Mechanical and Microstructural Evaluation of AA5083 Matrix Reinforced with SiC/B_4C Particles by Stir Casting Technique

R Raja, Sabitha Jannet, S Rajesh Ruban, Nikolaus Romanov, Morish Manohar

Abstract*: Particle reinforced aluminium matrix composites (AMCs) represent an important class of materials. They are primarily used in aerospace and automotive due to their excellent mechanical and tribological properties. In the present paper, Al 5083 alloy reinforced with Silicon Carbide (SiC) and Boron Carbide (B_4C) particles was fabricated by using stir casting technique. Stir casting is an attractive manufacturing route for AMCs because of its simplicity and cost efficiency. It is also very flexible in terms of material and geometry and can be used in mass production. Three composites with equal SiC content and different B_4C content were cast. Tensile, microstructure and wear tests were carried out and the microstructure of the composites was investigated. Whereas tensile strength and hardness values were almost constant, the wear rate decreased significantly with increasing B_4C content. The resulting micrographs showed a uniform distribution of ceramic particles in the aluminum matrix. However, clustering became more probable with higher reinforcement content.

***Index Terms:* Aluminium matrix composites, stir casting, tensile strength, wear rate.**

I. INTRODUCTION

During the last century, the significance of composite materials has increased tremendously, due to their high performance and light weight potential. Composites consist of at least two constituent materials, the matrix and the reinforcement. After combination, a new material with superior properties than the individual constituents themselves is formed. Classical reinforcements are shaped as fibres or particles. Whereas the properties of fibre reinforced composites are optimized in definite directions along the load paths of the final structure, particle reinforced materials exhibit almost isotropic behavior. Moreover, particle reinforced composites are less expensive and can be processed with methods similar to that used for monolithic materials [1]. According to the matrix material, composites can be classified into organic matrix composites (OMC), ceramic matrix composites (CMC) and metal matrix composites (MMC). The later provide excellent properties such as high strength and stiffness, thermal stability and low density as well as damping capacity and improved wear resistance [1-3]. These properties make them suitable candidates for the application in automotive or aerospace structures [2-4]. The most common metal used as matrix is aluminium due to its high specific strength, low density, good corrosion resistance and availability [1],[2],[5]. Compared to other important light metals like titanium or magnesium, aluminium is also a cheap material [5]. There are various methods to produce MMCs, for example, powder metallurgy (a solid state process), spray casting (a semi-solid process) or stir casting (a liquid state process) [1],[5],[6]. Among these, the stir casting method is very attractive because it is simple, more economical than other possible manufacturing routes, highly flexible in terms of material selection, size and shape and also applicable to mass production [7],[8]. On the other hand, the main challenge of stir cast composites is to achieve a uniform distribution of the reinforcement in the matrix and a good wettability of the particles with the matrix [1],[7],[8]. Moreover, porosity content in the cast MMCs should be kept at a minimum level and chemical reactions between the two constituents of the composite have to be avoided [7]. In the recent years, several research studies have been published which analyzed the influence of different reinforcements in AMCs such as SiC [1], Titanium DiBoride (TiB_2) [5], Tungsten Carbide (WC) [6], Alumina (Al_2O_3) [2], Copper (Cu) [3], Fe-aluminides [8] or fly ash [4]. In this work, aluminium alloy composites reinforced with SiC and B_4C particles were produced using stir casting technique. In order to assess the influence of the ceramic particles on the mechanical properties, tensile, hardness and wear tests were conducted and microstructure was examined using an optical microscope.

II. FABRICATION OF THE COMPOSITE

The base material selected for the present study was Al 5083 alloy which was reinforced with SiC and B_4C particles. Three different composites were prepared by varying the B_4C content while the SiC content remained constant. The chemical composition of the composites is given in Table I.

