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Determination of the effect of Si content on microstructure, hardness and wear rate of surface-refined Al-Si alloys

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Abstract

Surface refining of Al–Si alloy was carried out using the 'Gas Tungsten Arc' (GTA) heat source and the effect of Si content on the microstructure, hardness and wear properties of the surface modified alloys was evaluated. In order to further improve its wear resistance, the Surface Refining Process (SRP) was employed in this study. In the SRP, the surface of the parent material is melted by a suitable heat source and the molten zone is allowed to solidify progressively. It can be noted from the literature that e-beam and laser are the only heat sources employed. Both these sources are highly expensive and their productivity is also low. The depth of the modified layer by e-beam or laser process is found to be inadequate for wear applications. In order to overcome the above shortcomings, in this study, the surface refining of Al–Si alloy was carried out by using an inexpensive, high productivity and commonly available GTA source. In this work, the effect of Si content on the properties is evaluated by varying the Si content from 4-16 wt%. The alloys were sand–cast in the form of bar(150x30x30 mm). The Surface melting was carried out with the following GTA parameters: current-150 A, travel Speed-2 mm/s, arc length-3 mm, tip angle-180^0 and electrode diameter-2.4 mm. The hardness was measured at different locations by using Vickers Hardness Tester by applying 100 gm load for 15 s and an average value was taken. The wear testing was conducted as per ASTM G99 standard under a dry sliding condition in air using Pin–on–Disc wear tester. In this study, it was noted that the typical as–cast microstructure of the Al–Si alloy illustrating the elongated morphology of the eutectic–Si has been completely refined, and the eutectic–Si is finely dispersed within the α–Al matrix. It is inferred that the microstructure was refined due to fast cooling to have a globular eutectic–Si dispersed within a fine–grained matrix in the GTA process. It was found that the depth of the modified layer is significantly higher than that obtained in the e-beam/laser process. The hardness of the modified layer was found to increase when the Si content is increased from 4-16 wt%. The wear rate is found to decrease with an increase in the Si content whereas the coefficient of friction tends to remain the same. The wear mechanism was found to be adhesive. Finally, the peak hardness of the modified layer increased significantly upon ageing. The observations are in agreement with that of previous studies.

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Keywords: surface refining, Al–Si alloys, GTA, microstructure, hardness, wear rate.

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1. Introduction:

In commercial, industrial, automotive and aircraft applications Al-Si alloys are extensively used in recent years. The typical alloying are magnesium, copper, manganese, zinc and silicon. Al – Si alloys are of greater importance to engineering industries as they have high strength to weight ratio, high wear resistance, low density, low coefficient of thermal expansion etc. Si content in Al imparts low shrinkage and high fluidity, which proves in good weldability and castability. Al – Si system is a binary eutectic with limited solubility of Al in Si and limited solubility of Si in Al. According to the concentration of Si content in weight percentage, the Al – Si alloy system are divided into (i) Hypoeutectic (<12wt% Si), (ii) Eutectic (12 – 13wt%Si), (iii) Hypereutectic (14 – 25wt% Si) [1]. Al alloys which contain major additive elements of Si and Mg, are replaced with steel in automobile industries. These alloys are subject of several scientific studies in the past years and in several of these applications, the wear resistance plays an important role. The researchers have proposed a method called 'Surface Refining Process' (SRP) in order to further improve the tribological properties of Al – Si alloys. In the SRP, heat source is used to melt the parent material surface to form a molten zone and the zone which is melted is allowed to solidify across the length of the substrate as the heat source travels progressively. The researchers envisaged the benefits because of the formation of intermetallic compound and the fine grain structure, due to rapid cooling of the molten pool. As a result, it is expected to increase the hardness of the treated surface significantly.

The SRP studies of Al – Si alloys were conducted in the past where, the heat sources were employed e-beam or laser. It have been observed from the study of Hegge and De Hosson [2] that the laser refining of Al-Si alloys the resulting microstructure was

- Cellular near the top surface,
- Dentrite in the middle and
- Again cellular at the bottom of the modified layer.

Watkins et. al [3] has reviewed the work of Lasek et al [4], Luft et al [5], Leech [6], Pierantoni et al [7] and stated that the results are similar to that of Hegge and De Hosson [2].

By the literature review, it can be understood that laser or e-beam are the only heat sources employed in the SRP. Both these sources have low productivity and are also highly expensive. The depth of the modified layer called penetration is also found to be inadequate for wear application in the case of laser and e-beam melting practices as reported by Tomida and Nakata [8]. Therefore it is worthwhile to further investigate the surface refining of various composition on eutectic–Si of Al–Si alloys by using high productivity, inexpensive and commonly available 'Gas Tungsten Arc' (GTA) source.

