FABRICATION OF CAST ALUMINIUM-SILICON (Al-Si) AND ALUMINIUM-MAGNESIUM (Al-Mg) ALLOYS AND THEIR PROPERTIES

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Received: 19.07.2016
Accepted: 11.11.2016

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Abstract

In the present investigation, three distinct aluminium-silicon (Al-Si) containing 7 wt.%, 12 wt.%, 14 wt.% of silicon and two different aluminium-magnesium (Al-Mg) alloys containing 2.5 wt.%, 4.5 wt.% of magnesium were prepared by casting route method. The prepared Al-Si and Al-Mg alloys have homogeneous distribution of the second rich phase throughout the cast. The microstructural analysis was done by using both optical and scanning electron microscope. Hardness values were measured with a Vickers hardness tester and tensile properties were determined by using Instron universal testing machine. Further, the wear properties were studied by using a ball-on-plate wear tester. The obtaining results highlight the hardness, tensile properties and wear resistance are increases with increasing percentage of second rich phase in aluminium. The worn surfaces of these alloys revealed that the surfaces have cracks, grooves, scoring marks and debris.

Keywords: Casting, Vickers hardness, yield strength, Worn surfaces

1 Introduction

Considerable efforts have been devoted for replacing steel with aluminium alloys in manufacturing auto bodies because of their promising weight saving, that ensures fuel consumption and pollution reduction, or even improvement of certain safety and driving performances [1-3]. The aluminium alloys have some advantages such as a high corrosion resistance, low weight, low cost and good weldability [4-7]. Since 1920, after the first aluminium based alloy sheets introduced into car body construction [8], many attempts have been made on aluminium alloys to improve the construction of car bodies as well as many auto mobile parts. Nowadays, the environment protection and energy savings are important factors for society. So, we need to develop the vehicles which are eco-friendly and low weight for energy saving. [9]. The applications of aluminium alloys for the machine parts are increasing day to day in the industry. Recently, Al-Si alloys find applications in such tribological components such as clutches, cylinder

DOI 10.12776/ams.v22i4.760

p-ISSN 1335-1532
e-ISSN 1338-1156

liners and pistons in the automotive industry [10-12]. Favourable tribological properties combined with a low coefficient of thermal expansion have resulted in a wide spread use of hypereutectic Al-Si alloys. These alloys show good wear resistance, which is attributed to the presence of rich phase silicon particles distributed throughout the aluminium matrix [13-14]. Numerous authors have been reported on the wear behaviour of Al–Si alloys [6-8]. However, out of these reports, it has been observed that, only a few of them have been devoted for investigating systematically the effect of silicon content on the wear and frictional behaviour of aluminium. The wear properties of these alloys have been studied mainly under the dry sliding conditions. On the other hand, the Al-Mg alloys have a favourable formability due to solution hardening. These alloys can achieve high strength and high strain hardening ability, which enable a stable behaviour in the complex forming operation and reducing the further material flow in the locally strained regions [15-17]. Besides the favourable forming behaviour, the present solute atoms can induce some harmful surface appearance of produced auto body parts. The casting Al-Si and Al-Mg alloys are having many important applications in automotive and aerospace industry because of their light weight can help reduce the vehicle weight and improve fuel economy and good mechanical properties [18-20]. Therefore, it is worthy to study the properties of Al-Si and Al-Mg alloys. Consequently, these alloys have excellent cast ability, weldability, thermal conductivity, high strength to weight ratio, excellent corrosion and wear resistance [21-22]. In the present study, we systematically investigated the microstructural, mechanical and wear properties of Al-Si and Al-Mg alloys with different wt% of Si and Mg respectively, fabricated by casting route method.

