*10mm). To evaluate toughness and notch sesitivity the specimen should has a notch of 2mm deep, cut in one face. The notch angle is 45^{0} and the radius at its peak is 0.25mm. The specimen and impact machine are shown in the figure 9 and 10 respectively.

Wear Testing

Computerized Ducomfriction and wear monitor pin-on-disc wear test machine was used for the wear tests. The rotating disc was made of high carbon steel of diameter 50mm and hardness of 64HRC.

Fig. 9. Impact Test Specimen

Fig. 10. Charpy Testing Machine

TheAl-6%Si, Al-10%Si, Al-13%Si, Al-16%Si, Al-20%Si and Al-23% samples were held stationary and required normal load was applied through a lever mechanism. The tests were carried out only by vary in gone of the following three parameters and keeping other two constants: Applied Load is (10N, 20N, 30N) where Sliding Distance and Sliding Speed are kept constant. Time required to run the equipment is 1 hour. The reinforcement of Al2O3 particles in aluminum alloy enhances the abrasive wear of the matrix. The reinforcement of coarse particle shows better wear resistance (Das *et al.*, 2008). Chen *et al.*, 2008 investigated wear mechanisms in eutectic Al–Si alloys (11–12% Si) tested against a hard steel counter face and observed that the advancement of damage events generally comprised of the following steps:

- Wear of the top surfaces of silicon particles by the counter face.
- Embedding of silicon particles into aluminum matrix (or particle sinking-in).
- Plastic deformation of aluminum causing the formation of aluminum pile-ups adjacent to the sunken-in silicon particles.
- Wear of the elevated portions of aluminum plateaus by the counter face.

All the wear tests were carried out as per ASTM-G99 standard (Camille Murray, 2013) under unlubricated condition in a normal laboratory atmosphere at 50-60% relative humidity and a temperature of 28-320^{0}C. The specimen used is of 8mm diameter and 30mm length. Figure 11 shows the pin-on-disk equipment set up. The wear rate was measured from the volume loss per unit sliding distance. It is expressed in mm3/m. Volume loss was calculated using the plot, height loss versus time. The test parameters used for the wear test are shown in Table 2.

Fig. 11. Ducom friction and wear monitor pin on disc wear test machine

Table 2. Wear Testing Parameters

Test Parameters	Unit	Test Values
Speed	rpm	800
Velocity	mt/s	1.047
Time	s	3600
Distance	mm	3770
Load Applied	N	10,20,30

RESULTS AND DISCUSSION

Tensile Result

The influence of silicon in the cast Aluminum alloy gives the variations in the values of Yield Strength, Ultimate Tensile Strength and Total Elongation. Table 3 shows the values of UTS, YS and Total Elongation. Figure 12,13,14 shows the line graphs of UTS, YS and Elongation it can be observed that the curves are continuous when transition from elastic to plastic region takes place. Therefore, the yield strengths of the alloys are computed by 0.2% offset method, according to ASTM standard B557. From Fig. 12 and 13 it is observed that ultimate tensile strength and yield strength increases with the increase of weight percentage of silicon; while it is reverse for the total elongation. This is due to the presence of hard silicon precipitates which increases the hardness of Al-Si alloys.

Table 3. Tensile test Values

Compositions	Ultimate Tensile Strength	Yield Strength	Total Elongation
Al-6%Si	137.52	62.35	22.67
Al-10%Si	146.46	65.49	20.47
Al-13%Si	161.56	68.29	17.94
Al-16%Si	158.24	70.54	15.26
Al-20%Si	167.57	76.61	9.39
Al-23%Si	171.66	80.85	6.19

Hardness

The Rockwell hardness numbers for Al-6% Si, Al-10% Si, Al-13% Si, Al-16% Si, Al-20% Si and Al-23% Si are found to be in increasing order with respect to percentage silicon. This shows that hardness of the Al-Si alloy increases with the increase in the weight percentage of silicon. This may be due to the increment of silicon amount, which is harder. Figure 15,16,17 shows the line graphs of hardness values by varying the loads of 60,100 and 150 kgf.

