ENHANCEMENT OF MECHANICAL AND TRIBOLOGICAL PROPERTIES OF AA 6082-T6 COMPOSITES REINFORCED WITH TIN, GRAPHITE AND ZINC

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Abstract

In the continuous search of new lightweight materials for automotive engine parts and industrial applications, new materials with superior properties is always needed. Among various materials, the aluminium alloys are preferred due to their light weight and superior properties. In this work, the AA 6082-T6 was chosen as base material along with Tin, Graphite and Zinc as matrix about 2.5 wt.% in each. The work is mainly focused on analysis of various mechanical, metallurgical and tribological properties. In heat treated AA 6082-T6 with Sn + Graphite + Zn, only few surface defects were found with fine grain size, the elevated hardness and ultimate tensile strength higher than AA 6082-T6 about 8% and 10% respectively. The wear and friction ratios were also reduced up to 8% for the same combination. These results provide the importance of the novel process insight to prepare composite matrix materials having superior properties than existing one for automotive piston material applications.

Keywords: *AA6082-T6 Composites, Heat treatment, Tin (Sn), Zinc (Zn), Graphite (C).*

1. Introduction

Aluminum alloys are special alloys, which are being used in automotive and industrial applications. They possess better mechanical properties even at elevated temperatures (>350°C). Moreover, these alloys are more constrained towards sudden temperature changes. Owing to these issues, design and development of these aluminium alloys must be critically examined in order to achieve thermal and mechanical behaviors [1]. AA 6082-T6 alloy with SiC and B4C as reinforcements are used in many industrial applications due to its superior mechanical and tribological properties [2]. By increasing the TiC particle reinforcement with 6082-T6, the hardness of composites increases about 39% when compared to ordinary AA 6082-T6 and wear resistance also increases with along with sliding speed [3]. Moreover, the addition of Graphite and Mica reinforcements with AA 6082-T6 leads to enhance the hardness, tensile strength, dimensional stability during heat treatment and reduces the warpage [4]. Tensile strength and hardness of AA 6082-T6 Metal Matrix Composite (MMC) increases while increasing Si3N4 and Graphite content and as a result elongation is also reduced upto 3 - 4% [5, 6]. Addition of Al_2O_3 into AA 6082-T6 elevates the wear resistance to better level than other materials [7]. Addition of TiB2 into AA 6082-T6 increases the hardness and tensile strength up to16% and 21% respectively and reduces the wear rate up to 10% [8].

Uniform dispersion and growth of α-Al grains with inter-dendritic of aluminum AA 6082-T6 and silicon eutectic was relieved from the morphology of SiC, B_4C and combined SiC - B_4C composites. In some places, agglomeration of particles was increased with increase in reinforcement [9]. Addition of graphite particles in to AA 6082-T6 by stir casting method reduces the hardness about 12% and also wear rate with increase in reinforcement particles and sliding speed [10]. The AA 6082-T6 was reinforced with both hybrid (TiB_2 + BN) and mono (TiB_2 and BN) particles for effective bonding and to avoid porosity [11]. Here, shape and morphology changes due to fragmentation only in TiB_2 and not in BN. Also, the sliding resistance of hybrid (TiB_2 + BN) is found to be higher than the mono type composites due to the wear resistance of TiB_2 whereas Nano BN act as solid lubricant to the wear. Si_3N_4/Graphite reinforcement in AA 6082-T6 increases the mechanical and metallurgical properties, uniform dispersion and superior morphology than AA 6082-T6 [12]. Similarly, SiC/Graphite in AA 6082-T6 tends to increase the density while porosity, hardness and tensile strength were elevated to better level with increase of SiC/Gr particles [13].

The aim of this work is to fabricate the AA6082-T6 composites with the addition of Sn (2.5 wt.%), Graphite (2.5 wt.%) and Zn (2.5 wt.%) as mono and hybrid particles using bottom stir casting machine to achieve metal matrix composites with better properties. The encapsulating feeding method was followed for producing all the samples. Due to recasting effect, the T6 tempering is diluted in AA 6082-T6. All fabricated samples were processed under heat treatment that involves re-tempering process. Both heat treated and casted samples were tested in order to analyse and compare their surface morphology, mechanical and tribological properties for industrial applications.

2. Materials and Methods of Preparation

In this research work, AA 6082-T6 is used along with the elements of Sn, Graphite and Zn at different proportions. The chemical composition of AA 6082-T6 is given in Table 1.

