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# Impact of tungsten on the surface of aluminium- silicon alloy on microstructure, hardness and wear rate using GTA

**R Saravanan<sup>1</sup>, Sandeep Nair and M Krishnakumar**

Department of Mechanical Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, India

E-mail: r\_saravanan@cb.amrita.edu, sreenair92@gmail.com and mahavin1996@gmail.com

**Abstract.** A study was carried out to determine the effect of tungsten addition on hardness, microstructure and wear behaviour of surface modified as-cast Al - Si alloy. The heat source utilized for modifying the surface of the substrate was Gas Tungsten Arc. Tungsten were deposited on the Al - Si alloy substrate using poly vinyl alcohol as binder and the SMP were performed. By using Lyzer Instruments optical microscope and HITACHI SU6600 FE-SEM microstructural analysis was carried out. The hardness and wear rate of the modified layer were calculated by using a micro-hardness tester and a pin-on-disc wear tester machine. The presence of elemental composition in the modified layer was determined by using Energy Dispersive Atomic X-ray Spectroscopy and its confirmation through XRD analysis. It was inferred from this study that a fine grain microstructure was observed in the modified layer. The hardness and wear resistance was found to increase as a result of W addition and also due to the formation of dispersion strengthening mechanism. The coefficient of friction was found to be independent of the hardness.

## 1. Introduction

Aluminum-silicon (Al-Si) is the most popular cast aluminum alloys, which is widely used in automotive industries and aerospace industries because of its good castability, superior strength to weight ratio and good formability. However, the drawbacks of Al-Si alloys are lack of corrosion resistance, wear resistance, poor machinability and low tensile strength due to the presence of coarse grain structure and also the existence of porosity. In order to improve the performance of the Al-Si alloys as a measure to reduce the cost of the product. Many researchers have taken three approaches: namely, (i) addition of elements such as Ni, Cr and Ti as alloying materials to the conventional wrought and castable alloys, (ii) addition of reinforcements such as SiC, Al<sub>2</sub>O<sub>3</sub>, TiC and graphite in the form of mostly particulates to the bulk Al alloys, (iii) surface refining/alloying. Surface Alloying Process (SAP) has become an emerging technique for enhancing the corrosion and tribological properties of ferrous and nonferrous alloys. The objective is to form ultra-fine and hard structures on the modified surface so that surface properties are improved. Surface alloying is typically carried out by using e<sup>-</sup> beam, laser beam and gas tungsten arc as a heat source such as in order to form the alloyed layer. Many researchers have found out that modifying the surface by a heat source results in enhancement of hardness and wear resistance of various alloys

The microstructure and corrosion behaviour of Al-6.1Zn-2.9Mg-2.0Cu-0.15-Si alloy surface alloyed with Cr using laser heat source was investigated by Almeida et al. [1] and reported that the corrosion resistance increased substantially after surface alloying. Man et al.[2] in their work on Al- 0.8Si-0.7Fe-1.2Mg alloy pasted with a layer of SiC and Si<sub>3</sub>N<sub>4</sub> powders and also modified the surface using Laser as heat source found that the formation of a metal matrix composite on the surface

<sup>1</sup> To whom any correspondence should be addressed.



results in the improvement of the cavitation erosion resistance for specimens alloyed with  $\text{Si}_3\text{N}_4$ . The improvement in the surface characteristics of the aluminum alloys with the addition of alloying elements like niobium, chromium, titanium and silicon were observed by Almeida et al. [3] and Garcia et al. [4]. An investigation conducted by Liu et al. [5] and Mucklich et al. [6] on the surface of the aluminum alloy substrate after coating with Ni and reported the formation of intermetallic compounds like  $\text{Al}_3\text{Ni}_2$ ,  $\text{Al}_3\text{Ni}$  and  $\text{AlNi}$ . Gordani et al. [7], Razavi and Hasehmi [8] and Vaziri et al. [9] in their study reported that the formation of intermetallic phases by Laser surface alloying.