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Table I: Chemical composition of the composites

	Composite A	Composite B	Composite C
AA 5083	94 wt-%	92 wt-%	90 wt-%
SiC	5 wt-%	5 wt-%	5 wt-%
B_4C	1 wt-%	3 wt-%	5 wt-%

The stir casting process was used to fabricate these composites. The stir casting machine is depicted in *Fig. 1*, it consists of a furnace, a stirrer and a control panel. Pre-weighed aluminium plates were melted in a crucible placed inside the furnace by increasing the temperature above the melting point of the alloy at around 700°C. After preheating the reinforcement particles, they were added into the crucible and dispersed in the molten aluminium by the means of a mechanical stirrer. This is the most critical part since a uniform distribution of the reinforcement in the matrix is crucial to the mechanical properties of the composite. Finally, the melt was poured into a rectangular die and solidified at room temperature.

Fig. 1: Stir casting machine

III. RESULTS AND DISCUSSIONS

A. *Tensile Test*

Tensile samples were cut out of the cast composites according to **Fig. 2**. A computerized universal testing machine was used to perform the tensile tests. The respective sample was clamped at both ends by grips and tension was applied. While increasing the load, one could observe an elongation of the sample up to the point where the final fracture occurred. During the test, applied load and displacement were monitored.

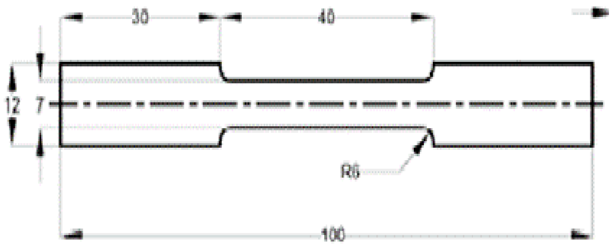


Fig. 2.Dimensions of samples

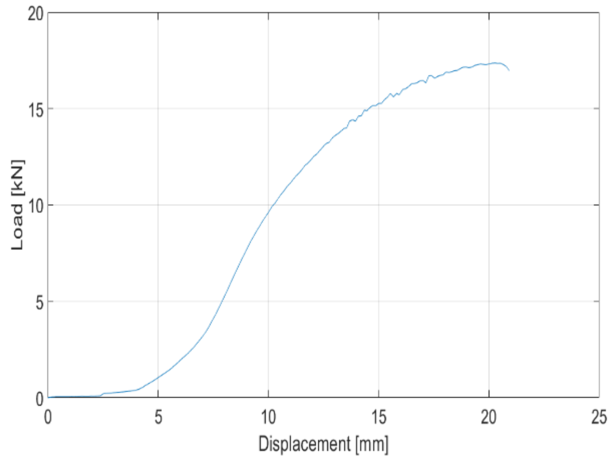


Fig. 3: Load-displacement curve for Composite A

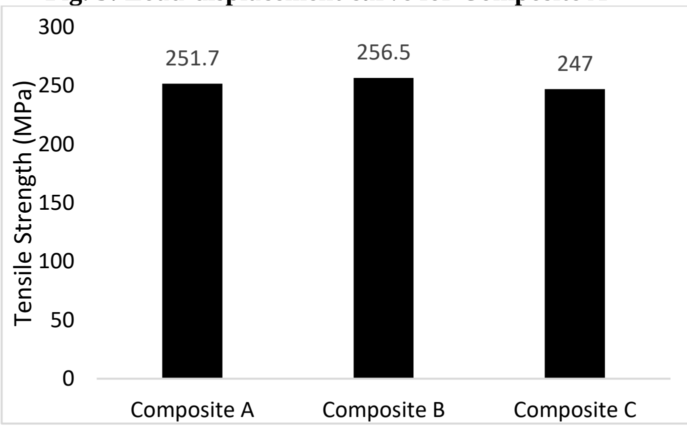


Fig. 4: Comparison of the tensile strength of the stir cast composites

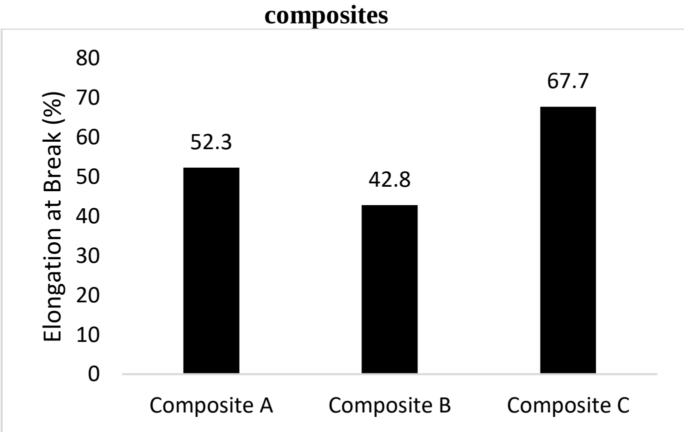


Fig. 5: Comparison of elongation at break of the stir cast composites

