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Wear and Residual Stress Analysis of Waste Sea Shell and B_4C Particles Reinforced Green Hybrid Aluminium Metal Composite

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ABSTRACT

Present work, evaluates the effects of Sea shell and B4C powder on the mechanical behavior of the aluminium material (Al 6082). Stir casting method was used to fabricate a hybrid composite of Al 6082 with sea shell and B4C. A linear reciprocating tribometer was used to evaluate the wear and friction behavior. The addition of sea shell and B4C particles, resulted in 7-13 % reduction in coefficient of friction and 32-43 % improvement in wear resistance as compared to the Al 6082 alloy. The average Vicker hardness was also improved by 20-70 %. The residual stresses developed during the mechanical testing were also measured to inspect the generation of residual stresses in the fabricated composite. Optical micrographs and scanning electron microscope (SEM) were obtained to analyze the prepared composites for the wear behavior. Waste sea shells were reinforced with B4C in Al 6082 alloys. Micro-hardness along with microstructure and residual stress of the developed green hybrid aluminium metal composite are compared and presented. The wear and friction data have also been shown in this paper for the use of green hybrid aluminium composite in tribological applications.

Key words: Sea shell; B4C; Wear; Friction; Residual stress .

INTRODUCTION

In the recent past, numerous efforts have been made to find out the natural fibers which could be used as reinforcement in the aluminium matrix (Athijayamani et al. 2015). Natural fibers are not man-made fibers. These are produced from animals or plants. From the last few years, the usage of natural fibers has gained a tremendous increase in the composite materials. Bamboo, bagasse, kenaf, flax, jute sisal are some of the natural fibers which are produced in abundance and has been used by researchers in the fabrication of composite materials. These reinforcements contain some important metallic compounds in them which helped in improving the mechanical properties of the aluminium. The low weight, cost, easy usage, good mechanical properties (tensile modulus, surface finish) are some of the factors due to which natural fibers are gaining so much attention in the fabrication of composite materials.

The marine environment has many living organisms like fishes, oysters, and sharks. These organisms protect themselves from the difficult condition by a covering known as shells and scales. These sea shells contribute to carbon-di-oxide pollution and need to be disposed of properly. The calcium carbonate ($CaCO_3$) reacts with the atmospheric air and generates carbon-di-oxide. The utilization of sea shells in the material industry is a positive move which protects the environment. The sea shells consist of calcareous material which has good thermal and mechanical properties. The outer layer of the shells is made of composite material which is brittle in nature and helps in providing higher adsorption force to the external loads. Due to these important factors, sea shells are finding their use in the composite material and coating applications. The calcinated sea shells were used in the NiP matrix by Jagatheeshwaran et al. (2015). The sea shell and NiP coatings were produced on the steel substrate and pin on disc experiments were performed for the determination of wear properties. The sea shell mixed composite coating resulted with better wear resistance as compared to the NiP coated and uncoated steel specimens. However, the sea shell mixed composite coating resulted in a higher friction force. This limitation of the sea shell mixed composite coating was overcome by Jagatheeshwaran et al. (2017) by incorporating ZnO particles in the NiP and sea shell. The wear and friction properties of the prepared coating were much improved as compared to the uncoated specimens. Chong et al. (2005) prepared the plastic materials using the sea shells for the fire retardation applications. The presence of $CaCO_3$ in the sea shell played an important role in providing the fire retardation properties of the plastic material. The $CaCO_3$ decomposes to calcium oxide and CO_2 at higher temperatures and hinders the oxygen supply required for the fire. Alvarenga et al. (2012) provided a detailed review of the usage of the olyster shells. Authors provided a detailed study of the impacts of sea shell wastes on the environment. The conversion of sea shells to powdered $CaCO_3$ also requires a lot of machine work which also affects the environment. In their study, the impact of sea shell when these are deposited to landfills and impact when these sea shells were transformed into raw material as $CaCO_3$ powder was considered. The depositing of sea shells to land had an impact 93mPt whereas powdered $CaCO_3$ had an impact of 58.97 mPt. Moustafa et al. (2015) used the sea shell for the fabrication of the acrylonitrile-butadiene-styrene copolymer. The effective utilization of the $CaCO_3$ in the sea shells was reported by the authors. For the comparison of different properties, commercially available $CaCO_3$ was also used to fabrication the composite. Later, the fabricated materials were compared for various mechanical properties. It is reported that the presence of sea shells enhanced the mechanical properties of the fabricated composite material.