An research on the laser surface alloying of Al alloy with Ni were carried out by Senthil Selvan et al. [10] and reported that the aluminum nickel intermetallic phase, precipitates are formed from the exothermic reaction between Al alloy and Ni inside the molten pool and also the formation of intermetallic phase results in the improvement of hardness and wear resistance. Biwas et al. [11] in their work on Al-11Si alloy found that the wear resistance increased significantly and the microhardness increased from 55HV to 87HV after surface modifying with laser. Heat source normally used for alloying of elements are e-beam and laser. The behaviour of NiP on Al alloy was determined by the degree of crystallization of NiP coating and the degree of dilution with the substrate, when it is treated with laser as heat source. Both factors are determined by the interaction time of the laser beam with the specimen as a function of the laser travelling speed as studied by Man et al. [2] Wong and Liang [12], and Watkins et al. [13]. The wear behaviour of Al-Si alloys were studied by Susnik et al. [14] and found that the wear resistance was improved significantly after laser surface melting. The recent study conducted by Arul and Sellamuthu [15] on GTA heat source shows the improvement in the arc efficiency by 75%. The feasibility of utilizing GTA as the heat source for wider coverage on Al-Si alloy for Surface Refining Process (SRP) was reported by Saravanan and Sellamuthu [16].

Boyuk [17] have added 4.2% Ni, to the Al -11Si alloy using the directional solidification method and found out that the hardness of the base alloy has increased from 82HV to 130HV for the Ni-added alloy and also there is an improvement in the tensile strength. The effect of 1%Ni addition on the surface of Al- 7Si - 0.5Cu - 0.35Mg were investigated by Farkoosh et al. [18] and reported that an intermediate phase ( $\text{Al}_3\text{FeSi}$ ) forms during solidification. However, the authors have reported that the hardness of the alloy will not decrease in the 300°C temperature range due to the thermodynamic stability of the  $\text{Al}_3\text{FeSi}$  phase. Venkateswara Rao [19] in his work on Al - 5.6Zn - 2.5Mg - 1.5Cu alloy found that the addition of transition elements leads an increase in the mechanical properties.

The effect of 5%  $\text{TiO}_2$  particulates addition on hardness of Al - 4.15Zn - 2.12Mg alloy made using liquid metallurgy and rheocasting techniques were investigated by Balasubramaniam et al. [20] and stated that the solid extrusions with  $\text{TiO}_2$  had higher hardness than the semi-solid extrusions and semi-liquid extrusions. Bharath et al. [21] studied the effect of 12%  $\text{Al}_2\text{O}_3$  addition on hardness and wear rate of Al - 0.43Si - 0.80Mg - 0.7Fe alloy using stir casting technique and reported that the hardness increased from 95HV to 180HV and wear rate decreased from  $14.7 \times 10^{-4} \text{ mm}^3/\text{Nm}$  to  $11.4 \times 10^{-4} \text{ mm}^3/\text{Nm}$  when reinforced with 12%  $\text{Al}_2\text{O}_3$ . Sajjadi et al. [22] in their comparison study of Al metal matrix made by stir and compo-casting of Al - 6.10Si - 0.42Mg alloy with 5wt%  $\text{Al}_2\text{O}_3$  particles as reinforcement stated that the hardness increased from 63BHN to 79BHN when casting were made using compo-casting technique. Gopalakrishnan and Murugan [23] have investigated the wear behavior of Al - 1.2% Mg - 0.8% Si - 0.7% Fe alloy with TiC particulate as a reinforcement made by stir casting method, they proven that the increase in TiC percentage leads to decrease the wear rate of the composite. Himanshu Kala et al. [24] in their study on Aluminum alloy made by stir casting have found that the hardness values increased with a decrease in the size of  $\text{Al}_2\text{O}_3$  particulates. Additionally, they noted that the hardness values increased with an increase in  $\text{B}_4\text{C}$  content. Suresh and Moorthi [25] in their study added  $\text{TiB}_2$  to Al- 1.08Mg - 0.63Si - 0.52Mn alloy to cast a Al metal matrix composite and found that the hardness increased from 65.53HV to 72.46HV after addition of 12%  $\text{TiB}_2$ . Also, they noted that the wear resistance increased with the addition of  $\text{TiB}_2$  particulates. The effect of SiC reinforcement on hardness of Al-Si - 18Cu - Mg - Ni alloy to fabricate pistons by