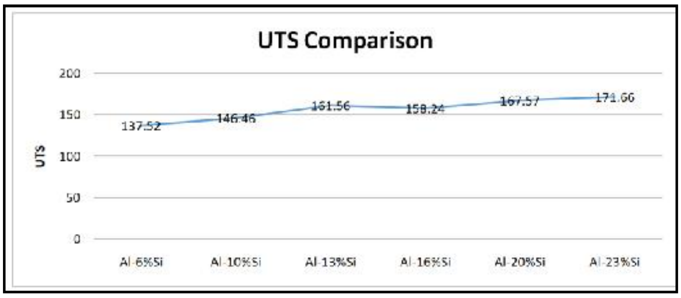

Fig. 12. UTS Comparison

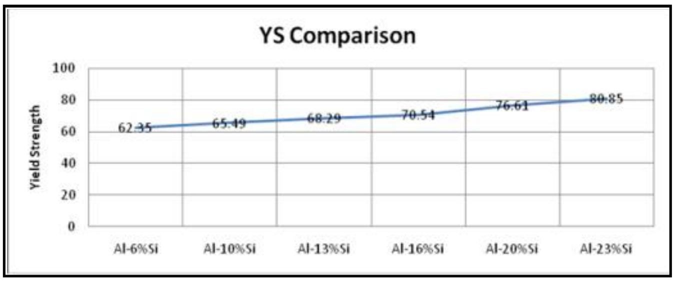

Fig. 13. Yield Strength Comparison

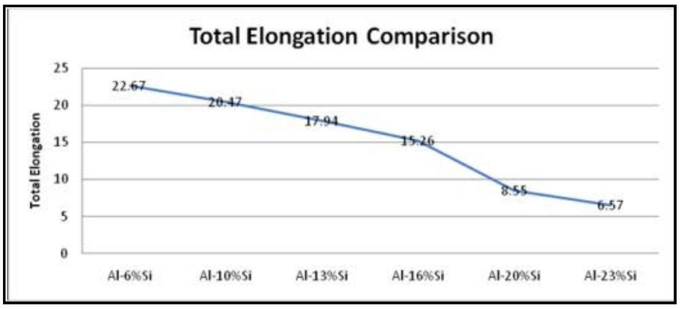

Fig. 14. Total Elongation Comparison

Toughness

Toughness of all the samples were conducted using charpy impact testing machine. For each composition, three impact values were taken and average value is reported. Table 4 and Figure 18 shows the different values of Al-%Si alloy compositions. The values shown are found to be increased till Al-13% Si alloy and then decreases for the next silicon percentages. The Al-13% Si is a eutectic alloy where the properties tends to be increased. Due to the eutectic reaction i.e; the liquid solution of fixed composition solidifies at constant temperature forms a mixture of two solid phases without an intermediate stage. While increasing the silicon content to the aluminum the brittleness increases and due to this hardness increases i.e; toughness or impact strength decreases. In hyper eutectic region where the primary alloy is silicon the impact strength first decreases and then gradually increases up to certain level.

Wear test

The wear tests of Al-Si alloys were carried out with varying applied load by keeping sliding speed and sliding distance constant. Before conducting the test, the pin on disk surfaces were polished with emery papers, so that the contact will be a smooth one. Each specimen was run for 1 hour to get the test results.