From the literature review, it is found that sea shell particles have been used to fabricate different composite coating materials. The sea shell has helped in improving the wear resistance of the products, however the friction force increases because of the presence of soft phase of the sea shell. To reduce the friction force as well as the wear from the aluminium material, attempts have been made in the present research, by incorporating the B_4C particles along with sea shell. A hybrid aluminium metal composite has been fabricated using the sea shells and B_4C particles using the stir casting method. The prepared composite was investigated for wear, friction, hardness and residual stresses for analyzing the effects of reinforcement particles.

2 MATERIALS AND METHOD

2.1 Matrix Material

Aluminium alloy (Al 6082) was used as the matrix material for the fabrication of the hybrid AMC. Al 6082 is the member of the Al-Mg-Si family and is mostly used in the construction industry. The chemical composition of the Al 6082 is given in Table 1.

Table 1. Chemical composition of Al 6082.

Element	Cr	Cu	Fe	Mg	Si	Zn	Al
%	0.25	0.1	0.5	0.8	0.6	0.9	Balance

2.2 Reinforcements

In the present work, Sea Shell (SSH) and Boron Carbide (B_4C) particles were used as reinforcements. The SSHs were produced by the exoskeleton of an invertebrate, and it generally has calcium carbonate. The presence of these elements makes it the potential reinforcement which could enhance the properties of the materials. The other reinforcement used is B_4C. B_4C is a very hard boron-carbon ceramic. The presence of these phases in the composite enhances the wear and friction properties of the composite. The average particle size for B_4C was 1-3 μm and for SSH it was 0.5-2 μm.

2.3 Fabrication of Hybrid Composite

There are many techniques which were used by researchers for the fabrication of hybrid aluminium composites (Erbayrak and Erbayrak 2020). Stir casting (Sharma et al. (2017)) and powder metallurgy (Nassar and Nassar (2017), Singh et al. (2018)) are among those which are mostly used. In this work, a stir casting setup was used to fabricate the composite. Initially, the SSH and B_4C powder were processed by using a ball milling setup to obtain the micro-sized particles and a proper mix as per the requirement. In the ball milling process, the SSH and B_4C were added with hardened steel balls in the ratio of 1:10 by weight. The Ball mill was rotated for 10 hours at 100 rpm to obtain uniform sized particles. The powdered samples of B_4C and SSH were examined under a scanning electron microscope for the homogeneous size distribution. In this work, two compositions of the hybrid composites were used. In the first composite, 8 w/w% of SSH and 4w/w% of B_4C particles were reinforced into Al 6082 and in the second composite 4w/w % of SSH and 8w/w% of B_4C were reinforced. The typical setup of the stir casting method consists of three main things. The first is the graphite crucible. This crucible is used to to keep the raw material and helps in melting it. The other part is the heating chamber which provides the required heat to melt the raw material and last part is the stirring system to mix the reinforcements homogeneously in the matrix material. The fabrication of the composite materials was done in a close atmosphere, and the reinforcements were introduced in to the molten metal at a constant rate as per the requirement measurements. For homogeneous mixing, the matrix and reinforcements are mixed with the help of a stirrer. It is done by using a mild stell blades stirrer. The chamber of the furnace was first heated to a temperature of 500ºC and then the crucible was filled with aluminum metal. The temperature of the chamber was increased to 900ºC to allow the aluminum to melt completely. The reinforcements were preheated in another heater to a temperature of about 200ºC. The stirring was started at a time when the metal reaches to fully molten sate. After stirring for 15 minutes at a temperature of 800ºC, the slurry was reheated and held at a temperature of 950ºC for 15 minutes so that, the slurry was in a completely molten state. A preformed metal mold was used to fabricate the samples. The slurry was then poured into the mold at a uniform rate to avoid trapping of gasses. Then the mold was allowed to cool and the metal was being ejected from the mold.

