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EFFECTS OF BORON CARBIDE ADDITION ON HARDNESS AND MICROSTRUCTURE OF Al-Si/B_4C COMPOSITE

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ABSTRACT

The aim of this research was to study the microstructure and microhardness of the Al-Si/B_4C composites containing 2-8 wt% of B_4C. The composites were prepared by stir casting technique. Homogenization treatment was carried out at temperatures of 540^oC for 4 hr and followed by ageing at 180^oC and 220^oC for 2 hr. Vickers microhardness test was performed to the composites. Microstructural study was carried out by optical microscopy. The results showed that the increase in boron carbide content seemed to increase the hardness of the composites. Heat-treatment had increased the hardness further due to spheroidization of Si. The presence of B_4C did not affect the microstructure of Al-Si alloy matrix significantly.

Keywords: Aluminum-Silicon Alloy; Boron Carbide; Stir Casting;

INTRODUCTION

Metal matrix composites (MMCs) reinforced with ceramic particulates have become an important class of structural materials. Properties of MMCs such as strength, elastic modulus, wear resistant and service temperature, are greatly improved by the addition of ceramics particles [1][2]. Aluminum base materials have received considerable attention because it is readily available, lightweight and under reasonable processing conditions reactive to boron carbide (B_4C) [3]. From several studies Al and B_4C react at temperature greater than 700^oC producing AlB_2 and Al_3BC and more complicated phases develop at temperature greater than 900^oC [3] that can be easily avoided because the melting point of Al is 660^oC.

Boron carbide (B_4C) particle is of interest because of its potential for enhancement of mechanical properties and it has lower density (2.52 gcm^{-3}) compared to other commercial reinforcing particles such as SiC and Al_2O_3. B_4C also is the third hardest materials after diamond and boron nitride and have high neutron absorption capability [4]. The suggested applications for this composite are structural neutron absorber, armor plate materials, and also substrate materials for computer hardisk [3]. Al-Si alloy was chosen in this study because Si is a common element to strengthen the Al besides Si plays important roles in the formation of a dense barrier layer that can limit B_4C decomposition and improve B_4C stability in the aluminum melt [5].

According to Zhang [5] there are two main manufacturing processes for aluminum based MMCs; the liquid mixing process and powder metallurgy process. The liquid mixing process is an effective method to economically produce large quantity of Al based MMCs. This liquid process has been employed to produce most of the commercial Al-based MMCs. The purpose of this experiment is to characterise the Al-Si/ B_4C composite fabricated via stir casting technique by using optical microscopy, scanning electron microscopy (SEM), energy dispersive X-ray analysis (EDX) and Vickers microhardness test.

MATERIALS AND METHOD

In this experiment, aluminum alloy with 11.1% Si was fabricated from pure Al and Si of 99% purity. The alloy was used as a matrix for the composite. Boron carbide particles with size of approximately 15.22 µm and purity of 97 % were used as reinforcement materials. Before melting process, aluminum granules and silicon chips were properly cleaned with acetone in ultrasonic bath.

The aluminum alloys was melted under controlled argon environment. Small amount of magnesium 1wt% was added to the mixture to act as a wetting agent [6][7] for molten Al and B_4C particles. The temperature was first raised to 750^oC to melt the Al-Si alloys before cooling down to 650^oC to get a semi solid state. At this stages preheated B_4C particles was added to the molten Al-Si and stirred continuously by means of a motor controlled stirrer. When uniformly mixed slurry was obtained the melt was reheated to 750^oC. After stirring for 5 minutes the mixture was immediately cast into a permanent steel mould.

The solidified MMCs were cut into small samples, polished with standard metallurgical procedures and etched by using Keller's reagent for microstructure analysis and hardness test. The samples were heat-treated at 540^oC for 4 hr then followed by ageing at 180^oC and 220^oC for 2 hr respectively and left for 14 days before performing hardness test using microhardness tester (Model Shimadzu HMV 2000). The microhardness measurement was done using a pyramidal diamond having face angle 136^o with 100 g indenting load and 15 sec dwelling time. An average hardness value was obtained for each sample from 15 measurements. The microstructural study was done using optical microscopy. A scanning electron microscope (Model Leo 1450 VPSEM) equipped with an energy dispersive X-ray analyzer was used to investigate phase distribution.