2 Experimental

Different compositions of Al-Si (Al-7%Si, Al-12%Si and Al-14%Si) and Al-Mg (Al-2.5%Mg and Al- 4.5%Mg) alloys were prepared by casting route method in a high frequency induction furnace. The furnace temperature was set at 720°C, which is well above the melting temperature of Al. When the Al is melted fully, the required amount of silicon and magnesium was added in the corresponding crucibles. For Al-Mg alloys, some loose Mg was added by wrapping them in aluminium foils, to avoid burn out. A plunger was used to keep solid Mg under the liquid pool till it gets melted. Some modifier and degassing agent were also added in the melt. Each melt was stirred for 30 s after the addition of the modifier, followed by a holding time of 5 minutes. The liquid was then poured into a metallic mould surrounded by fireclay bricks. The metallic mould was preheated at a temperature of 500°C.. The chemical compositions of the cast alloys assessed using optical emission spectrometer (model: ARL 3460 Metals Analyzer, Thermo Electron Corporation Limited). Microstructures of prepared alloys were observed under computerized Optical microscope (Model: Olympus BX51, Essex, UK). Vickers hardness tester (Leco LV 700) was used to determine hardness values of different compositions of Al-Si and Al-Mg alloys using 5Kg indentation load for a dwell time of 15 seconds. Ball-On-Plate wear tester (model: TR-208 M1) was used to determine the wear characteristics of alloys. The normal load applied on ball by dead weight through a pulley string arrangement. In the present study, no lubricant was used and the tests were carried out under dry sliding condition. A JEOL JSM-6480 LV scanning electron microscope was used to the study worn surfaces.

3 Results and Discussion

Fig. 1 shows the optical microstructures of different composition of Al-Si alloys. The Si rich phase is homogeneous throughout the Al matrix. Figure 1.1 (a) shows the Al-7%Si alloy, in this alloy Si rich phase (indicated with arrows) is like a long chain in the entire Al matrix and Al is having some rounded shape and this shape is formed due to breaking of dendrite arms because of the stirring action present in the liquid freezing at a fast rate in the metal mold. In this structure, the white regions are the α-Al, whereas the Si rich particles are distributed throughout the matrix. The similar type of microstructure was reported by Torabian et al. [23] for Al-8wt% Si. The microstructure of Al-12%Si alloy is shown in **Fig. 1**(b).

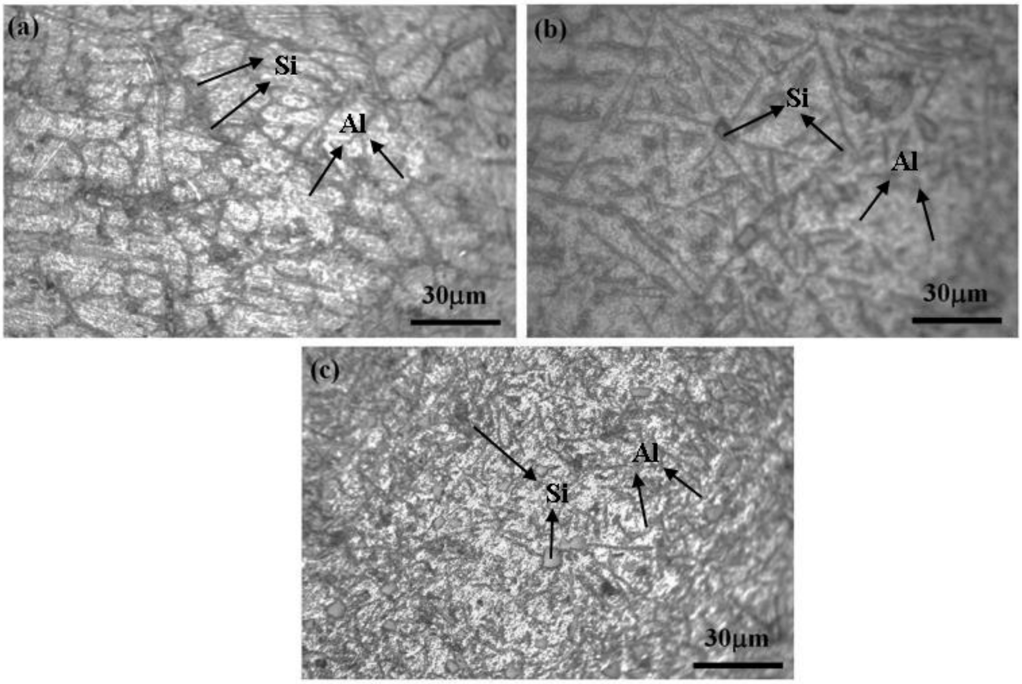

Fig. 1 Optical microstructures of (a) Al-7%Si, (b) Al-12%Si, and (c) Al-14%Si alloys

Here, long chain like structure is absent, instead some needle shaped Si can be observed. Very less number of the eutectic secondary Si particles is present in this alloy. From this microstructure, it has been observed that the Si particles are more in number than the hypoeutectic alloy. **Fig. 1**(c) shows the microstructure of hypereutectic Al-14%Si alloy. It consists of the primary α-Al dendrites, along with eutectic Si particles. The large number of eutectic secondary rich phase is distributed throughout the alloy. The secondary phase Si particles are fine and plate like structure. The microstructure of Al-Mg alloys is illustrated in **Fig. 2**. The Mg rich phase is homogeneous throughout the Al matrix. The microstructure shows that the elongated shaped Mg is present. Some pores (irregular black area) are also present in the microstructure of Al-2.5%Mg alloy (**Fig. 2**(a)). **Fig. 2**(b) shows the microstructure of Al-4.5%Mg alloy.