Table 1 Chemical Composition of AA 6082-T6

Element	Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
Composition	1.1	0.6	0.12	0.69	1.1	0.3	0.12	0.22	Bal

In order to increase the load bearing capacity and thermal properties, different materials such as Sn (Anti-scoring and Anti-frictional), Graphite (Solid Lubricant) and Zn (Improving strength and Wear resistance) were added as reinforcement materials. The numerous holes were drilled unto the depth of 5 mm in the aluminium (AA 6082-T6) rods and the reinforcement particles were packed in all the drilled holes. In each sample, the reinforcement particles were packed and then fed into the bottom pouring stir casting machine. If more than one reinforcement particle was used, then the particles were packed in the form of layer by layer. This method is preferred due to agglomeration, irregular materials dispersion and adding accurate weight percentage of reinforcement materials.

Table 2 - Details of Prepared Specimen

Elements in %	**Sample Name**
AA 6082-T6 + Tin (2.5 wt.%)	A1
AA 6082-T6 + Tin (2.5 wt.%) & Heat treated	A2
AA 6082-T6 + Graphite (2.5 wt.%)	A3
AA 6082-T6 + Graphite (2.5 wt.%)& Heat treated	A4
AA 6082-T6 + Zinc (2.5 wt.%)	A5
AA 6082-T6 + Zinc (2.5 wt.%) & Heat treated	A6
AA 6082-T6 + Tin, Graphite and Zinc (each 2.5 wt.%)	A7
AA 6082-T6 + Tin, Graphite and Zinc (each 2.5 wt.%) & Heat treated	A8

The AA 6082-T6 shaft with packed reinforced particles is placed inside the furnace of stir casting machine. The furnace was heated upto 850°C, even though the base metal could be melted between 670°C to 690°C. The molten state of base metal arrests the reinforcement particles in all directions. The coated single bladed stirrer is used to improve the particles dispersion throughout the molten slurry. The stirrer speed increased upto 500 rpm for 4 - 5 minutes, and then gradually reduced to zero speed. This process carried out in inert gas environment to avoid the oxidation during heating. The molten composites were poured from bottom side of furnace, to preheated (upto 500°C) circular chamber named bottom tap option. Then it is quickly air quenched to reduce the settling of reinforced particles in molten base metal.

The test specimens were produced into two sets such as casted MMC and heat treated MMC with various reinforcement weight percentages as shown in Table 2. All the heat treatment samples were subjected to solution heat treatment at 510°C - 530°C for 24 hours. After solution heat treatment, samples were quenched in lube oil at 60°C and then artificial aging was done between 160°C - 190°C for 8 - 10 hours. Then re-aging was done at 120°C for 8 hours.

This above procedure is repeated for all the four samples mentioned in Table 2. The heat treatment was carried out to simulate correlation with environment of engine combustion chambers.

Metallographic analysis

The fabricated composite samples were cut into 5mm x 5mm x 10mm using abrasive cutter. The specimen is prepared using emery papers of grits 220, 320, 400, 600, 800, 1000, 1200, finally by 1500 and burnished with diamond paste of 0.5 µm – 1 µm for metallurgical analysis. The etching process was carried out for test specimens using caustic etching process (10 g NaOH to each 90 ml of H_2O) as per ASM Handbook. The surface morphology and elemental characterization were analyzed by Scanning Electron Microscope (SEM) of TESCAN VEGA3 instrument attached with Energy Dispersive X -ray Spectroscopy (EDS). The EDS quantitative analysis was carried out at minimum of four various locations on each sample to ensure entire micro structure quality as well as the degree of variability in samples.

The fabricated flat shaped highly polished MMC specimens of size 10mm X 10mm was used to measure micro hardness on the top surface and cross sectional plane using Vickers micro hardness tester "HMV Micro Hardness Tester Shimadzu". Minimum of five tests were conducted from all the specimens and average values were considered. Each test was conducted for 20 sec at ambient temperature and the applied load was about 246 MN. The optical microscope was used to scan the worn surface of each sample.

Tribological testing

The testing was carried out in two different environments such as dry condition and continuously wetted condition using lubricating oil. The dimension of wear disc was 100 mm diameter and 8 mm thickness, the wear track diameter was about 80 mm. The pin diameter was 6 mm. The disc speed was kept constant about 150 rpm, 29.42 N of applied load and the test duration lasts up to 3000 minutes.