centrifugal casting technique were studied by Huang et. al. [26] and reported that the hardness increased from 73HRB at the skirt of the piston to 97HRB at the piston head and that the wear resistance was maximum at the head of the piston. The wear resistance and the hardness was increased significantly by the addition of SiC and  $\text{Al}_2\text{O}_3$  to Al-7.5Si-0.6Mg-0.5Fe-0.1Cu alloy were observed by Radhika et al. [27]. Moreover, it was also noted that the addition of  $\text{Al}_2\text{O}_3$  particulates alone to the alloy leads to the increases in wear rate because it reduces the fracture toughness and removes the lubricant layer. Saravanan and Sellamuthu [28] studied the hardness and the wear rate of as-casted Al-Si alloy by varying the content of Si from 4 to 16 wt. % using Gas Tungsten Arc (GTA) as a heat source and found that the hardness and wear resistance of modified surface increases with the increase in wt. % of Si.

In this research, the influence of tungsten addition on the surface properties of Al-Si alloy using GTA as a heat source was carried out. Not much research were carried out to determine the surface properties like hardness, microstructure and wear properties of Al-Si alloy with tungsten by using GTA as heat source. The aim of this study was to compare the microstructural information during surface alloying process with the resulting hardness, wear rate and coefficient of friction of cast Al-Si alloy.

## 2. Experimental procedure

The Al-Si alloy was prepared using sand mould casting technique. The Al - Si alloy was placed in the graphite crucible and melted using resistance type furnace at 700°C. The mould was prepared using wooden pattern. The composition of the as-cast Al - Si sample was determined by performing X-ray fluorescence spectrometry on the surface were reported in Table 1. The cast Al - Si specimens were machined into bars of dimension 150 mm × 30 mm × 30 mm followed by radiography testing in order to find the casting defects. The machined Al - Si bars were then pasted with tungsten powder using Poly Vinyl Alcohol (PVA) as binder. The weighing of exact 1g of tungsten powder and 1.5g of PVA are done using simple balance followed by continuous stirring of mixture in a beaker for 30 minutes. Under argon atmosphere surface alloying was performed over the pre-deposited tungsten layer using GTA as a heat source. All the experiments were conducted with following GTA parameters, 160A – Current, 2 mm/s – Travel speed, 3mm – Electrode diameter, 180° (Flat) – Electrode angle, 3mm – Arc length and 12 ltr/min – argon flow rate.

Table – 1 Composition of as-cast Al-Si alloy

Element	Si	Mg	Fe	Mn	Ti	Al
Wt. %	7.5	0.6	0.5	0.3	0.2	Bal

The microstructure analysis were conducted using Lyzer Instruments optical microscope and HITACHI SU6600 FE-SEM on the cross-section of the specimens. The substrate and the surface modified specimens were prepared using std. metallographic technique and polished with different grades of emery paper. The specimens were cleaned from dirt, and impurities with acetone and distilled water and dried out before performing the test. The specimens were etched using 5gm  $\text{FeCl}_3$ , 5ml HCl, and 100 ml of water solution. The elemental composition on the surface of modified alloy was determined by HITACHI SU6600 Energy Dispersive Spectroscopy (EDS). The major phases existing on the surface of modified alloy was determined by ULTIMA IV X-ray diffractometer using  $\text{Cu K}_\alpha$  radiation at 40 mA and 40 kV. Wolpert Wilson Vickers hardness tester was used to measure the microhardness (HV) on the top surface as well as across the depth of the modified layer. The specimens used for hardness testing were prepared metallographically and as per ASTM E92 standard the test was performed. An average value of hardness was calculated by taking ten readings at distinct locations on each sample and. The hardness values varied within the range of  $\pm 15$  HV for each

