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Surface fracture analysis of stir casted AA 6063/TiC/Gr hybrid composites under different solidification rate

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ABSTRACT

Aluminium Alloys (AA) are predominantly used in various fields of engineering applications. Among that the AA 6000 series is mostly preferred material for automobile applications. In this research work, the AA 6063 is selected as the matrix material and it is reinforced with Titanium Carbide (TiC) of 10 wt% and graphite (Gr) of 3 wt% using the liquid stir casting technique. The solidification is done with four different cooling rates for the composites and its effects on mechanical properties are analyzed. The hardness of the AA 6063/TiC/Gr hybrid composites is increased with an increase in cooling rate but the compressive strength is decreased because of the phenomenon of brittle transition. The higher tensile strength of AA 6063/TiC/Gr hybrid composite is achieved for the cooling rate of 3 °C/s. The microscopic analysis is carried out using the Scanning Electron Microscopy (SEM) for the tensile tested samples. From SEM images, it is inferred that the grains are refined and leads to brittle transition at the surface of composites.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Materials Engineering and Characterization 2019.

1. Introduction

In advancement in the manufacturing process and the material science has developed new engineering materials for the various applications of the modern society. For automobile applications, the Aluminium Alloys (AA) 6000 series is commonly selected. Especially for piston material, the AA 6063 is mostly preferred because of it's better mechanical and thermal properties [1]. Even though the mechanical strength of AA 6063 is adequate for the system, the self-lubrication effect is required for the system. For the improvement of self-lubricating, the graphite particles are reinforced to the aluminium composites [2]. On addition of graphite particles, the strength of the AA composites is reduced below the required strength of the piston material. To overcome this defect, the ceramic particles are added to form the AA hybrid composites [3]. Among the ceramic particles, the Titanium Carbide (TiC) is the highly preferred refractory hard ceramic material [4,5]. The TiC reinforced Aluminium-graphite hybrid composite has the better thermal and self-lubricating properties even at high operating temperature. This behavior makes the material more suitable for the high-temperature engine systems. This is due to its poor strength, which can be visible during the machining process [6,7]. For the enhancement of mechanical strength, the basic metallurgical route is controlled the solidification rate to improve the crystalline behavior of the hybrid composites [8]. For investigating the failure of the material, the morphological analysis on the fracture surface of the failure material is an effective way to spotlight the cause for failure [9,10]. In this research work, the effect of solidification rate on mechanical properties of the AA 6063 hybrid composites is studied and further, the fracture of the tensile tested samples are analyzed to conclude the phenomenon of material failure.

2. Materials and methods

The commercial casting grade Aluminum alloy 6063 is employed as the matrix material and its composition is tabulated in Table 1 and the Fig. 1 shows the stir casting setup. The content of reinforcements is selected based on the literature i.e. the 3 wt% of graphite is chosen from the results of [11] and the 10 wt% of TiC is selected from [12]. The current investigation is the comparative study of [13] and the results are recorded. The TiC and graphite (Gr) particles with the size of 16 μm to 20 μm are used as the rein-

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Table 1
Chemical composition of AA 6063.

Elements	Zn	Cu	Mn	Mg	Fe	Cr	Ti	Si	Al
Wt. %	0.05	0.1	0.12	0.6	0.34	0.1	0.06	0.23	Remaining

Fig. 1. Stir casting setup.

forcement. For manufacturing the AA 6063/TiC/Gr hybrid composites with 10 wt% of TiC and 3 wt% of Gr particles, 1000 g of aluminium charges are melted in a graphite crucible and heated up to a temperature above the alloys melting point. The temperature control of the molten melt is taken care of with thermocouples inserted into the melts to measure its temperature. A mixture of TiC and Gr particles are added into the melt within four minutes at 850 °C with mechanical stirring at 350 rpm. Finally, the melt is poured into a preheated metal mold with 850 °C casting temperature [14]. The mold is hold in the furnace and allowed to cool slowly at the rate of 1 °C/s and 3 °C/s. Similarly, for the next sample, the mold is hold in atmospheric condition for the natural cooling rate of 5 °C/s on average. In the next case, the rapid cooling of 10 °C/s is attained by quenching technique.