Hardness values of all samples were measured using a Vicker's hardness tester with dwell time of 15s and applied load of 5 kgf. For each alloy composition, five indentations were taken and average value is calculated. The **Table 1** shows the Vickers hardness number (VHN) of different compositions of Al-Si alloys and Al-Mg alloys. From the result, it has been concluded that the Vickers hardness number increases with the increase of Si percentage in the alloy. From the table 1 it can be reported the Al-14Si alloy having the more hardness (69±1.38) than the other alloys. This may be due to the increase of second phase Si content, which is harder. On the other hand, Al-4.5%Mg alloy having the higher hardness compared to the Al-2.5%Mg, the reason may be increasing the Mg content, the alloy becomes harder.

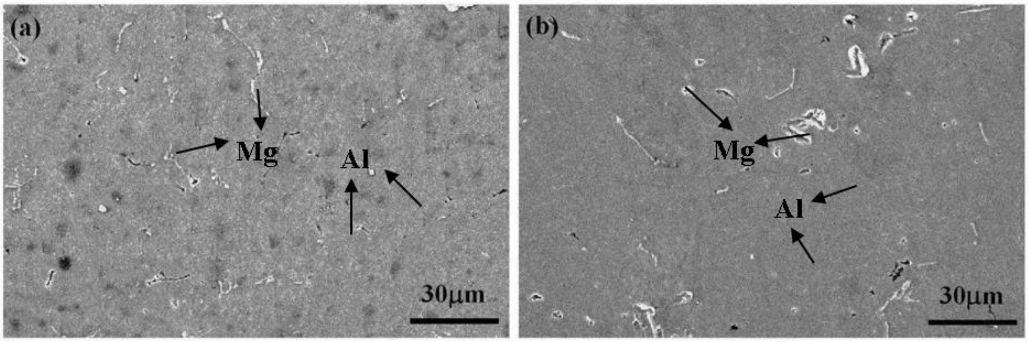

Fig. 2 Optical microstructures of (a) Al-2.5%Mg, and (b) Al-4.5%Mg alloys

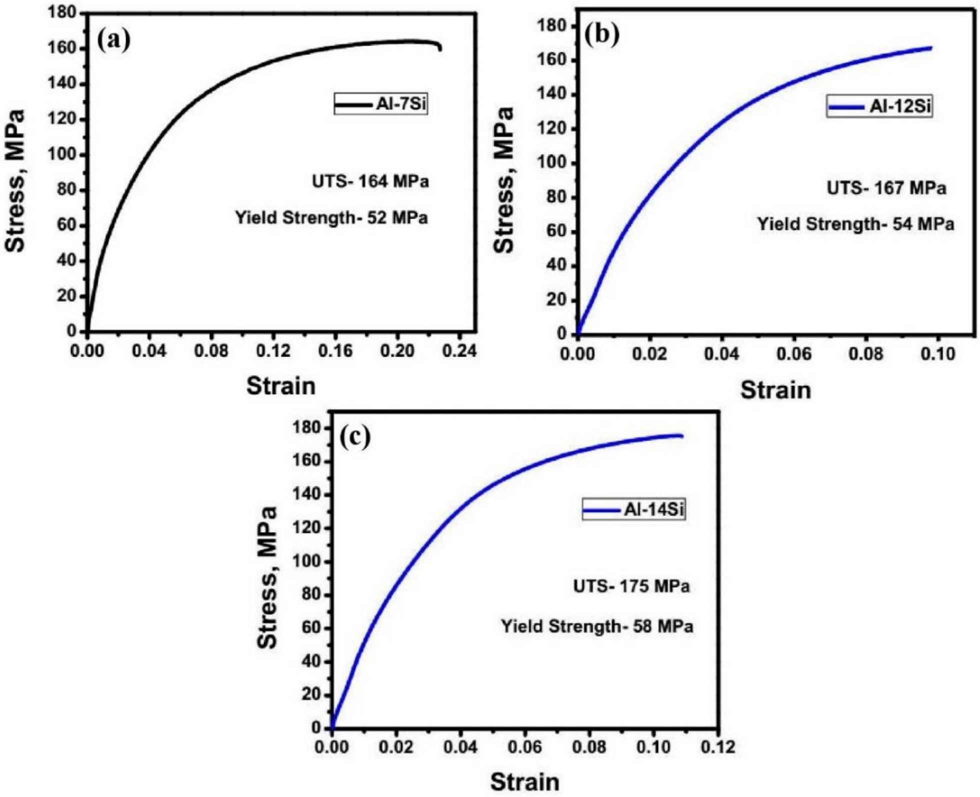

Fig. 3 Engineering stress-strain curves of (a) Al-7%Si, (b) Al-12%Si, and (c) Al-14%Si alloys

Fig. 3 shows the engineering stress-strain curves for the various compositions of Al-Si alloys. **Fig. 3**(a) illustrates the stress-strain curve of Al-7%Si alloy, it can be observed that the transition from

DOI 10.12776/ams.v22i4.760

p-ISSN 1335-1532
e-ISSN 1338-1156

elastic to plastic zone is continuous and hence the yield strength has been determined by 0.2% offset method. As of the results, it can be concluded that the ultimate tensile strength (UTS) is 164 MPa and yield strength is 52 MPa. From the **Figs. 3**(b) and **3**(c), it has been concluded that the tensile strength is increasing with the increase of Si content of the alloy. The average tensile properties of three alloys (Al-7%Si, Al-12%Si and Al-14%Si) have been determined from two experiments. It can be observed that there is a limit up to which the applied stress is directly proportional to the induced strain, the end of this linear