specimen. The testing was carried out by applying a load of 100 gm-f for a duration of 30 sec. Ducom wear testing machine was used to measure the wear and friction coefficient. The experiments were carried out as per ASTM G99 standard under dry sliding condition. Counter face material used was hardened steel (EN 31) disc plate with HRC 60 hardness and Ra 0.15 as surface roughness as reported by Saravanan and Sellamuthu [16]. The apparatus was furnished with LVDT sensors and data acquisition software. Specimens were weighed up after each period of testing using a weighing scale accuracy of 0.1 mg. The wear in terms of weight loss (mg) was calculated from Equation. (1). In the below equation,  $\Delta m$  infers the change in initial mass to the final mass in Kg ; F are the load acting in N and L are the sliding distance in M. The wear testing parameters are reported in Table 2.

$$\text{Wear in terms of Wight loss (mg)} = \Delta m / (F \times L) \quad (1)$$

Table 2 – Wear testing parameters

Parameters	Test values	Units
Time	10	Min
Velocity	2.5	mm/s
Load	20	N
Speed	424	Rpm
Sliding distance	1500	M
Track diameter	110	Mm

### 3. Results and discussion

#### 3.1 Effect of SAP on microstructure

Figure 1 shows the dendritic structure of the as-cast Al – Si alloy substrate showing the elongated morphology of the eutectic – Si as reported previously by Saravanan and Sellamuthu [16]. Figure 2 shows the microstructure of the Al – Si alloy modified with W by the Surface modification process. It can be seen that the modified structure is highly refined as tungsten particles is uniformly dispersed over the modified region as a result of fast cooling and also due to the dispersion strengthening mechanism takes place during the solidification in the SMP when compared to the as-cast microstructure.

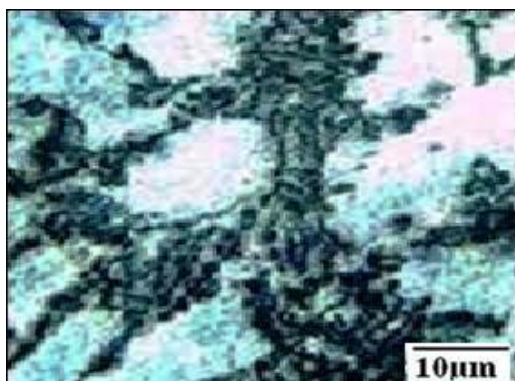


Figure 1 Microstructure of as-cast Al-Si alloy

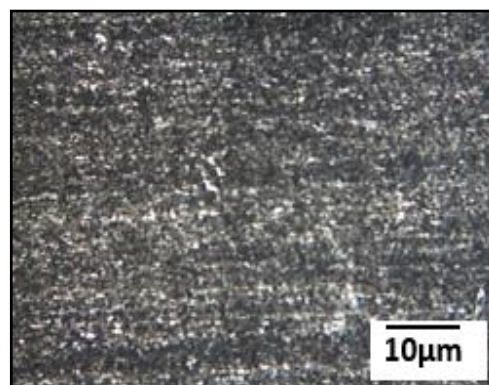


Figure 2 Microstructure of Al-Si alloy modified with W

Further, it can be noted that the eutectic – Si morphology is observed to be globular and an intermediate phase is also observed in the microstructure. It has been reported by Biswas et al. [11] that a refinement of microstructure occurs in his work carried out in the refining of the surface of Al - 11Si alloy by means of the laser as the heat source. Further, they have reported a transition of cellular from dendritic during solidification happens at an elevated scanning speed. Wong and Liang [12], Watkins et al. [13] and Susnik et al. [14] have also reported a similar observation.