2.4 Measurement of Properties

After the successful fabrication of the composites, several properties were evaluated. Wear and friction, micro hardness, and residual stress were the main properties which were evaluated for the prepared composites.

2.4.1 Wear and Friction

Rotary Pin on disc (Lal and Singh (2018), Singh et al. (2019), Lal and Singh (2019), Rana et al. (2020)) and reciprocating pin on disc (Sharma et al. (2019) are the two methods which has been generally used by researchers for evaluating wear and friction behavior. In this study, a linear reciprocating tribometer (LRT) was used for the measurement of the coefficient of friction of the prepared composite. LRT consists of a fixed flat plate and a reciprocating pin. The pin reciprocates on the flat plate with some frequency and stroke length under the effects of the load. The friction force between the flat plate and the pin was measured with the help of friction force sensors.

This friction force was later converted to the coefficient of friction by diving the obtained friction force by the applied load. The amount of wear from the plate and pin surfaces was measured by weighing the flat plate specimen by using a weighing balance with 0.0001 g accuracy. In this work, the prepared hybrid composites were used as the flat plate and hardened steel as pin specimen. The experiments were performed at 10 Hz of the frequency with 10 mm as stroke length. A load of 30 N was applied on the pin. Before starting the experimentation, the pin and flat plate surfaces were cleaned with the help of acetone and were dried well.

2.4.2 Micro-hardness and Microstructure

An optical microscope and scanning electron microscope (SEM) were used to inspect the distribution of the reinforcements in the aluminium matrix. The specimen surfaces were cleaned and polished by using different grades (400, 800, 1200, 1600 grit) of SiC abrasive papers. After this the wet polishing was performed with 0.05μm alumina powder. The prepared surfaces were etched and observed under an optical microscope at 50X magnification.

The micro-hardness of the material directly affects the wear and friction properties of the material (Jeyapandiarajan and Anthony 2019, Ullen et al. 2020). A Vicker hardness tester was used to measure the micro-hardness as per ASTM E-384 standards. A diamond indenter was used to indent the composite surface with a load of 3000 mN for 20 seconds. Three observation of hardness were recorded and average was taken to draw the results.

2.4.3 Residual Stress

With the change in the natural shape of the material, some residual stresses remain in the materials. These residual stresses are generally relieved by using the heat treatment process. The residual stresses in the material may have negative effects on the properties and lifetime of the material. So, it is important to measure the residual stresses to predict the quality of the materials. The residual stress in the prepared composites was measured with the help of a residual stress analyzer (Pulstec limited model-μ X-360n). The residual stress analyzer works the principle of Bragg's law. For the measurement, X-ray irradiation time was fixed at 30 seconds with tube current of 1 mA and 30kV voltage. The incidence angle and X-ray wavelength was set at 35º and 2.29 A. The diffraction data were calculated by using the diffraction peak positions. The residual stress in the material changes the lattice spacing. This change in lattice space was used to calculate the diffraction data and later residual stress.