In the present study, the effect on the microstructure is evaluated for the Al – Si alloy on various composition of Si (4, 8, 10, 12, 14, 16) wt% on the surface melting using GTA. The hardness is determined as a function of the process variables, namely, current, arc length and travel speed. Further, the wear rate and the friction coefficient (CoF) were determined in the as – cast and as – refined conditions. Finally, the penetration of a single layer is compared with that obtained in the laser SRP. No other study has reported this type of investigation.

2. Experimental procedure

The alloy was prepared by the sand casting process. Arc spectrometry was used to measure the composition. The alloy composition are reported in Table – 1. The cast substrate is machined to the size of 150 x 30 x 30 mm respectively.

2.1. Surface refining

Surface refining was done on the machined substrate using GTA heat source in-order to melt the substrate surface to form a modified layer upon solidification. The experimental setup is shown in Fig. 1. The process variables used namely current, speed, and arc length are reported in Table – 2. The surface refined alloy specimens were cut, polished and macro – etched using the usual metallurgical technique.

2.2. Hardness testing

The Mitutoyo Vickers Hardness Tester was used with an applied load of 100 gm for a duration of 15 s. The micro hardness was taken at different locations on the modified layer for each specimen and an average value was calculated.

Table – 1 Composition of Al – Si alloy

S.No.	Al%	Si% (±0.4)	Mg%(±)0.1)
1	Balance	4	0.4
2		8	0.4
3		10	0.4
4		12	0.4
5		14	0.4
6		16	0.4

Table – 2 Experimental parameters for surface refining

S.No	Parameter	Value	Unit
1	Current	150	Amps
2	Travel speed	2	$mm.s^{-1}$
3	Arc Length	3	mm

Table – 3 Wear testing parameters

S.No.	Parameter	Value	units
1	Speed	424	rpm
2	Track diameter	110	mm
3	Velocity	2.5	$m.s^{-1}$

Fig. 1 Experimental setup

2.3 Wear testing

The wear testing was conducted under a dry sliding condition in air using Ducon Pin – on – Disc wear testing machine. A hardened steel disc plate with a hardness of Rc 60 is used as the counter face material with the surface roughness of Ra 0.15µm. The tests were conducted as per ASTM G99 standard. The wear testing parameters are listed in Table – 3. The wear rate expressed as $mm^3.m^{-1}$ was calculated from the slope of the height loss versus time plot.

3. Results & Discussion

3.1 Microstructure

Table 4 shows a typical as-cast and refined microstructure of the Al–Si alloys illustrating the elongated morphology of the eutectic–Si and the microstructure of the modified region, where the eutectic silicon is finely dispersed within the α–Al matrix. It is inferred that the microstructure is refined due to fast cooling to have a globular eutectic–Si dispersed in a fine–grained matrix in the case of GTA process of this study. This observation is in agreement with that of Biswas et. al. [9] in the case of laser refined Al–11%Si alloy. Biswas et. al. [9] have reported a marginal variation in the dendrite arm spacing. The nature of the solidification is dendritic in the present study whereas Biswas et. al. [9] have reported that a transition between dendritic to cellular takes place at a high scanning speed. The observations similar to those cited above have also been reported by Wong and Liang [10], Susnik et. al. [11], Watkins et. al. [3] and Franke et. al. [12]. Therefore, it can be concluded that the observations of the present study is consistent with that of previous studies.

3.2 Penetration

It was noted from Fig. 2, in this study that the layer depth (penetration) is upto 3 mm maximum. This observation is similar to that of Biswas et. al. [9], where, the depth decreased from 800 to 300 µm with an increase of scan speed from 6 – 12 $mm.s^{-1}$. Susnik et. al. [11] have found that there was a marginal increase in the penetration with the laser power input. Franke et. al. [12] in his work had reported that the layer depth was up to 1.2 – 1.5mm while using e-beam as heat source. Based on the above observations, we conclude that the penetration is higher in the GTA process than that obtained in the laser and e-beam process.