portion is the yield point of the material, above which the material starts plastically deforming and when the applied load goes beyond the limit that can borne by the material, the specimen breaks. The stress at elastic limit is called yield strength. The maximum stress reached in a material before the fracture is termed as the ultimate tensile strength. The Al-14%Si alloy having the greatest tensile strength because of Si is the harder phase. Itcan also observe from the microstructure (**Fig. 1**) that Si rich phase is distributed uniformly throughout the matrix and there was formation of fine grain structure. Due to fine grain structure the tensile strength is increased. In the present work, the hypereutectic (Al-14%Si) alloy exhibits good mechanical properties than the hypoeutectic (Al-12%Si) and eutectic (Al-7%Si) alloys. In Al-Si alloys, with the increasing of Si rich phase, the ultimate tensile strength (UTS) and yield strength also increases. The hypereutectic Al-14% Si alloy shown higher UTS and yield strength compared to the other alloys.

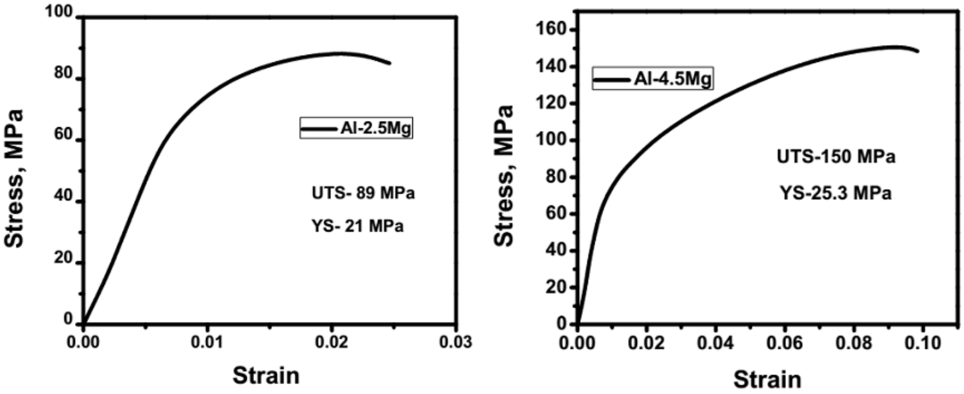

Fig. 4 Engineering stress-strain curves of (a) Al-2.5%Mg, and (b) Al-4.5%Mg alloys

Consequently, the tensile tests were carried out for the two different compositions of Al-Mg alloys (Al-2.5%Mg and Al-4.5%Mg). Each test was repeated two times for achieving good results. **Fig. 4** demonstrate the engineering stress-strain curves for the Al-Mg compositions. It can be shown that the UTS value is 89 MPa and yield strength is 21MPa. Results revealed that the tensile strength increases with the increase of Mg content in the alloy; it indicates that Mg content plays an important role in the Al-Mg alloy. The main reason for this increasing the Mg content in the alloy the fine grain size increases and the alloy becomes harder. In Al-2.5%Mg alloy having large porosity than the Al-4.5Mg alloy due to porosity the tensile strength is decreases this is also one of the reason.