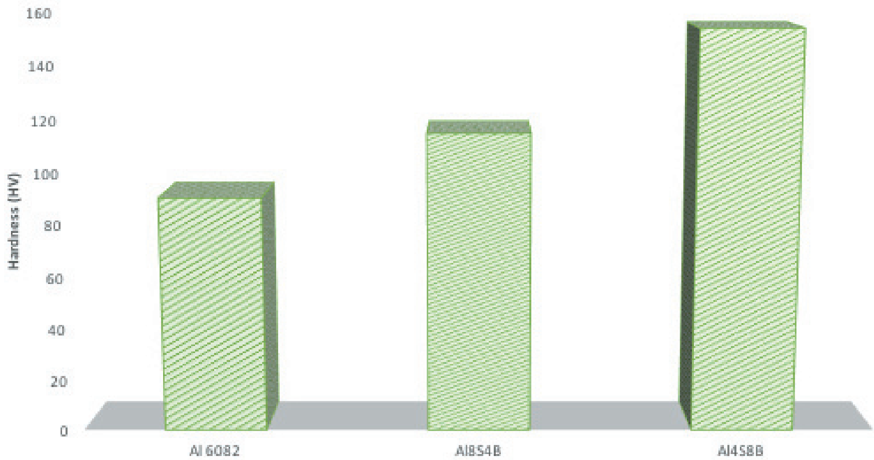
3. RESULTS AND DISCUSSION

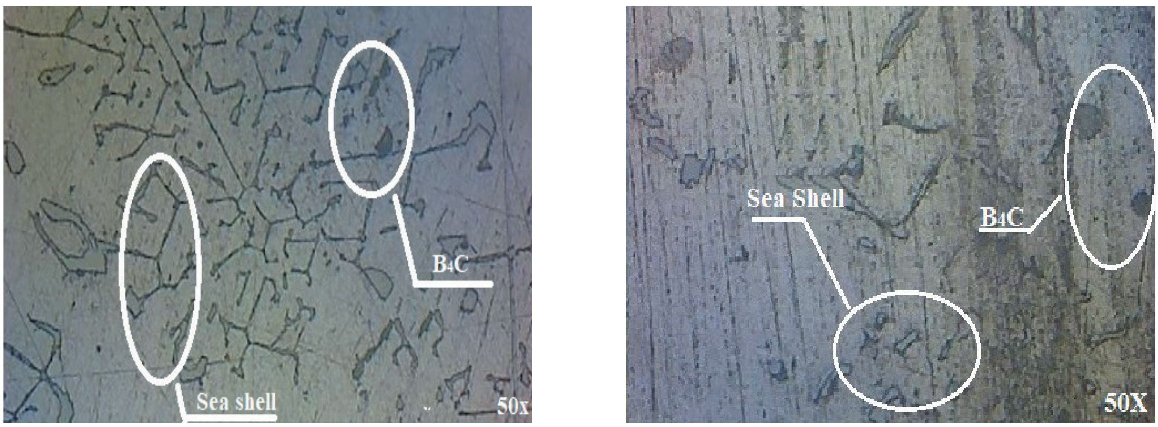
3.1 Microstructure and Hardness

The Vicker hardness measurement results are presented in Figure 3. It is inferred from the results that B_4C and SSH enhanced the hardness of the Al 6082 material. The Al 6082 had 90.13 HV Vicker hardness which increased to 114.63 HV with the addition of 8% SSH and 4% B_4C. With the further increase in B_4C contents, the Vickers hardness improved to 153.63 HV for 4%SSH and 8% B_4C sample.

The proper distribution of the reinforcement in the matrix material greatly enhanced the mechanical properties. For the inspection of the distribution of reinforcements in the Al 6082 alloy, optical micrographs along with scanning electron microscope (SEM) images were obtained. Figure 4 (a) presents the optical micrographs and SEM image for the Al8S4B. It was observed from the image that carbonate particles wear uniformly distributed throughout the matrix of the Al 6082. There were no protruded particles on the surface of composite. This distribution of SSH particles enhanced the machinability of the aluminium. The SEM image of Figure 4 (b) shows the B_4C protruding from the hybrid composite surface. These particles provided the wear resistance to the aluminium material.

Figure 3. Vicker micro-hardness observations





(a) (b)

Figure 4. Micrographs of (a) Al8S4B (b) Al4S8B

3.2 Wear and Friction

A linear reciprocating tribometer was used to measure the wear and friction properties of the fabricated composites. The composite samples were used as a flat plate on which a die steel pin was made to reciprocate under a normal load. Figure 5 presents the variation of the coefficient of friction. For the easy understanding of the COF curve, it was divided into four parts, these were "running in", "mixed zone", "steady-state" and "wear out". During the "running in" zone, the asperities of the plate and pin surface made contact, this in result increased the COF value. After the initial sliding, the asperities get removed and COF starts decreasing in the "mixed zone" and attained a near-constant value in the "steady-state" region as indicated in Figure 5. The "wear-out" region started at the end of the steady-state region and COF started to increase again. The average COF obtained for Al 6082, Al8S4B and Al4S8B were 0.89, 0.72 and 0.73 respectively. It was revealed that presence of SSH helped in reducing the COF values.