### 3.2 Phase Identification

Figure 3 show the cross-sectional SEM view of W modified Al-Si alloy. It is observed that the tungsten spreads out homogenously in the modified layer, shows the dispersion strengthening mechanism takes place after surface modification process. In the surface modified region, the structure was very fine with dense layer due to the difference in cooling rate on the surface alloyed layer. In order to find the presence of tungsten on the surface modified layer, EDS analysis was carried out (as depicted in Figure 4 (a)). The result shows that the tungsten are indeed present in the modified specimen. To further gain clarity on the crystallinity of the alloys, X-ray diffraction analysis was carried out for an W-modified Al-Si alloy specimen Figure 4 (b) shows the XRD pattern of W-modified specimen. The result confirm the presence of tungsten in the modified region, but the tungsten donot form any intermetallic compounds with any of the element of the Al-Si alloy as the melting point of tungsten is too high. Moreover, the tungten particles are fuse over the surface of the modified specimen and shows the existence of dispersion strengthening mechanism.

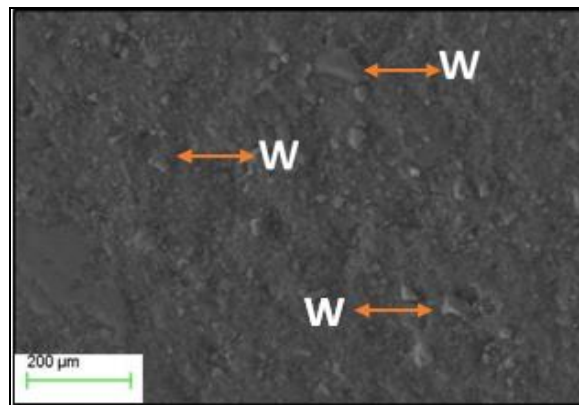
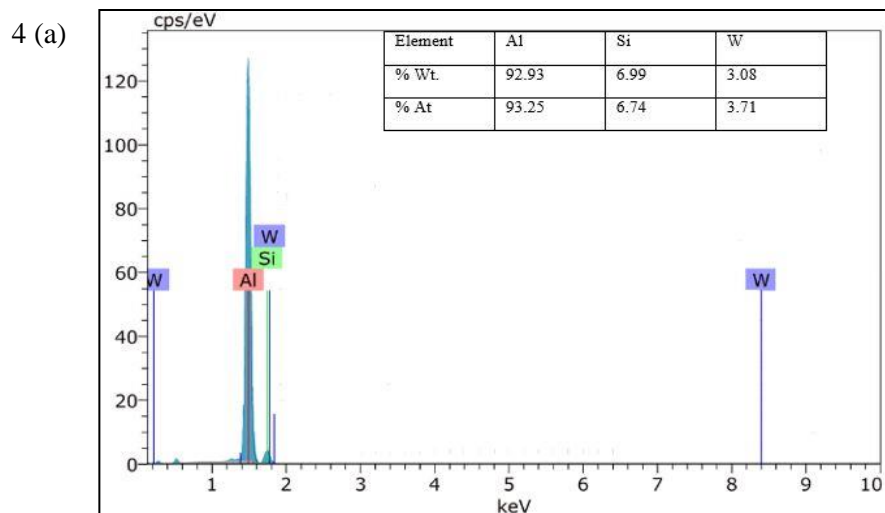


Figure 3 Cross-sectional SEM view of W modified Al-Si alloy





4 (b)