The stir casted AA 6063/TiC/Gr hybrid composites under different solidification rate are machined using Electron Discharge Machining (EDM) for evaluation of mechanical properties. The hardness of the composites is measured using a Brinell hardness tester with 10 mm ball indenter and 500 kg load. The hardness is measured at five different places on each sample (diameter 20 mm and 10 mm thickness) to obtain an average value of hardness. The uniaxial compression tests are performed on these samples (diameter 10 mm and 10 mm thickness) with computerized Universal Testing Machine (UTE 40) at room temperature and their ultimate compressive strengths are determined as per ASTM E9-09 standards. As per the ASTM E08-8 standard, the tensile strength is carried out using the cylindrical rod of diameter 15 mm and length 150 mm. The computerized Universal Testing Machine (UTE 40) is used to conduct the tensile test. The tensile strength is evaluated at crosshead speed of 2.5 mm/min. The fracture surfaces of the tensile tested samples are analyzed using Scanning Electron Microscope (SEM) (Model: Hitachi-S3400).

3. 3. Results and discussion

3.1. Hardness

The hardness of the AA 6063/TiC/Gr hybrid composites is graphically represented in Fig. 2. The hardness of the AA 6063/TiC/Gr hybrid composites has been increased with an increase in cooling rate. This is because of the obstacles to the movement of dislocation caused by the hard TiC ceramic phase [15]. Even though the hardness is the bulk property, the surface hardness of the AA 6063/TiC/Gr hybrid composites is increased with the increase of cooling rate, which states that the brittle nature on the surface of the composites.

3.2. Compressive strength

The compressive strength of the AA 6063/TiC/Gr hybrid composites is graphically represented in Fig. 3, which shows that the compressive strength of the AA 6063/TiC/Gr hybrid composites is decreased with an increase in cooling rate.

The decrease in compressive strength is insignificant since the fall is not above 10% in deviation. Apart from that the ceramic phase in the composite has the ability to store higher energy and to evenly distribute the load applied to the surface over the lattice of ceramic phase [16].

3.3. Tensile strength

The tensile strength of the AA 6063/TiC/Gr hybrid composites is graphically represented in Fig. 4. The tensile strength of the AA 6063/TiC/Gr hybrid composite casted at the cooling rate of 3 °C/s has achieved 264 MPa, which is 30% higher than the rapid cooling rate. This is phenomenon is due to the transition of the brittle phase for the cooling rate of 10 °C/s and ductile phase for the cooling rate of 3 °C/s. Also, during the tensile test, the stress transference from the aluminium matrix to the reinforced particles TiC.

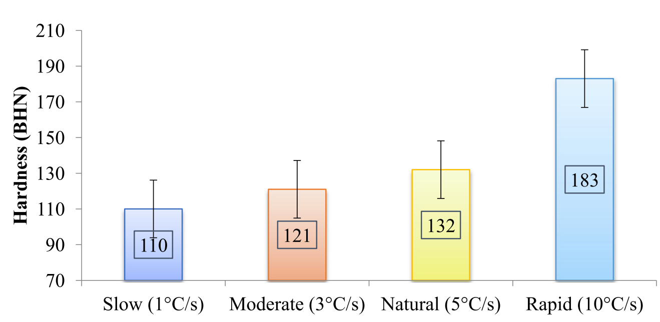

Fig. 2. Effect of solidification rate on hardness of AA 6063/TiC/Gr hybrid composites.

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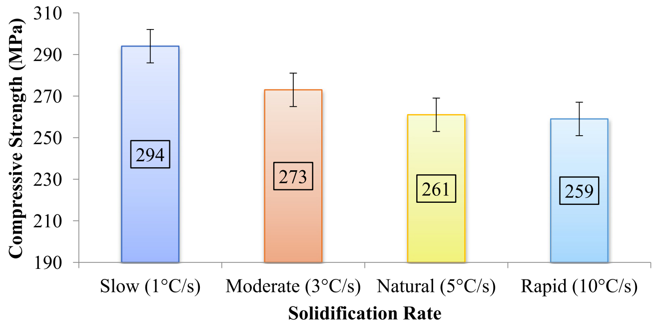

Fig. 3. Effect of solidification rate on compressive strength of AA 6063/TiC/Gr hybrid composites.

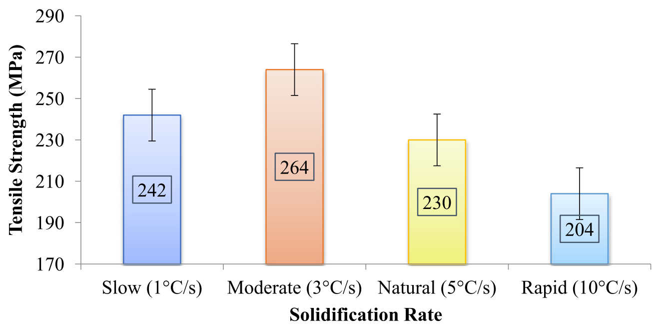

Fig. 4. Effect of solidification rate on tensile strength of AA 6063/TiC/Gr hybrid composites.