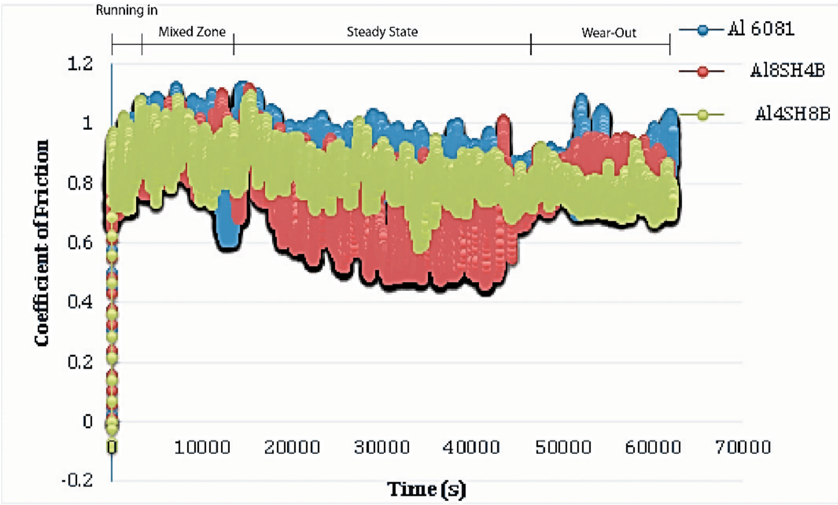


Figure 5. Variation of the coefficient of friction

The amount of wear from the plate samples was measured using a weighing balance. Figure 6 presents the wear in the form of mass loss. It is clearly seen from Figure 6 that, an average mass loss for the fabricated composites is lower, compared to the Al 6082 material. The mass loss for AlS8B4, Al4S8B and Al 6082 are 0.0459 g, 0.0393 g and 0.0759 g respectively. The presence of B_4C particles in the aluminium matrix greatly improved the wear resistance. The hardness of B_4C particles helped in improving the wear resistance. The B_4C particles prevented the wear of the aluminium matrix. The SSH present in the composite lowered the COF which also helped in reducing the wear. It was clearly observed from Figure 6 that, as more amount of B_4C was added in the composite, the mass loss further reduced. For the better understanding of the worn nature of the fabricated composite materials, SEM images were obtained for the wear samples. Figure 7 (a) presents the SEM image for the worn Al8S4B composite. Deep grooves and thick wear lines were observed on the worn surface. Wear debris detached from the composite were also observed on the surface. This indicated that the worn nature was mostly abrasive. The SEM image of Al4S8B indicated low amount wear wedges on the worn surface. Thin wear lines, as compared with the wear in Al8S4B, also showed lower wear for the AL48B composite. The presence of more B_4C helped reduce the mass loss for the Al4S8B composite (Figure 7(b)).