Fig. 5 shows the variation of wear rate with respect to load for Al-Si alloys. It may be seen that the wear rate is strongly dependent on the applied load and it increases with load. As silicon percentage increases in the alloy the wear rate decreases continuously. In this present work, the

Al-14%Si alloy having the low wear rate than the other alloys. The wear rates were observed in the three distinct applied loads (10N, 20N and 30N), at low load the wear rate is very low for all compositions of alloy. Wear in this region is interpreted as reflecting the fracture of the oxide layer at the wear interface, especially since the load levels involved are insufficient to cause deep penetration and deformation in the metal below the oxide [24-26]. At higher loads, the wear rate is more due to accelerated fracture of the oxide layer on the surface and thus cause increases the wear. As the surface oxide is removed, the fresh metal exposed is further oxidized. In this way, the wear rate is increases with increasing applied load but increasing Si content in the alloy the wear rate decreases. It is due to the presence of Si, which is harder phase in the alloy.

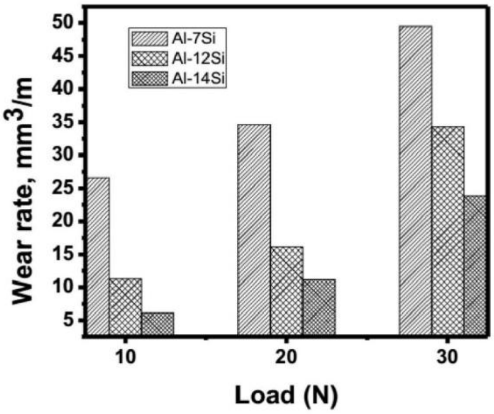

Fig. 5 Wear rate versus load of Al-7%Si, Al-12%Si, and Al-14%Si alloys

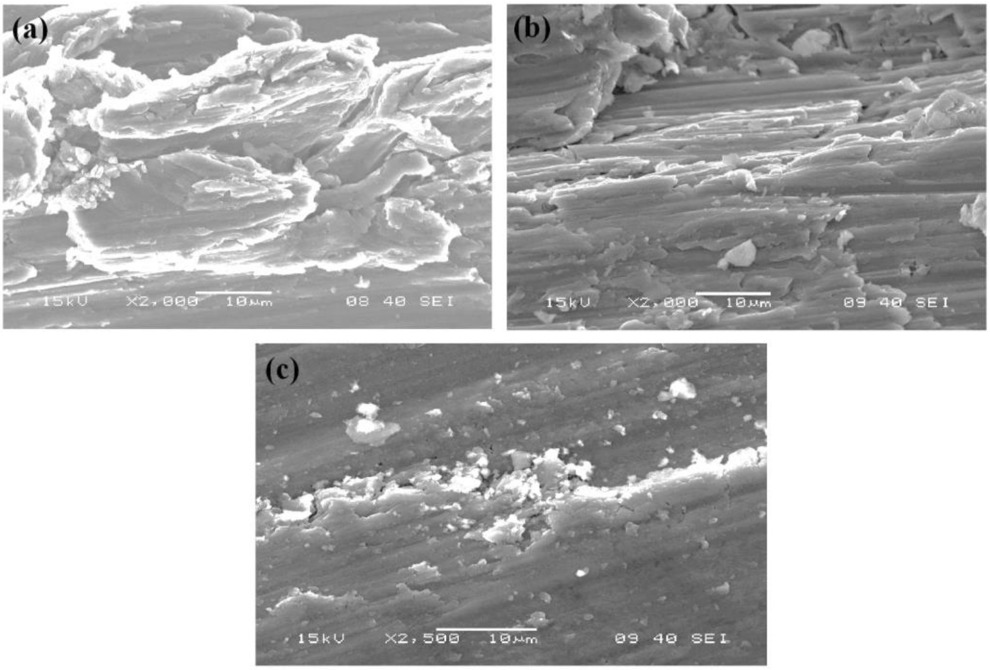

Fig. 6 Worn surfaces of (a) Al-7%Si, (b) Al-12%Si and (c) Al-14%Si alloys

DOI 10.12776/ams.v22i4.760

To investigate the wear mechanism, the surfaces of the worn samples were examined under SEM (**Fig. 6**). Typical SEM images are illustrated in **Fig. 6**(a)-6(c). On examination of the worn surfaces at lower magnification it can be observed that the micrographs contain fine scoring marks. The scoring depth decreases with increment of silicon percentage in Al-Si alloys. From the above discussion, the wear rate of Al-7%Si alloy is maximum, moderate wear rate is there for the case of Al-12%Si alloys and least for Al-14%Si alloy. The worn surfaces are in good agreement with the observations in wear rate. The scoring depth is lowest in Al-14%Si alloy. For high magnification images, evidence of extensive plastic flow and cracking can be observed. These are the two likely modes of crack initiation and propagation for the current set of Al-Si alloys. Cracks may initiate in the