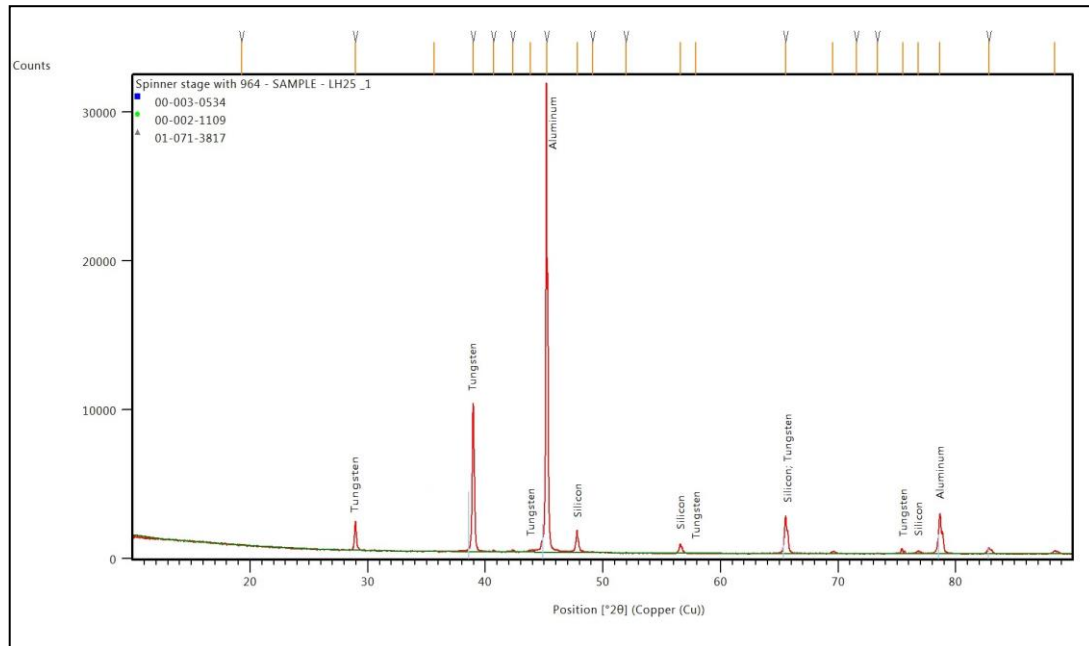


Figure 4 (a) EDS spectrum of W modified alloy, (b) XRD pattern of W modified alloy

### 3.3 Hardness

The comparison of hardness value of the substrate and W-modified samples as depicted in Figure 5. It was observed that the hardness of the Al-Si substrate was found to be increased from 65 HV to 394 HV for the W modified specimens, respectively. This improvement in hardness is due to formation of fine grains on the top surface of the modified specimen. In addition to grain refining, which is observed in modified specimens, the substantial increase in hardness (~ 606 % increase with respect to the substrate) may be attributed to the addition of tungsten on the surface of the modified region. The surface hardness of the modified layer is more and then decreases gradually along depth direction as shown in Figure 6, which confirms the presence of the gradient in the pattern due to the difference in cooling rate. This has also been confirmed from previous studies [16 and 28]. Hence, the above results illustrate that Gas Tungsten Arc (GTA) could be considered as an alternative heat source for surface modification process (SMP).

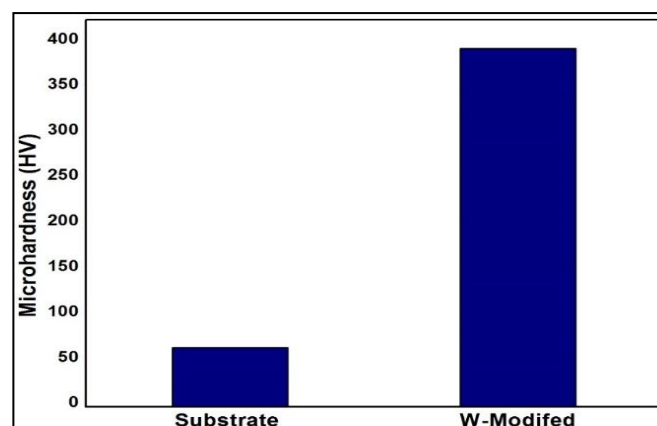


Figure 5 Hardness chart for the substrate and W-modified samples

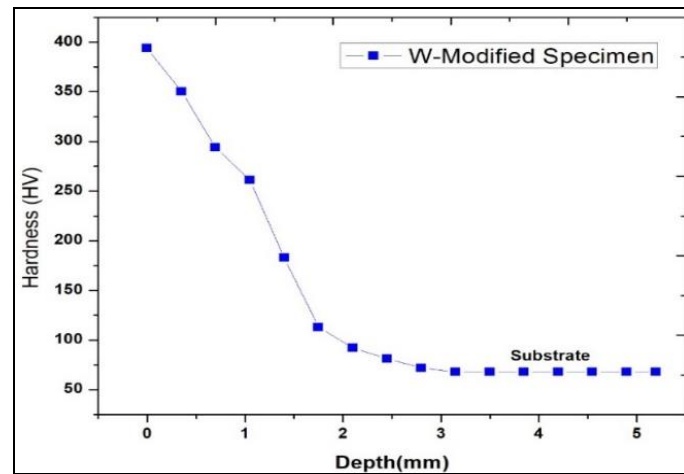


Figure 6 Hardness profile along the depth direction (mm)