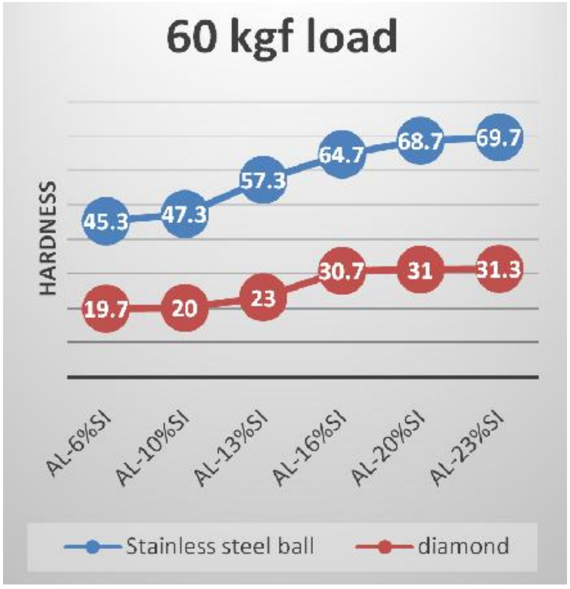

Fig. 15. Hardness values for 60 kgf load

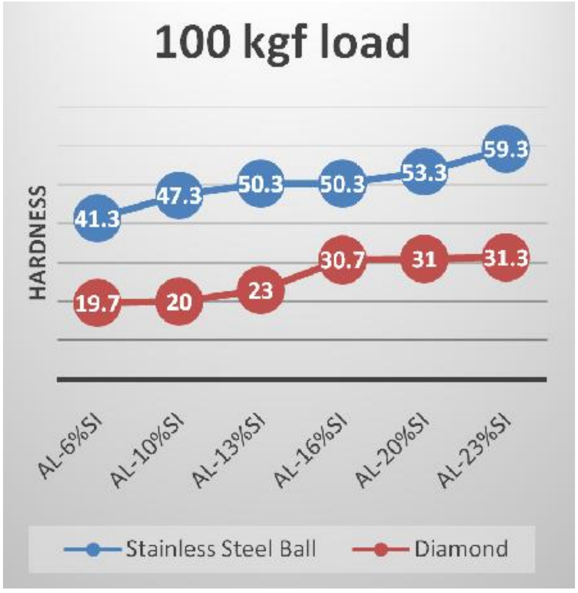

Fig. 16. Hardness Values for 100 kgf load

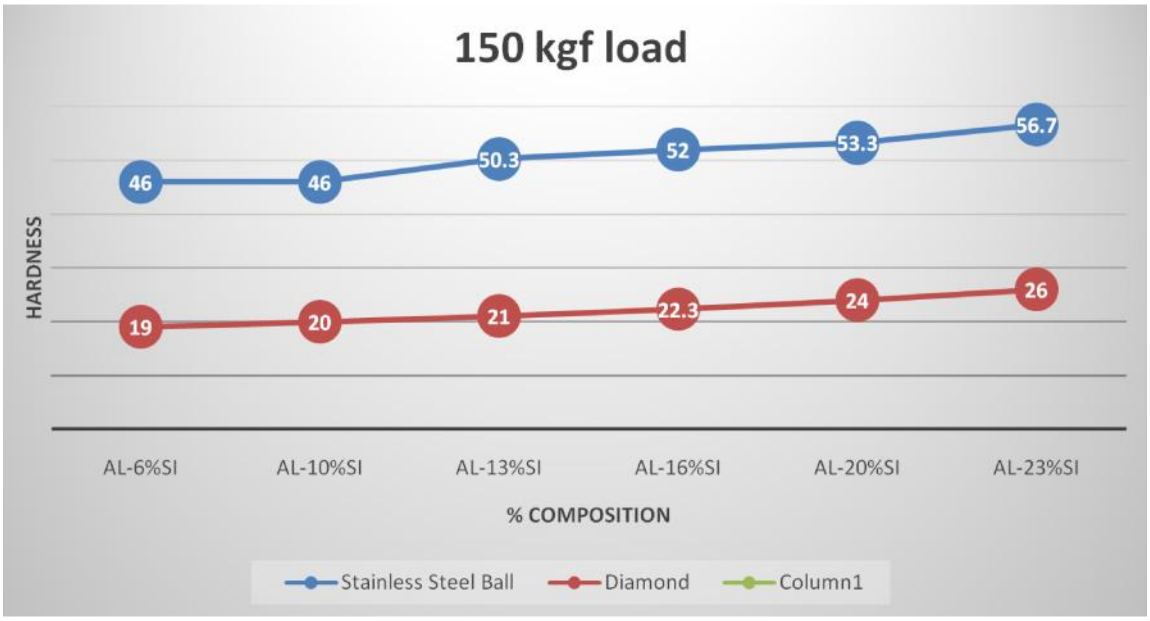

Fig 17. Hardness Values for 150 kgf load

Table 4. Charpy Impact Test values of various Al-Si alloys

Composition	Specimens 1	2	3	Average Value	Impact Strength(N/mm^2)
Al-6% Si	6	8	10	8	0.1
Al-10%Si	18	14	16	16	0.2
Al-13%Si	28	26	26	26.7	0.334
Al-16%Si	19	15	16	16.7	0.208
Al-20% Si	18	16	18	17.3	0.216
Al-23%Si	16	26	22	21.3	0.266

Table 5. Wear Test values of various Al-Si alloys

Composition	Avg. weight of specimen(Dm)			Wear rate(N/mm)		
	10N	20N	30N	10N	20N	30N
Al-6% Si	0.085	0.115	0.125	$2.2118*10^{-4}$	$2.9925*10^{-4}$	$3.2527*10^{-4}$
Al-10%Si	0.064	0.079	0.09	$1.6653*10^{-4}$	$2.0557*10^{-4}$	$2.3419*10^{-4}$
Al-13%Si	0.055	0.071	0.087	$1.4312*10^{-4}$	$1.8475*10^{-4}$	$2.2638*10^{-4}$
Al-16%Si	0.047	0.061	0.075	$1.2230*10^{-4}$	$1.5873*10^{-4}$	$1.9516*10^{-4}$
Al-20%Si	0.035	0.0486	0.062	$0.9107*10^{-4}$	$1.2646*10^{-4}$	$1.6133*10^{-4}$
Al-23%Si	0.022	0.0368	0.052	$0.5725*10^{-4}$	$0.9368*10^{-4}$	$1.3531*10^{-4}$

