Experimental investigations on Mechanical and Tribological behaviour of A356 with x wt% Boron Carbide and Fly Ash Hybrid Composites

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Abstract. The current research work aims to analyse the behaviour of mechanical and tribological characteristics of stir cum squeeze cast A356 with Boron Carbide (B₄C) and Fly ash (FA) Metal Matrix Hybrid Composites (MMHC’s) on hardness, wear rate and friction coefficient. Experiments were carried out through stir cum squeeze casting method by keeping the influenced process parameters constant and varying three different equal weight percentage (2.5, 5, 7.5wt%) of B₄C and FA with A356 alloy. Each prepared composite samples were tested for hardness and also, wear and friction characteristics were accomplished in a pin on disc tribometer apparatus. The wear and friction characteristics were obtained by varying the load of 10, 20, 30, 40N with a constant sliding distance of 2500m respectively on the tribometer. Experimental investigation results uncovered that the hardness of A356 with 7.5wt% B₄C and 7.5wt% FA MMHC’s was increased with an increment in the weight percentage of B₄C and FA. Also, there is an increase in the wear rate and a decrease in friction coefficient with a rise in the load from 10N to 40N. Overall, the wear rate of the MMHC sample was reduced with a higher wt% of B₄C and FA. The study reveals that the prepared MMHC’s via stir cum squeeze casting was a suitable component for automobiles.

1. Introduction

Metal matrix hybrid composites (MMHC’s) are playing a vital part in the engineering segments due to its excessive strength corresponding to its weight. MMHC exhibit excellent thermal & resistive ability against corrosion with applications in automotive & aerospace sectors [1, 2]. Aluminium alloys exhibit low density with good malleability, thermal conductivity and excellent cast ability properties. Because of the excellent properties and low density (2.7 g/cc), Cast aluminium-A356 alloy is used in automobile sectors and lightweight industrial applications, such as aeronautics and space vehicle [3]. Different reinforcement materials such as a) Titanium carbide, b) Silicon Carbide, c) Aluminium Oxide, d) Boron Carbide, etc are reinforced in the matrix material in order to attain better properties [4]. Boron carbide is one of the most predominant hard materials with excessive melting point, thermal stability, abrasion resistance, excessive hardness and minimum density value. The reinforcement of
Boron carbide in aluminium exhibit very high strength, stiffness, hardness and thermal conductivity. The fabrication of hybrid composites seeks a huge attention in current research world. The B4C and fly ash were the reinforcement material which can be obtained at the minimal cost. These elements with aluminium alloy can give enormous toughness and additional rigidity than the conventional metal matrix hybrid composites [5]. Fly ash is a gathered product from combusted coal as industrial waste which can be converted into industrial wealth, by utilizing it as a reinforcing component in the metal matrix composites. By introducing the fly ash in composite material may also increases the abrasive wear resistance of the metal matrix composites [6]. It is observed that the addition of 2.5% weight of fly ash and SiC components in the matrix material enhances the hardness and superior wear resistant properties of metal matrix composites [7]. Similar results are observed by introducing the modified fly ash with AA1200 Aluminium Alloy. The hardness property of the composites improved with rise in the amount of fly ash and wear rate was found to be decreased with 8 wt% of modified fly ash [8]. Also, it is noticed that the density of the composites is reduced with the addition of FA. Wear resistance of the composites increased with the adding A2O3 and FA reinforcements [9]. Overall, the mechanical responses such as a) Hardness, b) Compressive Strength, c) Ultimate Tensile Strength, and d) Young’s modulus can enhanced through enlarging the weight percentage of FA material. Thus, FA as reinforcement in matrix material further increases the properties of MMHC materials [10-13]. It is also observed that the hardness and ultimate tensile strength of the composites are increases by the addition of fly ash as reinforcement particles. Introduction of fly ash elements in the composites shows peak and then reduced with the higher weight percentage of fly ash particles. This reduction is recognized to a rise in the porosity content with growing wt. % FA and also, rupture and debonding of fly ash particles. [14]. By increasing the wt % of rice husk ash(RHA) in the reinforcement, various characteristic parameters such as a) Tensile Strength, b) Compression Strength and c) Hardness can be improved. It was concluded that the enhancement in the mechanical properties can be accredited to the high dislocation density. Although, it was observed that there is a decrease in tensile strength for the composites having rice husk particles more than 12% weight fraction. [15]. Increasing the FA and RHA reinforcement in MMC results in the improvement of tensile strength up to 10% of the reinforcement weight percentage. The increase in Rice Husk Ash with decrease in weight proportion of Fly ash results in the improvement in the hardness of the test specimen. For the combination of AlSi10Mg + 10% Fly Ash + 10% Rice Husk Ash composite, optimum hardness can be acquired. [16]