Figure 7 shows a comparison graph between the present studies with that of earlier conducted studies. Saravanan and Sellamuthu [16] had reported in his work that when Al - Si alloy was surface refined using GTA as a heat source and the hardness achieved was 160 HV. Barath et al. [21] reported in his work that 6061 alloy was fabricated with MMC's by using stir casting technique and the hardness obtained was 170 HV. Suresh et al. [25] in his study use  $\text{TiB}_2$  as reinforcement agent for fabricating of 6061 alloy and the hardness obtained was 70 HV. Moreover, the outcome of this study is consistent with the earlier studies.

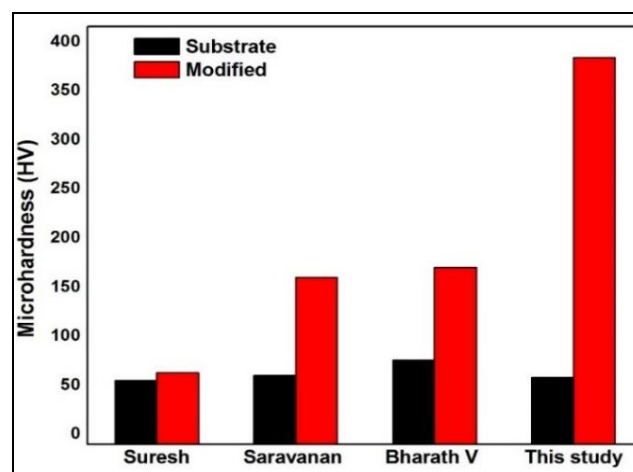


Figure 7 Hardness comparison chart

### 3.4 Wear and Friction Coefficient

Weight losses for the substrate and W modified specimens with hardness is shown in Figure 8. The wear of the modified alloy was found to be decreased significantly ( $\sim 72\%$ ) compared to the substrate. Also, it can be clearly observed that the weight loss has been reduced with the increase in the hardness by GTA surface modification process (as shown in Figure 8). This significant reduction in wear of W modified specimen is consistent with the hardness presented in Figure 6 and are attributed to the formation of fine grains on the top surface of the modified specimen. This study is in concurrence with the Archard's theory [29].