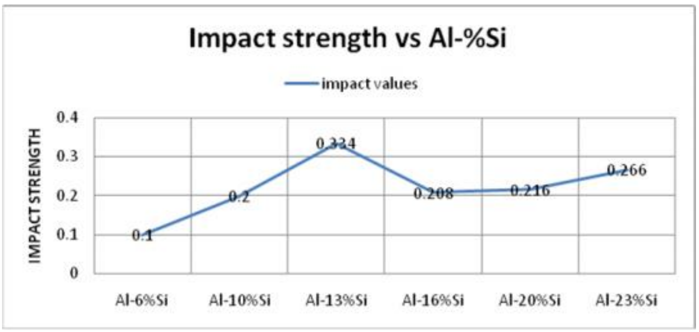

Fig. 18. Toughness values of various Al-%Si alloy compositions

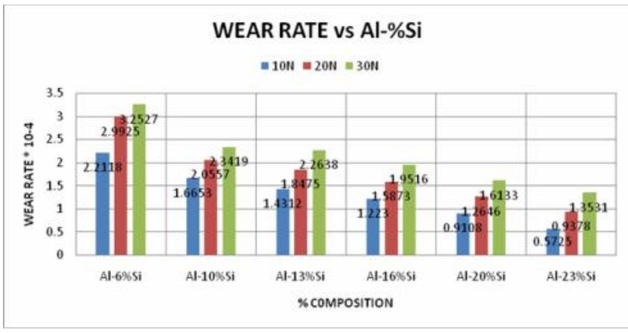

Fig. 19. Wear Test values of different Al-%Si alloy compositions

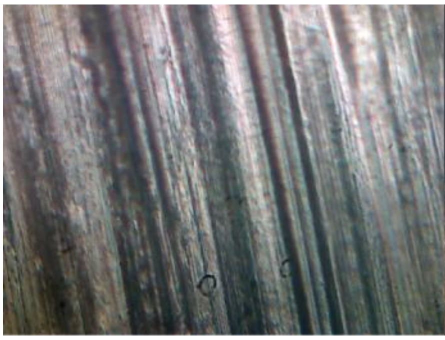

Fig. 20. Al-6%Si

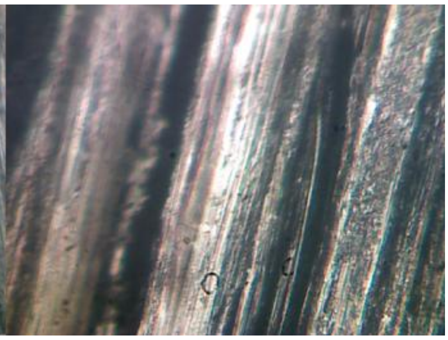

Fig. 21. Al-10%Si

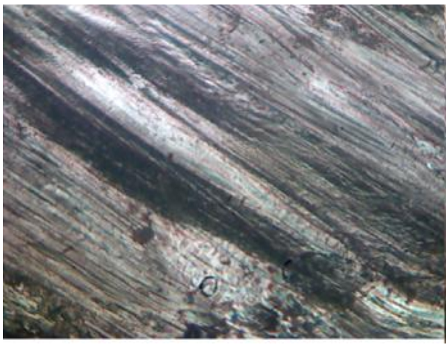

Fig. 22. Al-13%Si

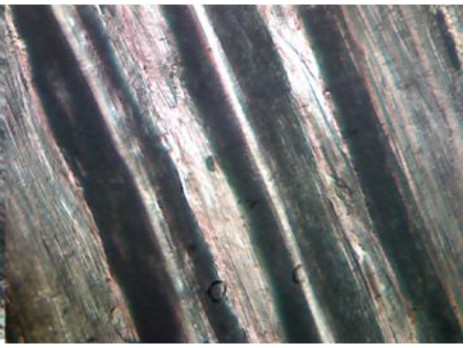

Fig. 23. Al-16%Si

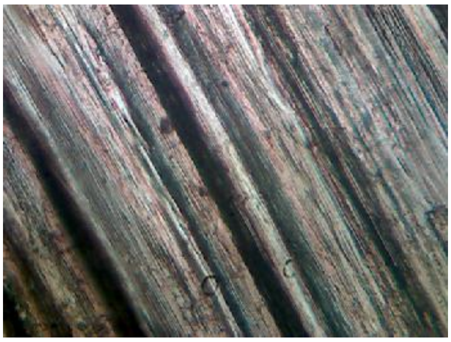

Fig. 24. Al-20%Si

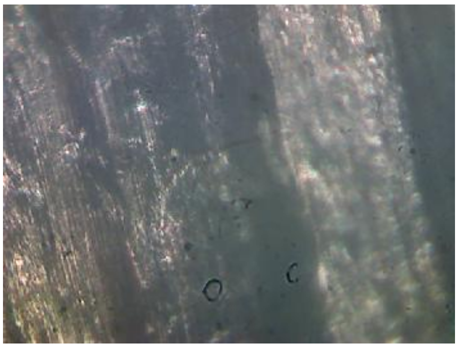

Fig. 25. Al-23%Si

The mass loss in the specimen after each test was estimated by measuring the weight of the specimen before and after each test using an electronic weighting machine having accuracy up to 0.001mg. Care has been taken that the specimens under test are continuously cleaned with woolen cloth to avoid the entrapment of wear debris and to achieve uniformly in experimental procedure. The test pieces are cleaned with tetra-chloro-ethylene solution prior and after each test.

The wear test values tabulated in Table 5. The wear rate decreases as the hardness of the alloy increases. It is in agreement with that of Archard's adhesion theory of wear as given in eq 1 (Pramila Bai and Biswas, 1991).

$$WR=k\times W/H \qquad \ldots\ldots (1)$$

Where, WR=wear rate in mm3/m; k=wear coefficient; W= applied load in N; H=hardness in N/mm2. It is noticed that the height loss due to wear decreases when the percentage of silicon increases. The decrease in the height loss with increasing percentage of silicon can be attributed to the presence of hard silicon particles adhered to the alloy. By keeping the sliding speed and sliding distance constant height loss may vary due to different loads applied on it by testing the specimen for one hour.