From the results, we can observe that there is only a small difference between the tensile strength values. It can be concluded that the influence of the B_4C particles on the tensile strength is negligible as the SiC content is constant for all the samples. However, elongation at break differs reasonably. So, the B_4C content influences strongly the ductility of the material. Fig. 3 is a graph showing the load-displacement curve for Composite A, the curves for the two other composites are quite similar. By increasing the load, the change in length is increasing monotonically until the tensile strength of the material is reached. After that point, one can observe a small decrease of the load up to the final failure of the sample.

B. *Microhardness Test*

Vickers hardness test is an appropriate method to determine the microhardness of composites. A diamond indenter in the form of a square-based pyramid is pressed into the surface of the material and the size of the left impression is measured. With the mean diagonal d of the resulting indentation area A and the applied load F, Vickers hardness HV can be calculated from equations (1) and (2), where F is in kgf and d in mm. For each sample, Vickers hardness was evaluated at ten different locations and the averaged value was considered as the microhardness of the respective composite.

$$A = \frac{d^2}{2 \cdot \sin(136°/2)} \quad (1)$$

$$HV = \frac{F}{A} \quad (2)$$

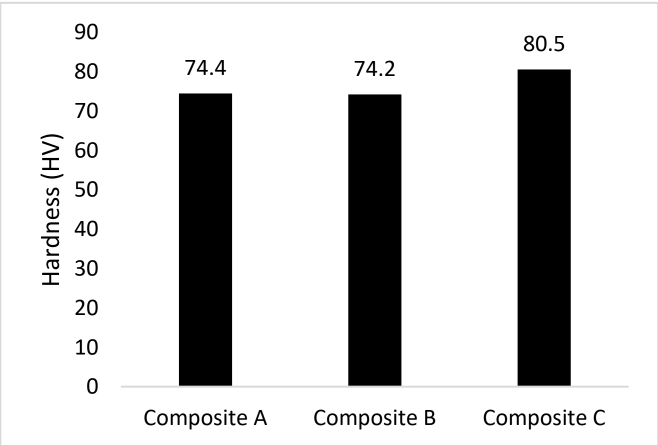


Fig. 6: Comparison of microhardness values

Vickers hardness is almost constant for composite A & B but the composite with 5 wt% B_4C has a slightly higher microhardness. This can be attributed to the incorporation of more ceramic particles in the ductile aluminium alloy.

C. *Wear Test*

Dry sliding wear tests were conducted using a Ducom pin-on-disc apparatus. The process parameters were 25N Normal load, 1.5m/s sliding velocity and 2500m sliding distance. The dimensions of the pin samples were 12 mm in width and 10 mm in thickness. The pins and the disc were polished prior to the test to ensure a smooth contact surface. While pressing the pins against the flat rotating disc, height loss and friction force were continuously recorded. The wear rate W_s, which is defined as volumetric loss ΔV divided by the total sliding distance l_s, can then be easily by using below equations.