3. Results and Discussion

Morphology and elemental characterization

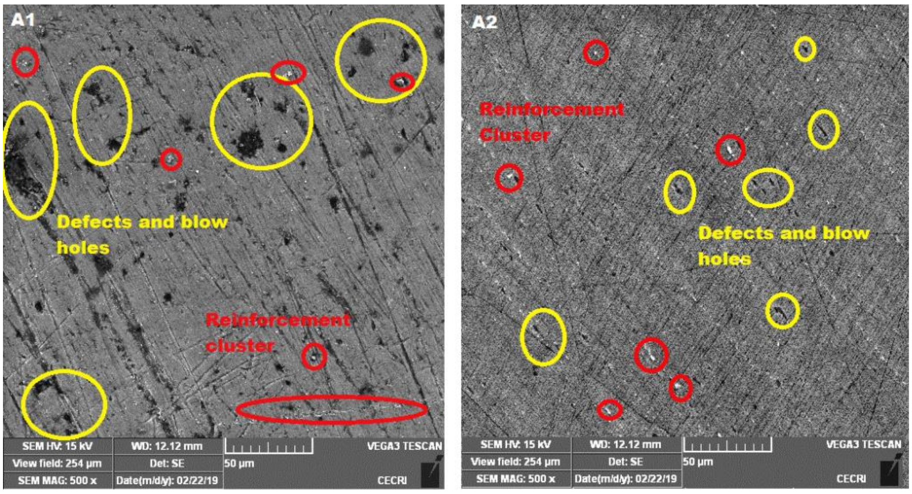


Fig 1. SEM pictures of AA 6082- T6 having 2.5 wt.% of Sn (A1) and heat treated (A2)

Figure 1 shows morphology of AA6082-T6 having 2.5 wt.% of Sn as both untreated (A1) and heat treated (A2) in Scanning Electron Microscopy (SEM). The (A1) composite contains more blow holes, defects and larger cluster compare to the heat treated (A2) composite. Also, (A1) has lower quality and breaks many times during secondary operations such as cutting, machining and sample preparation. Whereas the heat treated samples are in better quality and show no breaking during sample preparation. In Figure 1, the yellow circle denotes defects and blow holes, red circle and arrow indicates the cluster formation. The size of blow holes and reinforcement clusters of (A1) were larger compared to heat treated one, also Sn cluster are uniformly dispersed after heat treatment.

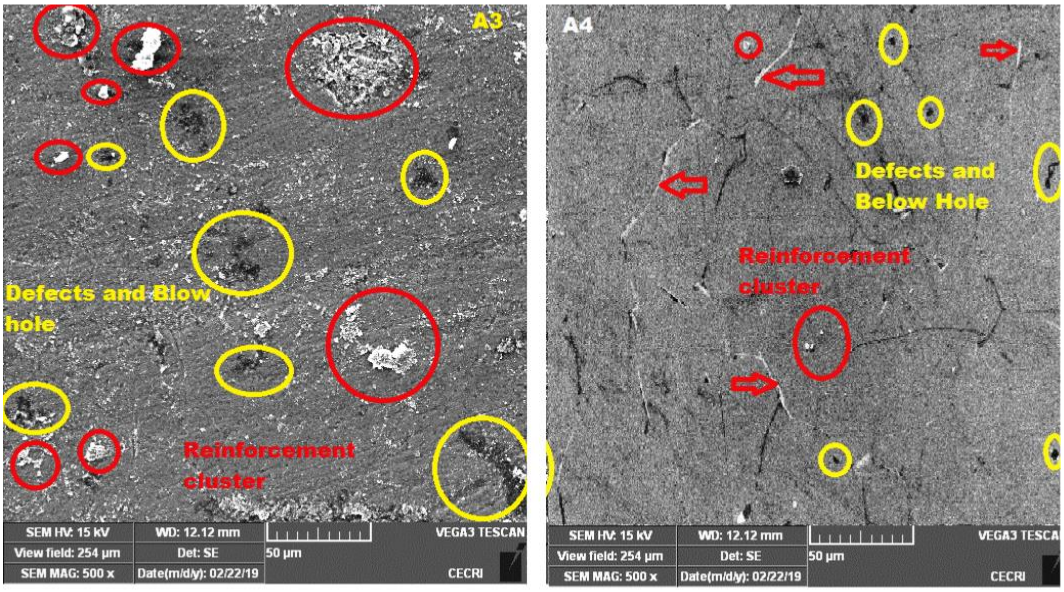


Fig. 2 SEM pictures of AA 6082-T6 having 2.5 wt.% of graphite (A3) and heat treated (A4)

Figure 2 shows morphology of AA 6082-T6 having 2.5 wt.% of graphite as both untreated (A3) and heat treated (A4). The yellow circles denote defects and blow holes, red circle and arrow indicates the cluster formation. More clusters of reinforcement particles were found with untreated samples whereas cluster size reduction and particle dispersion were increased in heat treated. The quantity and size of blow holes reduced with heat treated samples than untreated samples as observed earlier.