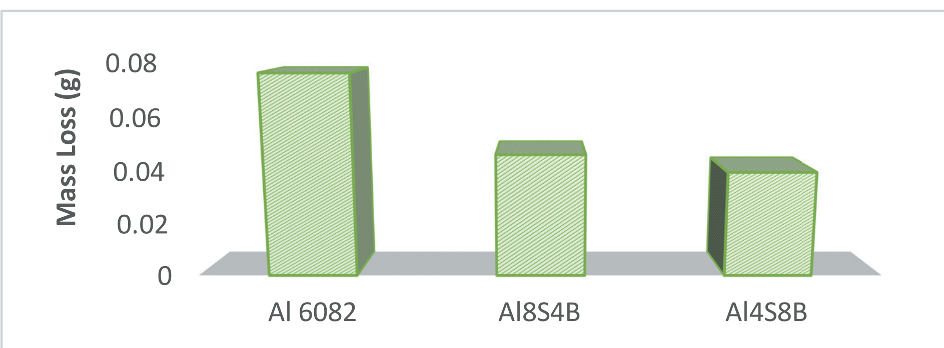
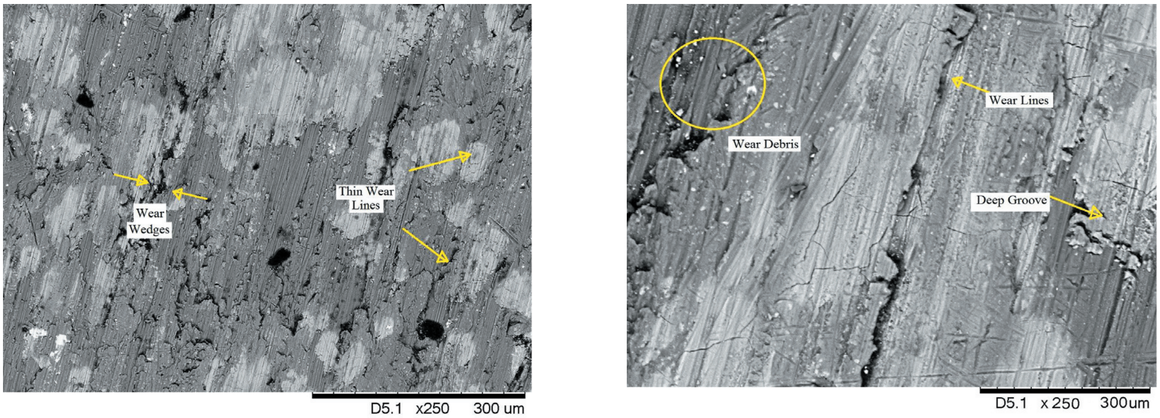


Table 6. Mass loss from the fabricated materials



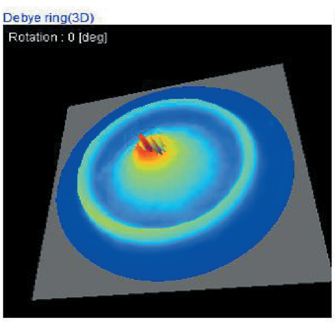
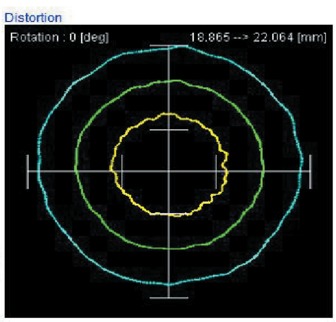
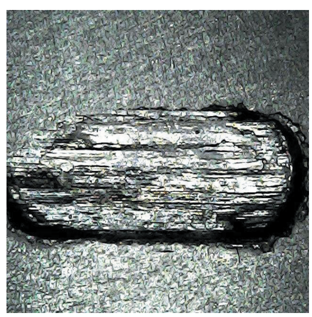
(a) (b)