$$\Delta V = \Delta h \cdot A \quad (3)$$

$$W_s = \frac{\Delta V}{l_s} \quad (4)$$

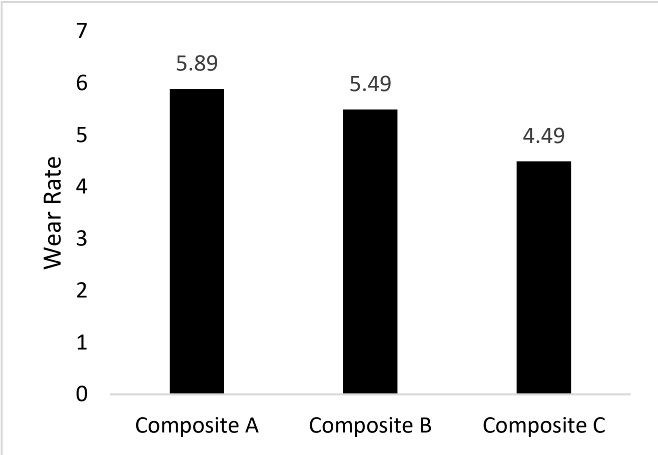
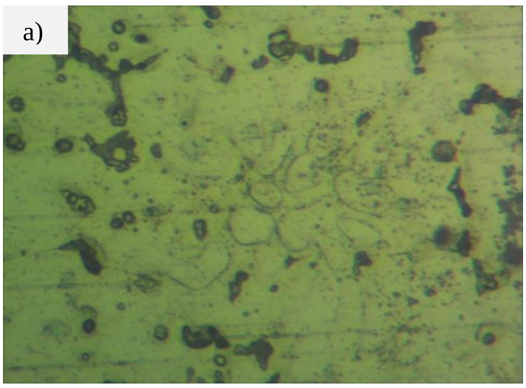


Fig. 7: Comparison of wear rate of the composites

Higher percentage of B_4C decreases the wear rate and thus improves the tribological behavior of the material.

D. *Microstructural Examination*

The samples were prepared for microstructural characterization by grinding them with emery paper, followed by polishing on a twin disc polisher with 3-4 µm and 0.5-1 µm sized diamond paste and etching with Keller's reagent. After that, the microstructure was examined with the aid of an optical microscope and digital images were captured by a camera.



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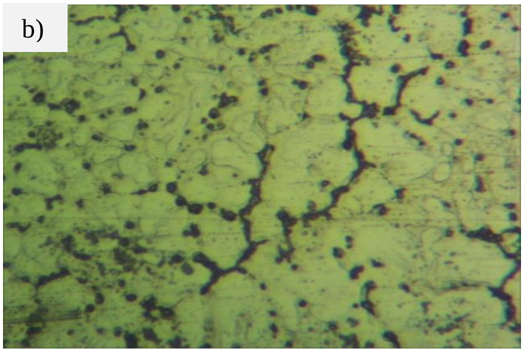

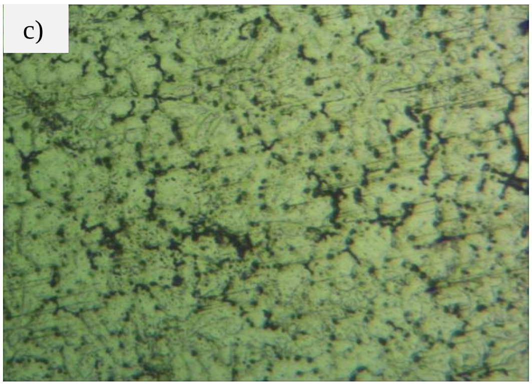

Fig. 8: Optical Micrographs of a) Composite A b) Composite B c) Composite C

Fig. 8(a) to Fig. 8(c) show optical micrographs of the stir cast composites where the green regions represent the matrix material and the black-point shaped regions the incorporated reinforcement particles. As can be seen from the microstructure, particle agglomerations are primarily formed along the dendrite boundaries of the aluminium alloy. Additionally, there are micropores inside the matrix which appear as small black dots in the micrographs. The best distribution of the particles in the matrix is achieved for composite A, with increasing reinforcement content more cluster occur in the microstructure.

IV. CONCLUSION

1. The influence of B_4C particles of the particles on the tensile strength is negligible as the SiC content is constant for all the fabricated composites.
2. B_4C content strongly influences the ductility of the material.
3. Although SiC particles contribute to the increase in hardness, increase in B_4C content also increases the hardness of the composites.
4. Higher percentage of B_4C decreases the wear rate of the composites.
5. The best distribution of reinforcement particles in the matrix is observed in Composite A. Clustering occurs as the reinforcement particle content increases.

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