The addition Zn with AA 6082-T6 improves the surface morphology compared with Sn and graphite as individually shown in Figure 3. Size of blow holes was reduced after heat treatment process and improved material distribution. In terms of hybrid composites having Sn + Graphite + Zn, size of clusters and defects were reduced appreciably, also the reinforcement clusters were diffused throughout the samples during heat treatment as shown in Figure 4. This diffusing effect could be the reason for the observed increase in the strength of the components.

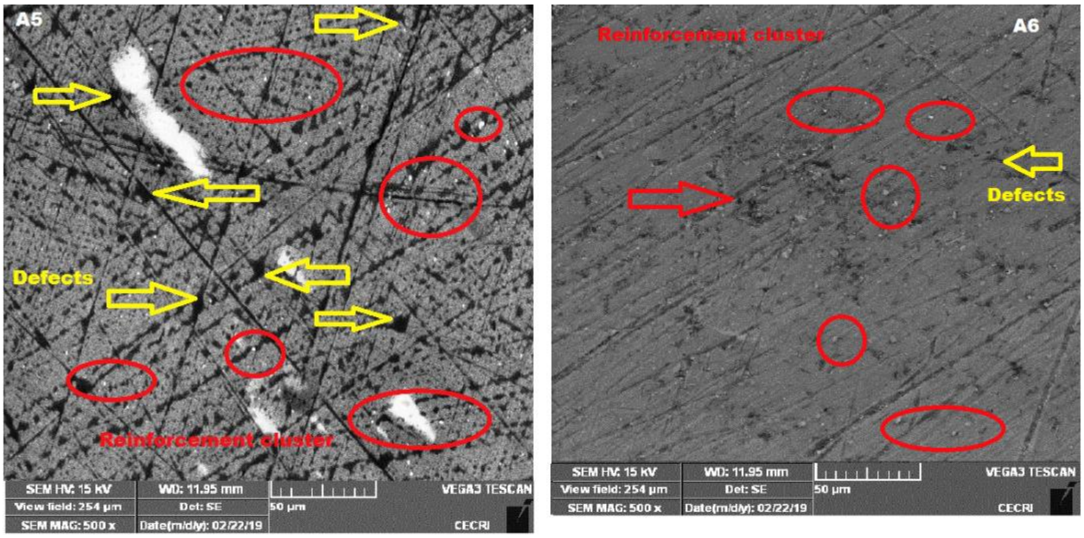


Fig. 3 SEM pictures of AA 6082-T6 with 2.5 wt.% of Zn (A5) and heat treated (A6)

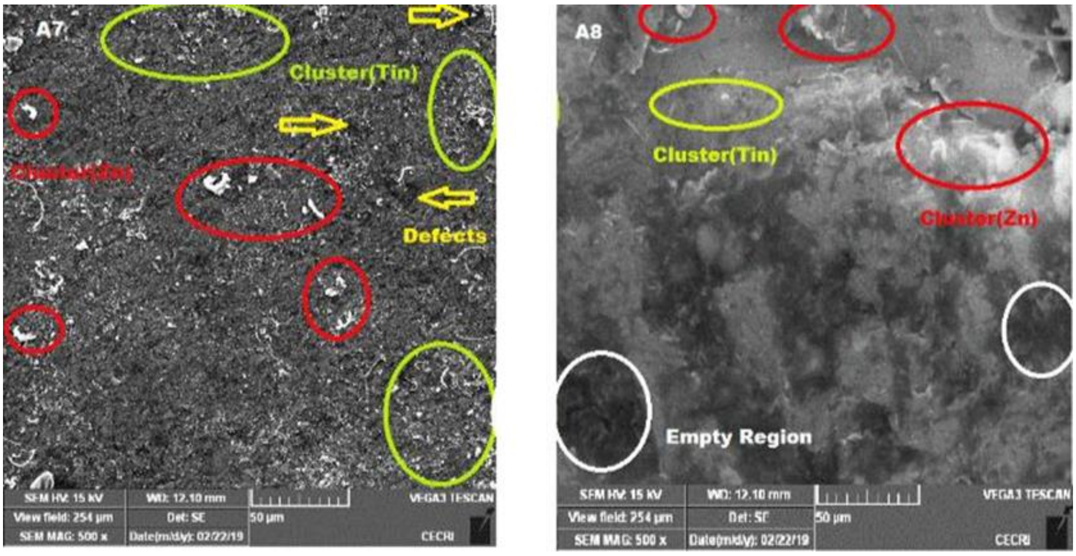


Fig. 4 SEM pictures of AA 6082-T6 having 2.5 wt.% of each Sn, graphite and Zn (A5) and heat treated (A6)

Mechanical Behaviour

The micro hardness values are measured using Vikers hardness tester, the hardness values obtained for both cast and heat treated samples from various positions. The Figure 5 indicates that a hardness value of AA 6082-T6 was about 95 Hv whereas casted aluminum element matrix composites (AMMC) varied between 59 Hv and 71 Hv. The hardness of heat treated samples varied from 57 Hv to 109 Hv. Hardness of hybrid cast AMMC obtained was 67.89 Hv whereas heat treated AMMC produced about 103.76 Hv. From this study, it is observed that there was an increase in hardness values about 27% to 33% after heat treatment. In case of hybrid composite, addition of Zn has resulted in significant increase of hardness values when compared to AA 6082-T6.