This is because of orowan mechanism by which a dislocation bypasses impenetrable obstacle where a dislocation bows out considerably to leave a dislocation loop around a particle. The tensile strength is high for 3 C/s cooling rate due the aluminium grains extruded along the TiC particles. This result is agreed with the mechanism stated by [17].

3.4. Fracture surface analysis

The fracture surface of the tensile tested samples is analyzed to evidence the cause for the failure, which is shown in Fig. 5. The grain refinement occurs at slow solidification and moderate solidification, which leads to an increase in tensile strength of the samples. On failure, the grain boundaries are completely cracked for the AA 6063/TiC/Gr hybrid composite casted at the solidification rate of 1 °C/s, which is shown in Fig. 5(a). Similarly, for the AA 6063/TiC/Gr hybrid composite casted at the solidification rate of 3 °C/s, the grains boundaries are elongated by the ductility and withstand for higher load before failure, which is shown in Fig. 5(b).

The AA 6063/TiC/Gr hybrid composites casted at natural and rapid solidification rate have experienced the brittle transition and fails with the exact consequence of the grain size and grain boundary effects [18]. From Fig. 5(c), it is inferred that the transition of brittle nature has leads to delamination of surface layers for the AA 6063/TiC/Gr hybrid composites and results in failure at low load. Similarly, from Fig. 5(d), it is inferred that the grains form a scratchy abrasive shape, which leads to poor bonding of the reinforcements to the matrix.

4. Conclusion

The AA 6063/TiC/Gr hybrid composites are successfully casted at different solidification rate and their mechanical properties are evaluated. The hardness of the AA 6063/TiC/Gr hybrid composites is increased with an increase in cooling rate but the compressive strength is decreased with an insignificant range because of the brittle transition and hard ceramic TiC. The tensile strength of the AA 6063/TiC/Gr hybrid composite casted at the cooling rate of 3 °C/s has achieved 264 MPa, which is 30% higher than the rapid

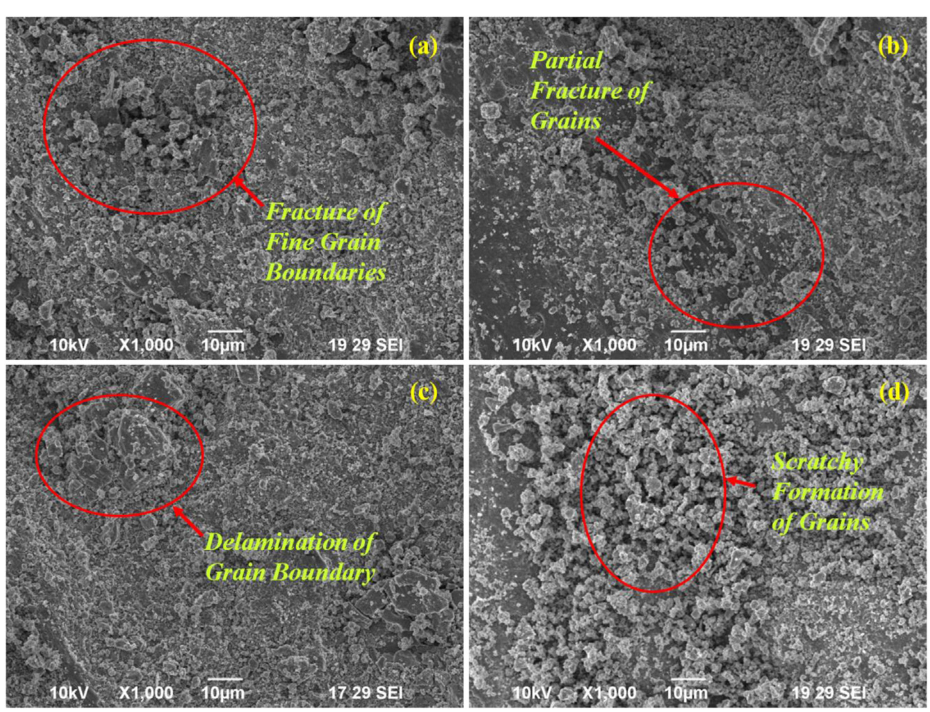

Fig. 5. Fracture Surface analyses for tensile tested samples of stir casted AA 6063/TiC/Gr hybrid composites with solidification rates of (a) Slow (1 °C/s), (b) Moderate (3 °C/s), (c) Natural (5 °C/s) and (d) Rapid (10 °C/s).

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cooling rate. This is because of the elongation of grains boundaries by the ductile nature of the material and it leads to withstand for higher load before failure.

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