Calculated Formulas

1) Vs = D/t, Vs = PDN /60
Sd = (Vs* Time) mt
Wr = Δm * 9.81/ Sd

Diameter of the pin on disc (D) = 25mm

R = D/2 = 12.5mm

2) N = 800 rpm
Vs = PDN/60 = {P*(25*10-3)*800} /60=1.047 mt/s
Sd = 1.047*3600 = 3769.911184 mt

Wear Micro structures

The worn surfaces of the samples were examined under optical microscope to investigate the wear mechanism. The wear scoring depth in case of Al-6%Si alloy is more as compared to Al-10%Si and goes on decreasing in addition of silicon percentage. Where the scoring depth is lowest in case of Al-23%Si alloy. The presence of scoring marks may be due to abrasion by entrapped debris, hard asperities on the hardened steel counter face or work hardened deposits on the counter face (Basavakumar *et al.,* 2009). It is also possible that the hard dispersoid particles or fractured pieces are mechanically dislodged during wear. The pinholes so formed act as potential sites for nucleation and growth of cracks. When cracks grow and get interconnected, a layer of metal gets removed (Das *et al.,* 2008). The wear microstructures of Al-6%Si, Al-10% Si, Al-13% Si, Al-16%Si, Al-20%Si and Al-23%Si are shown in figures 20,21,22,23,24,25 respectively.

Conclusions

The conclusions drawn from the conducted investigations are as follows:

- The aluminum-silicon alloys are made from sand casting so theirbe a homogeneous distribution of silicon throughout the cast.
- The amount of primary silicon increases with increase in silicon amount in the cast.
- Yield strength an increases with the increase of weight percentage of silicon.
- Ultimate tensile strength increases with the increase of weight percentage of silicon.
- Total elongation decreases with the increase of weight percentage of silicon.
- Hardness of the Al-Si composite increases with the increase in amount of silicon present.
- Toughness of the Al-Si composite increases up to eutectic region and tends to decrease in hyper eutectic region and then gradually increases.
- The height loss due to wear decreases when the percentage of silicon increases.

REFERENCES

Archard, J. F. 1953. “Contact and rubbing of flat surfaces”, *Journal of Applied Physics*, Vol 24, No 8, pp981-988.

Balamugundan, B., Karthikeyan, 2014. Enhancement of Mechanical Properties on Al-alloys.

Basavakumar, K.G., Mukunda, P.G., Chakraborty, M. 2009. Dry sliding wear behaviour of Al–12Si and Al–12Si–3Cu cast alloys, Mater. Des., Vol. 30, pp. 1258–1267.

Camille Murray, 6 Morgan, Ste 156, Irvine CA 92618. Nanovea.com

Chen, M., Alpas, A.T. 2008. Ultra-mild wear of a hypereutectic Al–18.5 wt. % Si alloy, Wear, Vol. 265, pp. 186–195.

Das, S., Mondal, D.P., Sawla, S., Ramkrishnan, N. 2008. Synergic effect of reinforcement and heat treatment on the two body abrasive wear of an Al–Si alloy under varying loads and abrasive sizes, Wear, Vol. 264, pp. 47–59.

Ilangovan, S. Effects of solidification time on Mechanical properties and Wear Behavior of Sand cast Aluminum alloy.

Jonathan, A. Lee NASA- Marshall Space Flight Centre, Mail code ED33, Huntsville, AL 35812, USA.

Pramila Bai, B.N. and S.K. Biswas, 1991. Effect of magnesium addition and heat treatment on mild wear of hypoeutectic aluminium-silicon alloys,*Acta Metall. Mater.*, Vol. 39:5, pp. 833-840.

RitizoYonagawa, Degassing and deoxygenating agent for use in casting an aluminum alloy. Patent US3194695.

Standard test method for wear testing with a pin-on-disk Apparatus.

Standard Test Methods for Tensile Testing Wrought and cast Aluminum and Magnesium Alloy products.

www.kettometals.com/Article 80.htm salvaged on 16th April 2001.

****