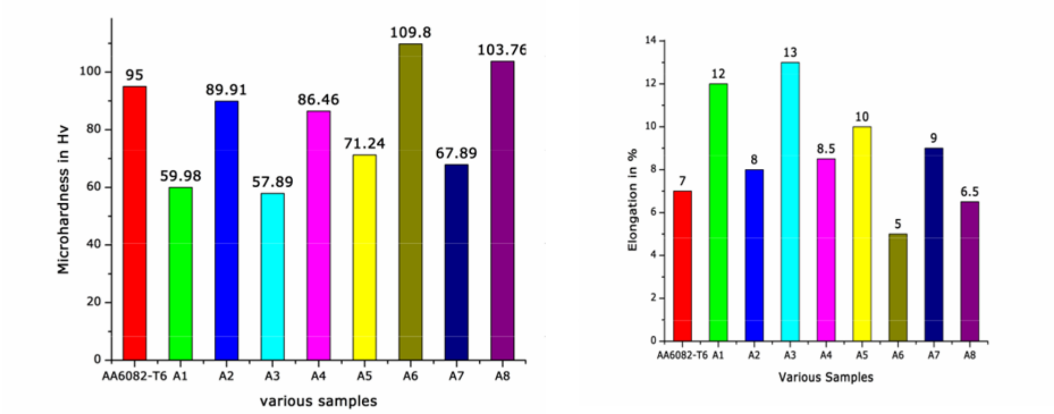


Fig. 5 Micro hardness and elongation effects on untreated and heat treated samples

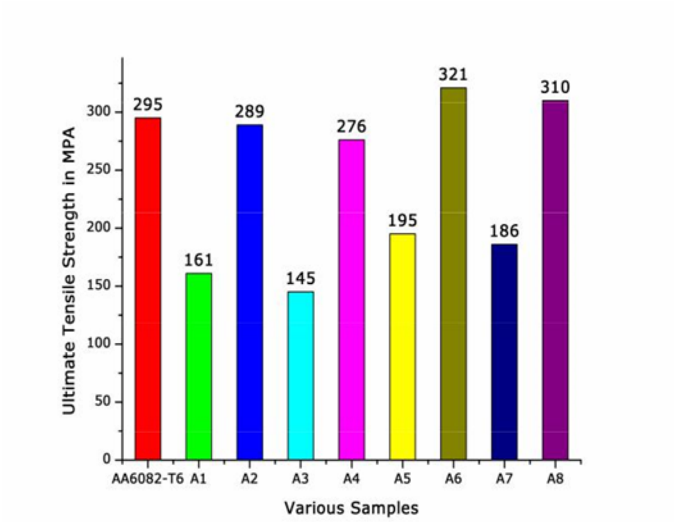


Fig. 6 Ultimate ensile strength effects on the untreated and heat treated samples

The highest ultimate tensile strength was observed with heat treated samples than untreated casts as shown in Figure 6, although the percentage of elongation was higher with cast samples as shown in Figure 5. When alloys are subjected to heat treatment, single homogenous phase is formed, followed by quenching process tends to retain the solute component in unstable state. The continuation of aging and precipitation process under 180°C, rejects the solute atoms and forms a cluster as coherent precipitate. The strained region around coherent precipitant reduces the movements of dislocation. Due to this, the strength and hardness were increased with reduced ductility. The reduction of ductility has balanced with increment of strength (reduction in % of elongation). The lowest elongation was absorbed with heat treated AA 6082-T6 with 2.5 wt.% Zn (A6) and hybrid AA 6082-T6 (A8) than AA 6082-T6.