highly work-hardened layer, particularly in the subsurface region. When cracks grow, they get interconnected, so that a layer of metal is removed. It is also possible that the hard-dispersed particles or fractured pieces thereof are mechanically dislodged during wear. The pinholes so formed act as potential sites for nucleation and growth of cracks, paving the way for delimitation wear.

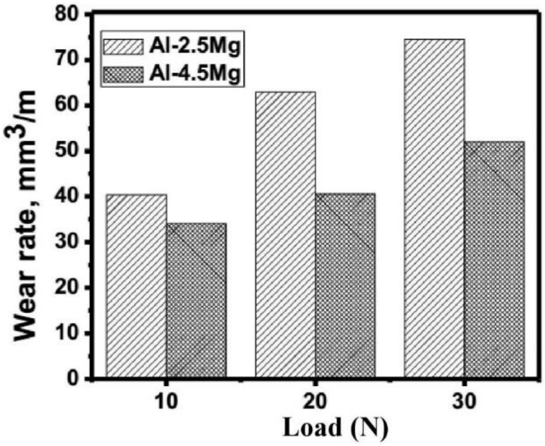

Fig. 7 Wear rate versus load of Al-2.5%Mg and Al-4.5%Mg alloys

For Al-Mg alloys the variation of wear rate versus applied load shown in **Fig. 7**. At low loads wear rate is small because the contact surface area would be less and friction between two sliding surfaces would be less. Due to less friction, the harder material will grind the softer material at lower rate. When the applied load is increased, the surface area in contact would also be increased because of this friction between two sliding surfaces would increase. Due to friction and more surface area in contact with the harder material, it will grind the softer material at higher rate [27-30]. In this present work, it has been reported that the wear rate is increased with increasing load and decreased with the increasing Mg content in the alloy. The morphologies of worn out surfaces of Al-2.5%Mg and Al-4.5%Mg are illustrated in **Fig. 8**, obtained under SEM for moderate load (20 N) and dry sliding conditions. For all the testing rounds, it was observed that, at lower magnification Al-Mg alloys have smooth and narrow tracks.

The images do not reveal huge variation in their appearances, although tiny voids and grooves can be observed in the Al-2.5%Mg alloy. The formation of these voids just below the surface of Al-2.5%Mg alloy appears to be due to shear fracture; typical of abrasive wear [28]. The in-depth examination of the worn surfaces at high magnification reveals dislodgement of wear debris from the surface. The extent of dislodgement of material is more in case of Al-2.5% Mg alloy (**Fig. 8**(a)) as compared to Al-4.5% Mg alloys. Formation of cracks and voids are observed in the Al-2.5% Mg alloy; these are shown by arrow marks in **Fig. 8** (b). Overall, it is clear from the high magnification worn surfaces that the wear of Al-2.5% Mg alloy is more as compared to Al-4.5% Mg alloys.