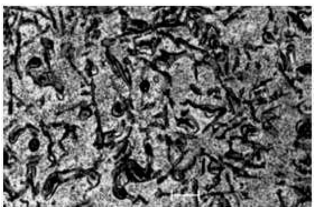
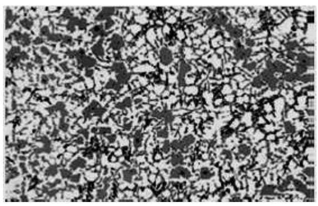
S.No.	Composition	As – cast	Refined
1.	Al - 8% Si		
2.	Al – 12%Si		
3.	Al – 16%Si		

Table. 4 Microstructure images of as–cast and refined for various composition of Al – Si alloys 200 X

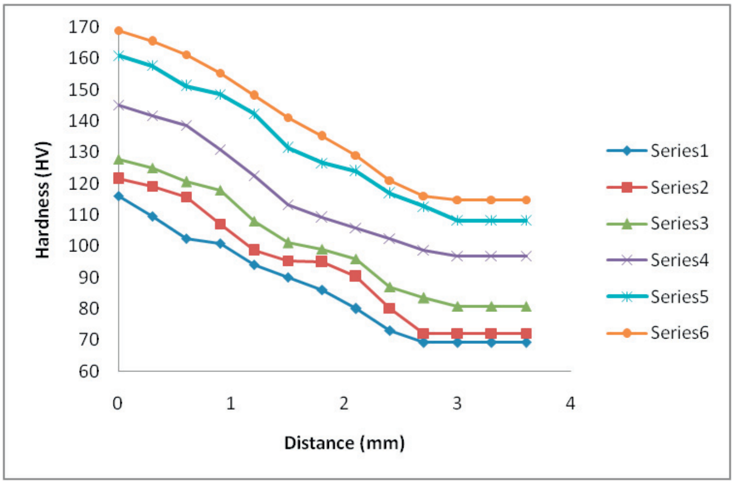


Fig: 2 Hardness versus Distance (layer depth)

3.3 Hardness

Fig. 2 shows a typical hardness profile in which the hardness decreases from the top surface to the bottom of the refined layer. The variation shown in Fig. 2 can only be attributed to the silicon content difference between the top and the bottom of the refined layer. Biswas et. al. [9] have also shown such a behaviour in the laser refined Al–11%Si alloy, whereas Susnik et. al. [11] has shown no such variation. Franke et. al. [12] have also shown such behaviour in e-beam refined layer on Al–35%Si alloy. Fig. 3 shows the variation in hardness with Si content for the substrate as well as refined Al–Si alloys. The hardness of the substrate increased from 70 to 115Hv with increase in Si content. Further, hardness of the refined alloy increased from 116 to 170 Hv. This is attributed to the grain refinement as a result of rapid solidification due to the surface refining process.

Fig. 4 shows a comparative study of the hardness obtained in this study with that of previous studies. It can be inferred from the bar chart that the results of this study are comparable to those of Biswas et. al. [9], Susnik et. al. [11] and Franke et. al. [12]. This finding illustrates that GTA could be considered as an alternative heat source for surface refining.

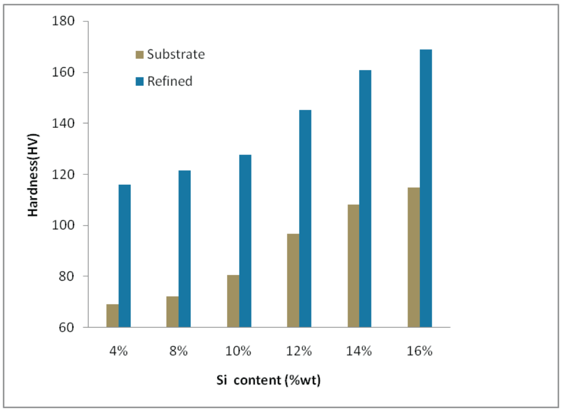


Fig. 3 Hardness versus Si content (%wt)

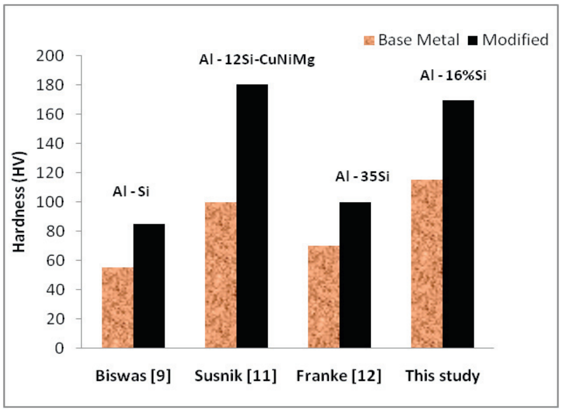


Fig. 4 Hardness comparison with previous studies

3.4 Wear rate

Fig. 5 shows a typical wear plot. Fig. 6 shows the wear rate for different Si content. It is observed that the wear rate decreases marginally with increase in Si content for substrate and refined alloy. It can also be inferred that the wear resistance for surface refined specimen is reasonably good when compared to that of substrate material.