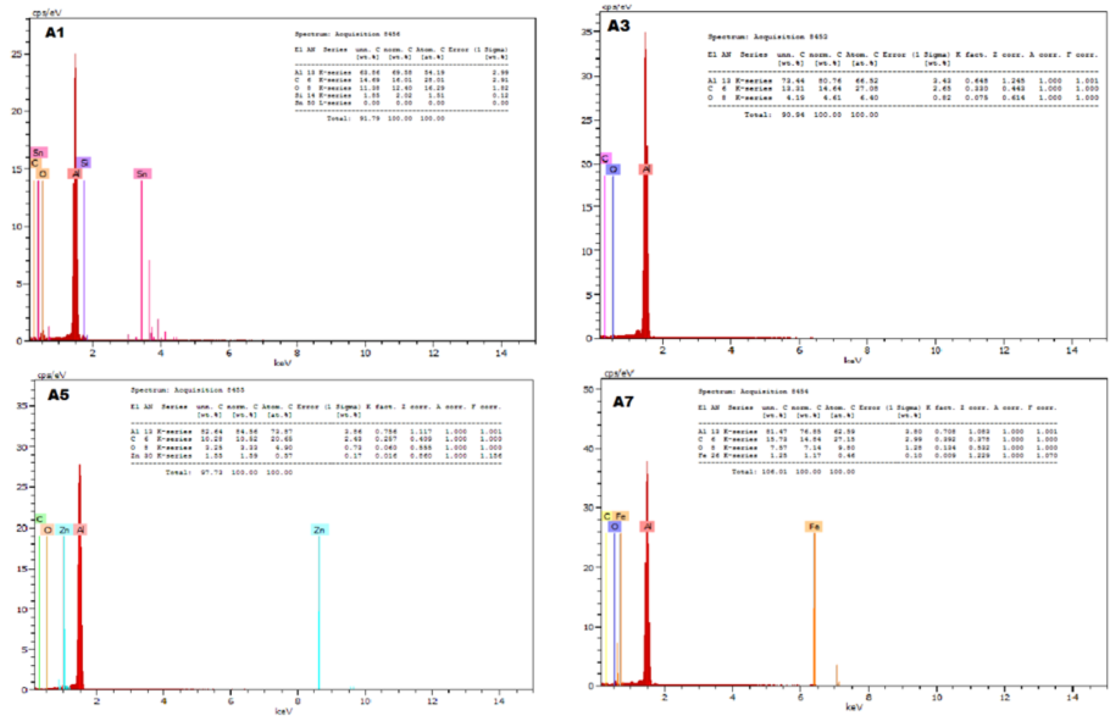


Fig. 7 Energy Dispersive X-ray Analysis of untreated and heat treated samples of AA 6082/T6 with each 2.5 wt. % of Sn, graphite and Zn as individually and as hybrid

Figure 7 shows the energy dispersive X-ray analysis of the composite samples to find out the reinforced elemental dispersion. Figure 7 - A1 ensured the presence of Sn particles in the samples. Figure 7 - A3, confirmed the graphite particles presence in AA 6082-T6. Also Figure 7 - A5 shows the presence of zinc reinforcement in AA 6082-T6. In the hybrid AA 6082-T6 as shown in Figure 7 - A7, EDAX plots ensured the presence of Sn, graphite and Zn particles and shows high dispersion of reinforcement elements.

Tribological Studies

Figure 8 shows wear rate of untreated and heat treated samples with respect to sliding distance. The wear of AA 6082-T6 varied between 0.0031 and 0.0037 mg/m whereas lowest wear rate found with heat treated AA 6082-T6 having Zn (A6). Due to melting and stir casting, cast AA 6082-T6 element matrix composite of different samples found higher than 6082-T6 heat treated composite. After novel heat treatment with all cast AA 6082-T6 element matrix composite, the wear rate was found to reduce gradually when compared to AA 6082-T6 heat treatment. The lowest wear rate was found with heat treated AA 6082-T6 with Zn (A6) and Hybrid AA 6082-T6 (A8) is about 0.0026 and 0.0027 mg/m respectively