Table 1 Various mechanical properties of Al-Si and Al-Mg alloys

Composition	Avg VHN	UTS (MPa)	Yield strength (MPa)
Al-7%Si	52±1.31	164±2.3	52±1.6
Al-12%Si	66±0.78	167±1.8	54±1.8
Al-14%Si	69±1.38	175±2.4	58±2.1
Al-2.5%Mg	54.6±1.10	89±2.1	21±2.4
Al-4.5%Mg	63±1.30	150±2.2	25±2.2

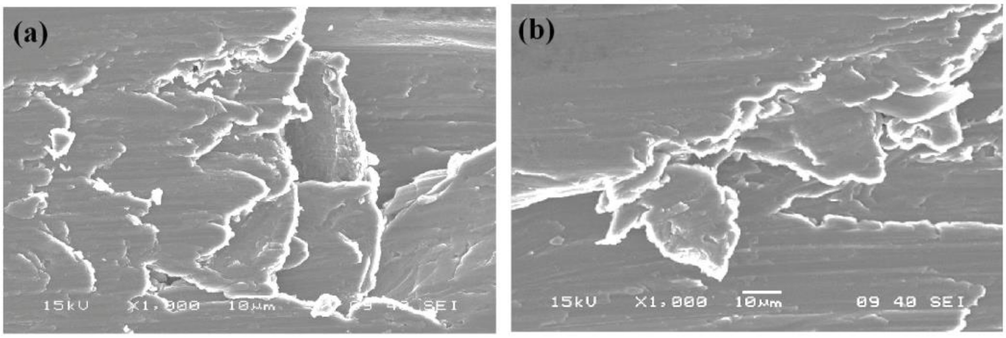

Fig. 8 Worn surfaces of (a) Al-2.5%Mg, and (b) Al-4.5%Mg alloys

4 Conclusions

In the summary, the prepared Al-Si (Al-7%Si, Al-12%Si and Al-14%Si) and Al-Mg (Al-2.5%Mg and Al- 4.5%Mg) alloys have homogeneous distribution of the second rich phase throughout the cast. The chemical composition analysis of the prepared alloys revealed this fact. Hardness, yield strength and ultimate tensile strength increases, with increasing Si content in case of Al-Si alloy as well with increasing Mg content in case of Al-Mg alloy. The increment in strength is associated with reduced total percentage of elongation. The wear rate is dependent upon alloy composition. The wear rate decreases with increasing Si content and Mg content of the respective alloys. The nature of the wear process changes with change in alloy composition and experimental conditions. Scoring marks at lower magnification greatly vary for different compositions of Al-Si alloys, whereas variation is less in case of Al-Mg alloys. The high magnification images reveal cracking of the surface, formation of voids and dislodging of debris from the surfaces.

References

[1] I. J. Polmear: Materials transactions, JIM, Vol. 37, 1996, No. 1,p, 12-31, doi: 10.2320/matertrans1989.37.12

[2] W. S. Miller, L. Zhuang, J. Bottema, A. J. Wittebrood, P. De Smet, A. Haszler, A. Vieregge: Materials Science and Engineering A, Vol. 280, 2000, No.1, p.37-49, doi: 10.1016/S0921-5093(99)00653-X

[3] J. Hirsch: Materials Transactions, JIM, Vol. 52, 2011, No. 5, p.818-824, doi:10.2320/matertrans.L-MZ201132.

[4] T. Dursun, C. Soutis: Materials & Design, Vol. 56, 2104, No. 1, p.862-871, doi:10.1016/j.matdes.2013.12.002.

[5] A. K. Dahle, Y. C. Lee, M. D. Nave, P. L. Schaffer, D. H. StJohn: Journal of Light Metals, Vol. 1, 2001, Sl. 1,p. 61–72, doi: 10.1016/S1471-5317(00)00007-9

[6] A Heinz, A Haszler, C Keidel, S Moldenhauer, R Benedictus, W.S Miller: Materials Science and Engineering: A, Vol. 280, 2000, No. 1, p. 102–107, doi : 10.1016/S0921-5093(99)00674-7

[7] B. C. Pai, G. Ramani, R. M. Pillai, K. G. Satyanarayana: Journal of Materials Science, Vol. 30, 1995, No. 8, p. 1903-1911, doi:10.1007/BF00353012

[8] A. Charai M. X. Pan, A. M. Sherman: Materials Science Forum, Vol, 331, 2000, No. 2, p. 3-4, doi:10.4028/www.scientific.net/MSF.331-337.3

[9] R. Ambat, N. N. Aung, W. Zhou: Corrosion Science, Vol. 42, 2000, No. 8, p. 1433-1455, doi: 10.1016/S0010-938X(99)00143-2

[10] D. Li, C. Cui, X. Wang, Q. Wang, C. Chen, S. Liu: Materials and Design, Vol. 90, No. 1, 2016, p. 820–828, doi:10.1016/j.matdes.2015.10.078