The automobile and aeronautical industries are searching for materials with great mechanical responses and fabricated in advanced casting processes [17]. Traditional casting process couldn’t make parts with required strength due to some major drawbacks like porosity, segregation, hot tears etc. [18-20]. Totally distinct approach for making specific element is possible with the help of squeeze casting, an emanating metal forming method to eliminate micro porosity and to give isotropic properties and diminish part manufacturing [21-22]. This method was applied on many metals, starting from lead and zinc, low melting alloys to iron and nickel, high melting alloys. The stir cum squeeze casting method was the uncomplicated method for the manufacture of MMHC. The squeeze operation on the casted component enhances the properties by making the grain size finer and by making the uniform distribution of the reinforcement [23-24]. The squeeze casting method for aluminium-fly ash MMHC’s shows many advantages. It exhibits excellent compatibility among the aluminium and the FA particles, its matrix-alloy structure gets improved, and some pores of the FA are sealed by metal and activation of pressure in the FA - metal bond [25].

Based on the literature review, stir cum squeeze casting processing route is utilized in this present research work to fabricate the A356 aluminium alloy with three different weight percentage of B4C and FA particles, since there is no work carried out. From the literature review it is concluded that, higher the percentage in weight of reinforcement particles might reduce the properties of the composite materials. So, in order to enhance better characteristics of A356 aluminium alloy, three different equal weight percentages of 2.5, 5 and 7.5 wt % of B4C and fly ash are chosen in our work. The reinforcement of B4C and FA processing through stir cum squeeze casting fabrication route is the novelty of this paper. In order to know the impact of reinforcing phase in the MMHC material,
mechanical and tribological behaviours such as hardness, wear rate and coefficient of friction (CoF) in the composite specimens are discussed.

2. Materials and methods

2.1 Manufacture of composites
Initially, A356 aluminium alloy were melted at a high heat of 725°C temperature in a steel container and maintained at same temperature till a liquid phase at homogeneous condition is formed. The chemical composition of the A356 aluminium alloy is denoted in the table 1.

| Contents | Si     | Mg    | Mn    | Zn    | Fe    | Cu    | Al     |
|----------|--------|-------|-------|-------|-------|-------|--------|
| weight % | 7.288  | 0.354 | 0.028 | 0.008 | 0.144 | 0.011 | Balance |

After the impurities are removed, the motorized stirrer rotating at a rate of 300 rpm for the time of 5 minutes is imparted to create a sufficient vortex. In order to develop the wettability present in B₄C elements, while stirring the melt, the preheated reinforcement particle of 2.5wt% of B₄C and 2.5wt% of FA are gradually added along with wettability salt K₂TiF₆. Before adding FA in the MMHC materials, it is pre-treated based on the following steps, a) required weight percentage of FA is taken in the graphite container and it is preheated to 800°C for 3 hours to find the LOI (Loss of Ignition) b) In the second step, it is cooled to environmental temperature and then the preheated FA is cleaned in distilled water to eliminate carbon. c) Finally, it is dried at 110°C for 48 hours to eliminate the water to get the desired fly ash material.

Then it is shifted to the preheated die over bottom pouring casting arrangement. Hydraulic unit with 50 Ton (250 MPa) capacity and firmly fitted punch was used to apply the required squeeze pressure. Molten metal is melted in a bottom pouring electric furnace (2 litre capacity) with a maximum range of 1200°C. Inbuilt preheated pathway unit with a capacity of 400°C was used to carry the molten metal to the metallic die steel die. After pouring the fine vortex of metal into the preheated die cavity, liquid metal is subjected to an immediate 140 Mpa of squeeze pressure on the top surface of the molten metal. The specimen of A356 aluminium alloy with 2.5wt% of B₄C and 2.5wt% of FA is taken from the die when it is solidified. The same experimental technique is followed for reinforcing B₄C and FA
with 5 and 7.5 percentage of weight. The stir cum squeeze casting arrangements and casted specimen are presented in the figure 1 and figure 2.