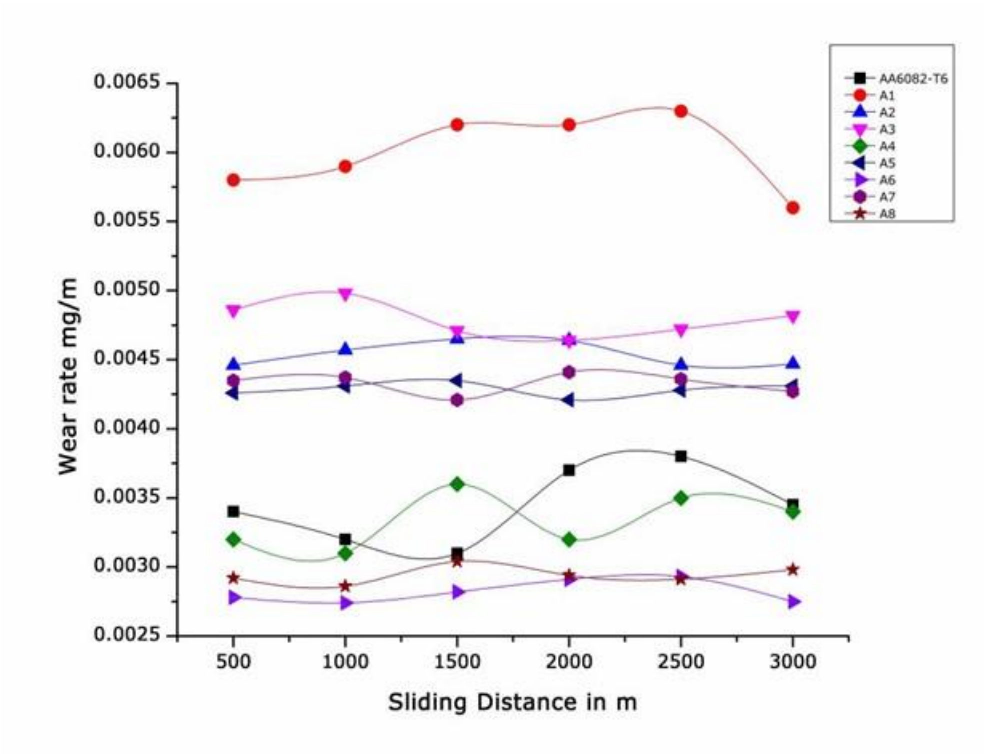
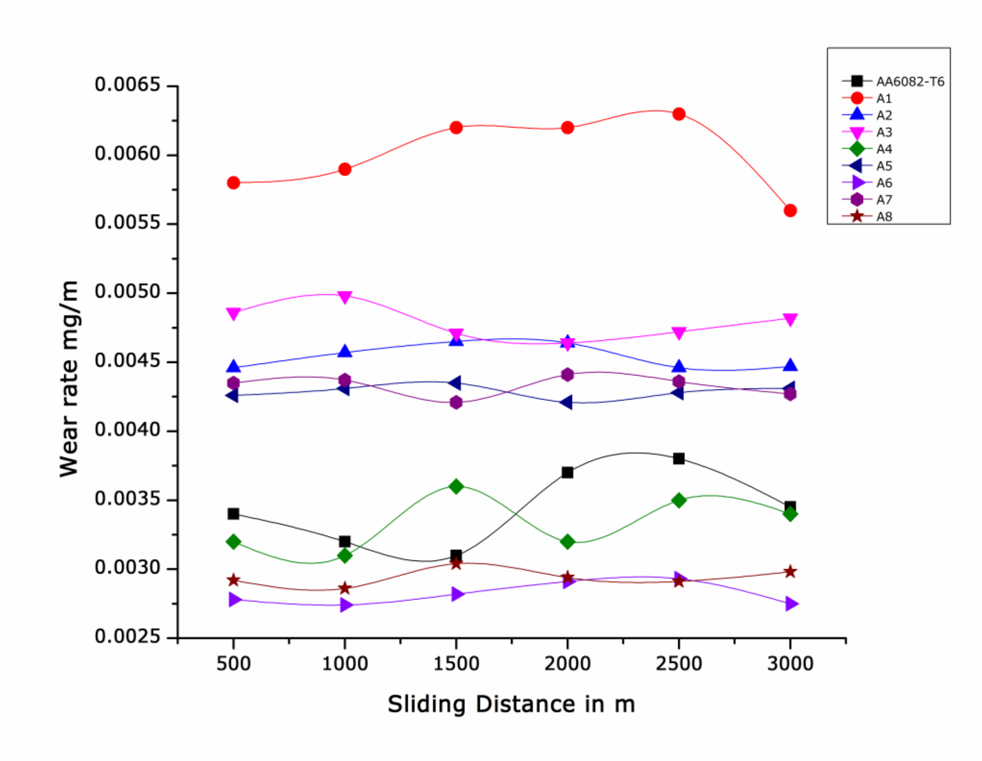


Fig. 8 Wear rate of untreated and heat treated samples of AA 6082-T6 with each 2.5 wt.% of Sn, graphite and Zn as individually and as hybrids.