Fig. 5 Wear rate versus time

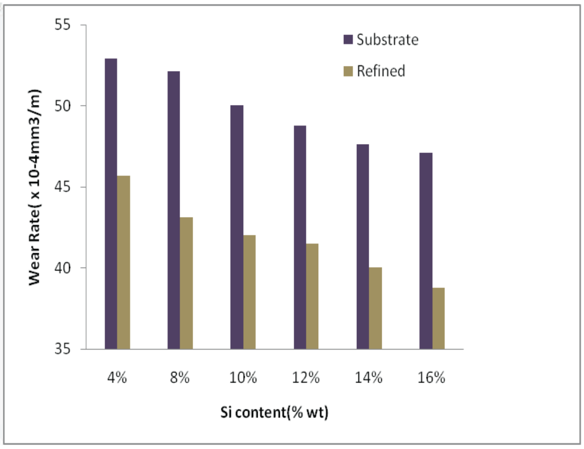


Fig.6 Wear rate versus Si content

Fig. 7 shows a typical plot of CoF with time. The CoF value remains almost a constant for all the conditions as shown in Fig. 8. Therefore, the Si content and refined surfaces do not have influence on CoF.

Fig. 7 Coefficient of Friction versus time

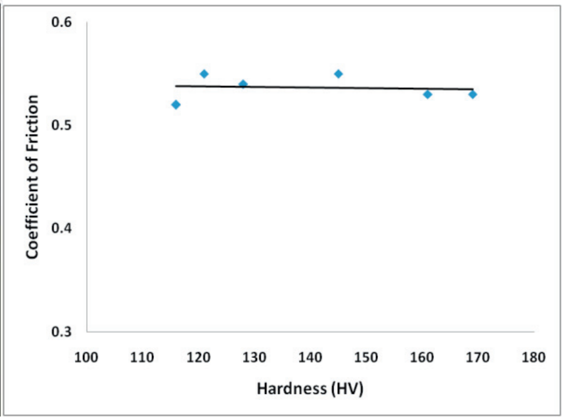


Fig. 8 Coefficient of Friction versus hardness

4. Conclusion

The eutectic–Si within a fine–grained α–Al matrix showing a globular distribution on the refined microstructure was successfully formed by the surface refining process using GTA as heat source. The hardness increased and the wear rate decreased significantly as the result of the increase in Si content as well as due to the surface refinement. The hardness shows the gradient along the depth of the refined layer owing to the difference in the cooling rate experienced in the refined layer. GTA is found to be a reasonably good heat source for surface refining process when compared to that of other heat sources like e-beam and laser. The results obtained in this study are comparable with that of previous studies.

References

[1] Davis J.R, Aluminium and aluminium alloys, ASM international handbook committee, p 3
[2] H.J. Hegge, J.T.M. De Hosson, Scripta Metall: Et Meter.: Vol. 24 (1990), p. 293
[3] K.G. Watkins, M.A. McMahon, W.M. Steen: Matl Sci and Eng A 231(1997) p. 55
[4] J. Lasek, P. Bartuska, V.Synecek, 3rd Int. Conf. on Al. Alloys, Trondheim, Norway, 22 – 26 June 1992.
[5] U. Luft, H.W. Bergmann, B.L. Mordike, in: B.L. Mordike (Ed.), Laser Treat. of Matl, DGM informationsgesellschaft mbH, Oberursel, Germany, 1987, p.147
[6] P.W. Leech, Thin Solid Films Vol. 177 (1989), p 133
[7] M. Pierantoni, M. Gremaud, P. Magnin, D. Stoll, W.Kurz : Acta Metallurgica et Materialia Vol. 40 (1992), p 1637
[8] S.Tomida, K.Nakata, Surf. and Coat. Tech. 174 – 175 (2003) p. 559
[9] A.Biswas, B.L. MorDike, I.Manna and Dutta Majumdar: Lasers in Engg. Vol 18 (2008), p. 95.
[10] T.T.Wong, G.Y.Liang: J of Matl. Proc. Tech. Vol. 63 (1997) p 930
[11] Janez Susnik , Roman Sturm ,Janez Grum, J. Mech. Engg, Vol. 58(2012), p. 614
[12] Rainer Franke, Ingrid Haase, Macro Klemm, Rolf Zenkerwear: Wear Vol. 269 (2010), p. 921.