2.2. Metallurgical, Mechanical and Tribological Test
The Scanning Electron Microscope is utilized to analyse the microstructure of the MMHC material. The specimens after casted from squeeze casting process in subjected to the microscopic analysis in order to analyse its metallurgical properties. The Vickers hardness method of testing is conducted to find the hardness of the A356 aluminium alloy with various percentage in weight of B₄C and FA. By applying 0.1 kgf of sample load, the hardness of the MMC material can be obtained. The dwell time and indentation time is kept constant as 20 and 15 seconds respectively. The pin on disc testing technique is utilized to determine the CoF and wear rate. The prepared casted samples were made with the dimensions of 10mm x 10mm x 15mm (Length x Width x Height). The wear test is conducted according to the ASTM G99 standard [26-27]. The sample specimen is placed tightly on the specimens holder. The desktop computer which is integrated with the pin on disc machine is turned on to display the results. The examinations were conducted by fitting the specimen as constant on a revolving steel disc (EN-36) which has a disc hardness of 65 HRC. In this research, sliding distance of 2500 mm is kept as constant and the varying load of 10,20,30,40N is applied on the wear testing samples. Weight loss of each sample are noted for the varying load of 10,20,30,40 N. The pin on disc wear testing apparatus is displayed in the figure 3(a) and figure 3(b).

Figure 3. Pin on disc wear test apparatus

3. Results and Discussion

3.1. Metallurgical Analysis
The weight proportion of B₄C and FA reinforcement materials in the A356 matrix material modifies the metallurgical properties of the metal matrix hybrid composites. The standard squeeze casting parameters such as speed of the stirrer and squeeze pressure makes a sound casting. The Scanning Electron Microscopic image of A356 aluminium alloy with 5wt% B₄C and 5wt% FA composite specimen is exhibited in the figure 4. The microscopic examination reveals that there is an absence of porous defects in the composite sample with an even dissemination of reinforcement elements over the aluminium matrix. When the weight percentage of the reinforcement particle increases, the grain refinement gets improved which is resulted to increase in hardness of the material. The micro and nano particles present in B₄C and FA increases the hardness of the MMHC materials which is purely depends on the distribution of the reinforcement particles.
3.2. Vickers hardness
The hardness values are measured for A356 aluminium alloy with three different composition of B₄C and FA as 2.5, 5 and 7.5wt%. The hardness value of A356 aluminium alloy with 2.5wt% of B₄C and 2.5wt% of FA is found to be 102 VHN. The hardness value of A356 aluminium alloy with 5wt% of B₄C and 5wt% of FA is found as 138 VHN. Similarly, the hardness value of A356 aluminium alloy with 7.5wt% of B₄C and 7.5wt% of FA is obtained as 152 VHN.

3.3. Wear rate
The wear rate is the change in volume occurred due to wear in the testing sample. The wear test samples prepared from the casted samples are tested for tribological properties. The specimen 1 is
prepared from the casted sample of A356 aluminium alloy with 2.5 wt% of B₄C and fly ash. Similarly, the second and third specimens are prepared from the casted samples which had 5 wt% & 7.5 wt% of B₄C and fly ash respectively. The specimens prepared for analyzing the tribological properties are shown in the figure 7. By applying various loads of 10, 20, 30, 40N the wear rate is found to be 0.0061, 0.0070, 0.0076 and 0.0082 g/m respectively for the sample 1. Same load conditions are applied for the sample 2 & 3 and, the wear rate of the MMHC materials is measured. The wear rate is found as 0.0039, 0.0048, 0.0059 and 0.0065 g/m for the respective loads of 10, 20, 30 and 40N for sample 2. Similarly, the wear rate is obtained as 0.0025, 0.0031, 0.0041, 0.0049 g/m for the corresponding loads of 10, 20, 30 and 40N for sample 3. It is found that the wear rate obtained for various loads in sample 1 and in sample 2 is greater than that of the wear rate found in sample 3. The change in wear rate with respect to the load value for the various samples is graphically represented in the figure 8. Reduction in the wear rate with respect to the percentage of B₄C and FA is graphically represented in the figure 9. Thus, when the weight percentage of B₄C and FA gets increased, the wear rate of the composite samples gets decreased. This is because, when the percentage of B₄C and FA is increased, the hard materials present in boron carbide and fly ash prevent samples from high wear.