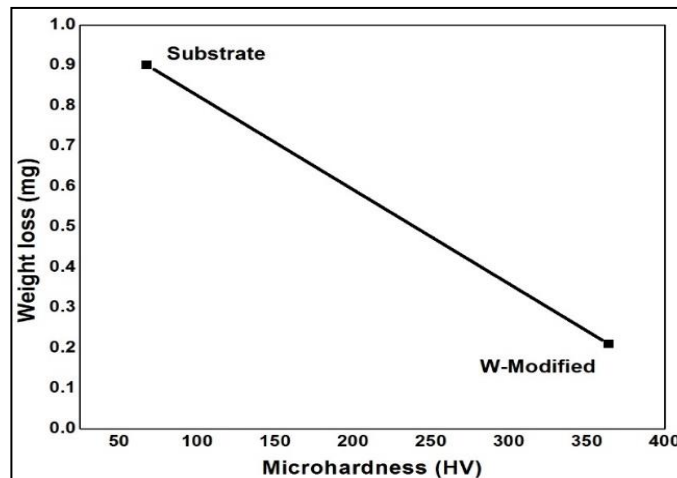


Figure 8 Wear plot for substrate and W-modified specimens

Figure 9 shows the comparison of the wear interm of weight loss (mg) reported in the literature along with the value obtained in this study. The wear of the present study is comparable to that of Saravanan and Sellamuthu [16], Barath et al. [21] and Suresh et al. [25]. The reason for the high reduction in the wear obtained in this study is attributed to the grain refined structure and W addition on the surface modified region. Saravanan and Sellamuthu [16] had reported in his work that when Al - Si alloy was surface refined using GTA as a heat source and the wear achieved was 0.98 mg. Barath et al. [21] reported in his work that 6061 alloy was fabricated with MMC's by using stir casting technique and the wear obtained was 0.55 mg. Suresh et al. [25] in his study use  $\text{TiB}_2$  as MMC's for fabricating of 6061 alloy and the wear obtained was 0.44 mg. Moreover, the present study is in agreement with the previous reported studies.

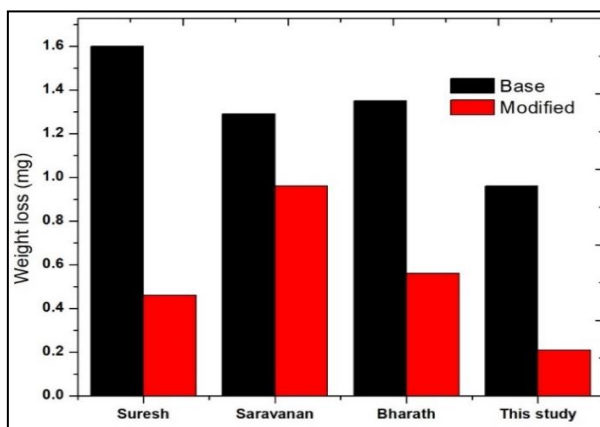


Figure 9 Wear interm of weight loss (mg) comparison graph

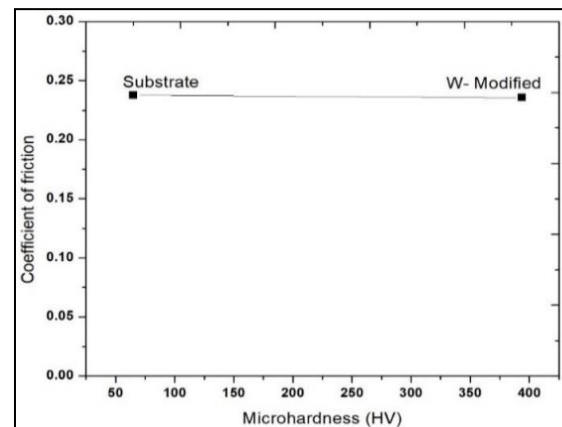


Figure 10 Frictional Coefficient of substrate and W modified specimens as function of hardness (HV)

Figure 10 shows the variation in hardness with frictional coefficient for substrate and surface modified alloy. The Frictional coefficient was observed to be constant, independent of the hardness and W content. The friction coefficient values for substrate and W modified specimens are 0.242 and 0.240 respectively. Hence, the W addition and GTA process parameters may enhance the hardness and wear resistance without significantly influence the coefficient of friction, which has an agreement with Saravanan and Sellamuthu [28].

#### 4. Conclusion

Surface modification of as - cast Al-Si alloy was carried out by using W powders as reinforcement particles with GTA as heat source. The following conclusions are summarized below:

1. Surface modification of Al-Si alloy with tungsten addition showed an improvement in surface properties of the alloy. The cross sectional SEM image of the modified layer reveals the formation of fine grains in the surface modified region and is attributed to the rapid solidification.
2. EDS and XRD analysis confirms the presence of tungsten on the surface of the modified layer.
3. The hardness on the surface of the modified region was found to be 394 HV for W-modified specimen which is much higher compared to the substrate of 65 HV. Also, the hardness is decreased along the depth direction shows the existence of gradient in the modified region.
4. In dry sliding wear condition, a significant improvement in wear resistance was noticed along with a substantial reduction in friction coefficient through surface modification.
5. The GTA heat source was found to be effective for surface modification process.

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