[11] Y. Zhang, X. Miao, Z. Shen, Q. Han, C. Song, Q. Zhai: Acta Materialia,Vol. 97, No. 2, 2015, p. 357–366, doi: 10.1016/j.actamat.2015.07.002

[12] D. Li, C. Cui, X. Wang, Q. Wang, C. Chen, S. Liu: Materials & Design, Vol. 90,No. 1, 2016, P. 820–828, doi:10.1016/j.matdes.2015.10.078

[13] M. I. A. E. Aal, H. S. Kim: Materials & Design, Vol. 53, 2014, p. 373–382, doi:10.1016/j.matdes.2013.07.045

[14] N. Kang, P. Coddet, C. Chen, Y. Wang, H. Liao, C. Coddet: Materials & Design, Vol. 99, 2016, p.120–126, .doi: 10.1016/j.matdes.2016.03.053

[15] B. Zou, Z. Q. Chen, C.H. Liu, J.H. Chen: Applied Surface Science, Vol. 298, 2014, p. 50–55,doi: 10.1016/j.apsusc.2014.01.078

[16] B. H. Lee, S. H. Kim, J. H. Park, H. W. Kim, J. C. Lee: Materials Science and Engineering: A, Vol. 657, 2016, p. 115–122, doi: 10.1016/j.msea.2016.01.089

[17] M. A. García-Bernal, R. S. Mishra, R. Verma, D. Hernández-Silva: Materials Science and Engineering: A, Vol. 670, 2016, p. 9–16, doi:10.1016/j.msea.2016.05.115

[18] T. Ying, M. Y. Zheng, Z. T. Li, X. G. Qiao: Vol. 608, 2014, p. 19-24, doi: 10.1016/j.jallcom.2014.04.107

[19] X. Xu, Z. Yang, Y. Ye, G. Wang, X. He: Materials Characterization, Vol. 119, 2016, p. 114–119, doi:10.1016/j.matchar.2016.07.011

[20] I. S. Golovin, A. V. Mikhaylovskaya, H. R. Sinning: Journal of Alloys and Compounds, Vol. 577, 2013, p. 622–632, doi: 10.1016/j.jallcom.2013.06.138

[21] D. K. Dwivedi: Materials Science and Engineering: A, Vol. 382, p. 328–334, doi:10.1016/j.msea.2004.05.014

[22] K. G. Basavakumar, P. G. Mukunda, M. Chakraborty: Materials Design. Vol. 30, 2009, p.1258-1267, doi: 10.1016/j.matdes.2008.07.003

[23] H. Torabian, J. P. Pathak, S. N. Tiwari: Wear characteristics of Al-Si alloys, Wear, Vol, 172, 1994, No. 1, p.49-58, doi:10.1016/0043-1648(94)90298-4

[24] R. L. Deuis, C. Subramanian, J.M. Yellup: Dry sliding wear of aluminium composites-A review, Composites Science and Technology, Vol. 57, 1997, No. 4, p.415-435.doi:10.1016/S0266-3538(96)00167-4
[25] M. M. Haque, A. Sharif: Journal of Materials Processing Technology, Vol. 118, 2001, p.69-73, doi: 10.1016/S0924-0136(01)00869-X
[26] B. N. Pramila Bai, S. K. Biswas: Characterization of dry sliding wear of Al-Si alloys, Wear, Vol, 120, 1987, No. 1, p.61-74, doi:10.1016/0043-1648(87)90133-5
[27] E. Aghion, B. Bronfin: Magnesium Alloys Development towards the 21st Century, Mater. Sci. Forum, Vol, 350-351, 2000, No. 2, p.19-30, doi:10.4028/www.scientific.net/MSF.350-351.19
[28] A. K. Gupta, D. J. Lloyd, S. A. Court:Materials Science Engineering. A, Vol. 316, 2000, p.11-17, doi : 10.1016/S0921-5093(01)01247-3
[29] D. S. Mehta, S. H. Masood, W. Q. Song:Journal of Materials Processing Technology, Vol. 155–156, 2004, p.1526-1531, doi : 10.1016/j.jmatprotec.2004.04.247
[30] H.İ. Demirci, H. Evlen:Journal of Alloys and Compounds, Vol. 510, 2012, p. 26–32, doi: 10.1016/j.jallcom.2011.08.074