Figure 7. Specimens prepared for Wear Test

![Specimens prepared for Wear Test](image_url)

Figure 8. Amount of reinforcement vs Wear rate for different load conditions

The applied load on the time of wear test is a factor that influences the wear rate. For the specimens with 2.5% of B₄C and 2.5% of FA, the wear rate is obtained as 0.0061 g/m for the load of 10N. When load is increased from 10N to 20N, the wear rate also gets increased from 0.0061 g/m to 0.0070 g/m. The corresponding responses of wear rate are enhanced when the load applied is increased in all the tested specimens. Thus, when the applied load is increased, wear rate also increased and vice versa. From the study it reveals that the adhesive wear and severe material removal is prevented due to the existence of hard reinforcement elements and relatively better interfacial bonding of matrix with B₄C and FA reinforcing particles. This is because the sample 3(A356 reinforced with 7.5 wt% of B₄C and FA) shows a lesser wear rate when compared with a sample 1 and sample 2 (A356 reinforced with 2.5 & 5 wt% of B₄C and FA respectively).
To confirm the results obtained from the pin on disc wear test, Scanning Electron Microscopic (SEM) image of the worn-out surfaces were taken for the sample with low load and high load as shown in the figure 10 (a) and 10 (b). In the sample with high load condition the flow of material is observed from the image, due to high wear rate. When the load is increased from low to high, the particles are peeled out from the matrix material and results in a higher wear rate. The formation of wear debris can also be seen from the SEM image worn surface.

3.4. Coefficient of Friction
The coefficient of friction (CoF) is the change in frictional force based on the applied load. The CoF value diminishes with rise in load. When the weight percentage of B₄C and FA is increased, the CoF value gets increased. Thus, the sample 3(A356 with 7.5% of B₄C and 7.5% of fly ash) exhibit the highest CoF value and inversely A356 composite sample with 2.5% of B₄C and 2.5% fly ash has the least CoF value. The change in CoF with respect to the increase in load value for different weight percentage of B₄C and FA is graphically represented in the figure 11.
4. Conclusion

In this research work, MMHC of A356 aluminium alloy with B₄C and FA of various weight percentages of 2.5, 5 and 7.5 were fabricated successfully by stir cum squeeze casting processing route. The Vickers hardness test is done to analyze the mechanical properties. Wear rate and CoF for the composite materials are evaluated from the pin on disc wear test apparatus. From the results observed from various tests, the succeeding conclusions are drawn from the investigation.

- The composite material with 7.5wt% of B₄C and 7.5wt% of FA exhibited the greater hardness value. Thus, the hardness value increases when the weight percentage of B₄C and FA gets increased.
- The wear rate of the composite specimen with 7.5wt% of B₄C and 7.5wt% of FA is reduced when compared to the lower weight percentage of B₄C and FA. Thus, the wear rate of the MMHC material decreases when the weight composition of reinforced material gets raised. The wear rate of the composite specimen with 7.5wt% of B₄C and 7.5wt% of FA get raised when the applied load is increased.
- The CoF value increases with the rise in weight percentage of the reinforcement material in the A356 aluminium alloy. Also, the CoF value of the composite specimen with 7.5wt% of B₄C and 7.5wt% of FA decreases as a result of increase in the applied load.
- Thus, the high strength metal matrix hybrid composite with high wear resistance was fabricated with proper utilization of industrial waste material, A356 reinforced with 7.5 wt% of B₄C and 7.5 wt% of FA metal matrix hybrid composite was highly recommended for the automobile industry to manufacturing of automobile components such as piston due to its excellent mechanical and tribological properties.

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