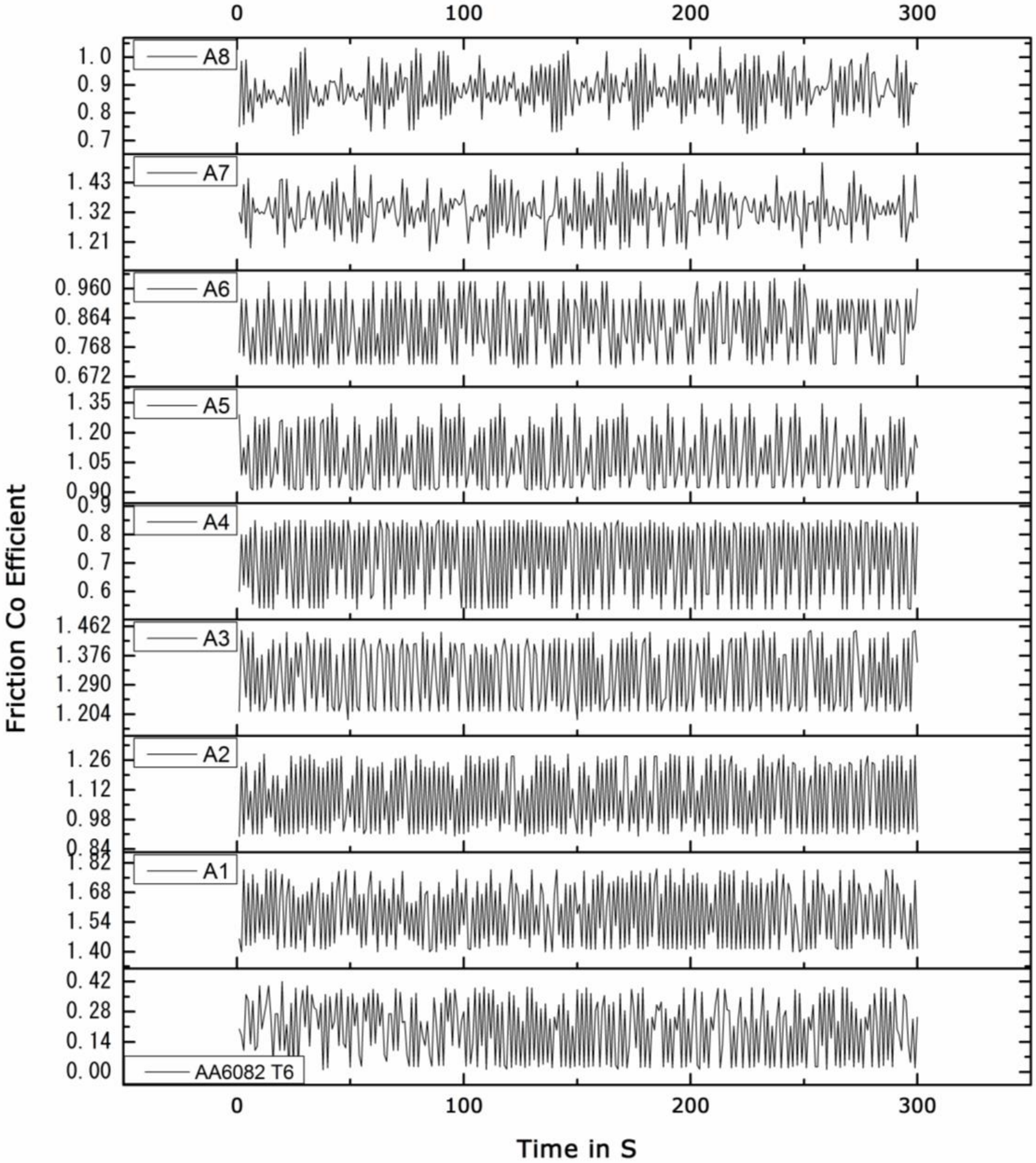


Fig. 9 Friction co efficient of the untreated and heat treated samples of AA 6082-T6 with each 2.5 wt.% of Sn, graphite and Zn as individually and as hybrid.

Figure 9 shows that friction co efficient of all samples in which heat treated element matrix composite were found lower compared to cast element matrix composite. Similar to wear rate, the Zn with element matrix composite and hybrid element matrix composite have better friction resistance than AA 6082-T6.

4. Conclusions

In this study, AA 6082-T6 having element matrix composite of different reinforcement were casted and heat treated using novel method. The mechanical properties such as micro hardness and tensile strength were found to be lower for all untreated samples than heat treated AA 6082-T6 samples. After heat treatment, mostly all the mechanical and microstructural properties were improved, especially in heat treated AA 6082-T6 with Zn (A6) and hybrid AA 6082-T6 element matrix composite

(A8), whereas the casted AA 6082-T6 element matrix composite found to be having inferior properties. The SEM analysis revealed the grain size reduction and improved elemental dispersion throughout the heat treated samples which helped to increase the mechanical properties. The friction and wear analysis found that the addition of zinc separately and hybrid (Tin, Graphite and Zinc) with AA 6082-T6 under heat treatment enhances the friction and wear resistance than AA 6082-T6. Applying these heat treated materials on automotive piston materials could improve the life and its performances with reduction in cost for replacing it frequently.

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