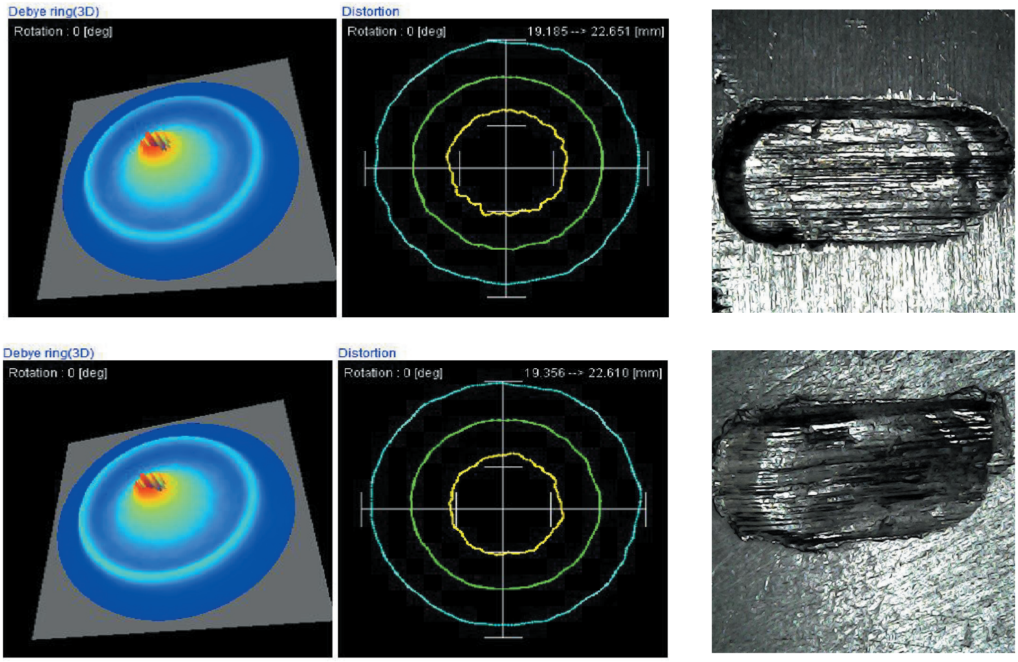
Figure 7. Scanning electron microscope image for (a) Al8S4B (b) Al4S8B composite

3.3 Residual Stress Analysis

A residual stress analyzer was used to measure the residual stress in the fabricated composites.. It was seen that the Al 6082 had a minimum amount of residual stress as compared to the fabricated composites. The Al 6082 had 99 MPa as residual stress. Al8S4B and Al4S8B had 129 MPa and 127 MPa residual stress. The introduction of reinforcement materials into the matrix of Al 6082 generated this residual stress which needs to be released before commercially using the materials.

For a better understanding of the residual stresses, debye ring and distortion profiles were also generated for all the samples. The Debye ring as shown in Table 5 represents the concentration of the residual stress in the tested materials. The value of the residual stress increases from the red region to the blue region. The region of the worn sample where, the pin makes the first contact with the composite material resulted with maximum residual stress, and as the pin moved on the surface, the residual stress kept on decreasing. The distortion rings indicated the damage occurred on the material which lead to the generation of residual stresses. The distortion images shown in Figure indicates the same amount of damage to all the three considered material. No abrupt or sudden damage was reported.

Debye Curve	**Distortion Curve**	**Wear Area Inspected**	**Material**
			Al 6082



Al8S4B

Al4S8B

CONCLUSIONS

In the present experimental work, Sea shells and B4C particles were reinforced into the Al 6082 alloy for improving its wear and friction properties. A stir casting setup was used to fabricate two-hybrid composites. Al 6082with 8%w/w sea shell and 4%w/w B4C and Al 6082 with 5%w/w sea shell and 8%w/w B4C composites were prepared. These composites were tested for various mechanical properties and the following conclusion could be drawn from this experimental study.

1. The sea shell and B4C particles were successfully used to fabricate the composites. Scanning electron microscope images indicated a uniform distribution of the sea shell and B4C particles in the Al 6082 matrix.
2. The micro-hardness tests revealed that reinforcements enhanced the hardness of the composite. B4C is the major contributing factor which improved the hardness. There was an increase of upto 70 % as compared with the hardness of Al 6082 material.
3. The reinforcements also improved the wear and friction properties of the composite. The average coefficient of friction enhanced to13% with comparison to Al 6082. The wear loss from the Al 6082 also gets reduced with the introduction of sea shell and B4C particles. The wear reduced upto 43%. There was a reduction of mass loss to 34% for Al8S4B material and 43% with Al4S8B material. However, the reinforcement in the Al 6082 resulted in some increase in the residual stresses. The residual stresses in the fabricated composites increase to 30%.

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