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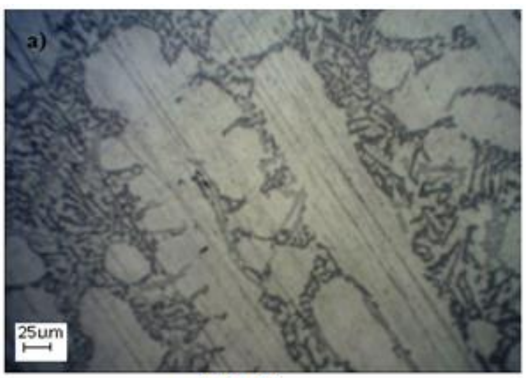
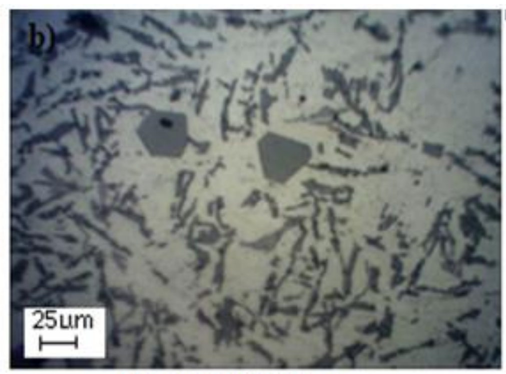
RESULTS AND DISCUSSION

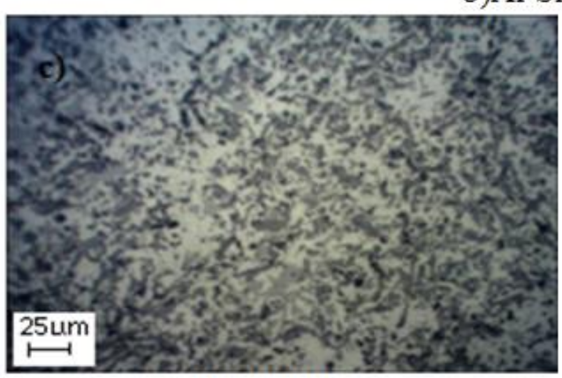
Figure 1a shows the microstructure of as-cast Al-Si alloys which made up of dendrite of α-Al with eutectic silicon phases in the interdendrites region. It is clearly shown that needle-like Si located in between α-Al dendrites. Figures 1b and 1c show that changes in microstructure had taken place in the composites containing 4 and 8 wt% B_4C where dendritic α-Al phase became smaller and thinner than the as-cast composite . This indicates that the addition of B_4C particles into the composite has decreased the dendrite size of the α-Al. The presence of B_4C particles promotes dislocation and recrystallization of the α-Al that lead to grain refinement [3]. Figures 2 and 3 show the needle-like Si as in Figure 1 has transformed into spheroids after ageing at 180 and 220^{o}C for 2 hr.



a)Al-Si



b)Al-Si/4%B_4C



c)Al-Si/8%B_4C

Figure 1: Optical micrographs of as- Cast Al-Si/B_4C Composites a)Al-Si, b)Al-Si/4%B_4C and c) Al-Si/8%B_4C

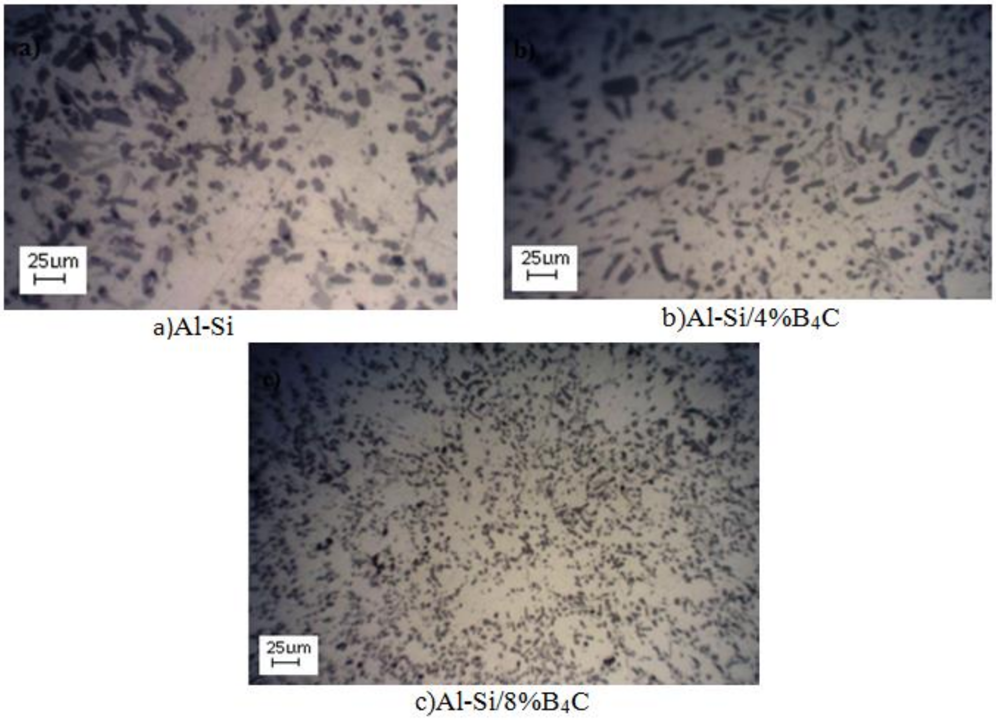


Figure 2: Optical Micrographs of Al-Si/B_4C composites aged at 180^oC for 2 hr a) Al-Si, b) Al-Si/4%B_4C and c) Al-Si/8%B_4C

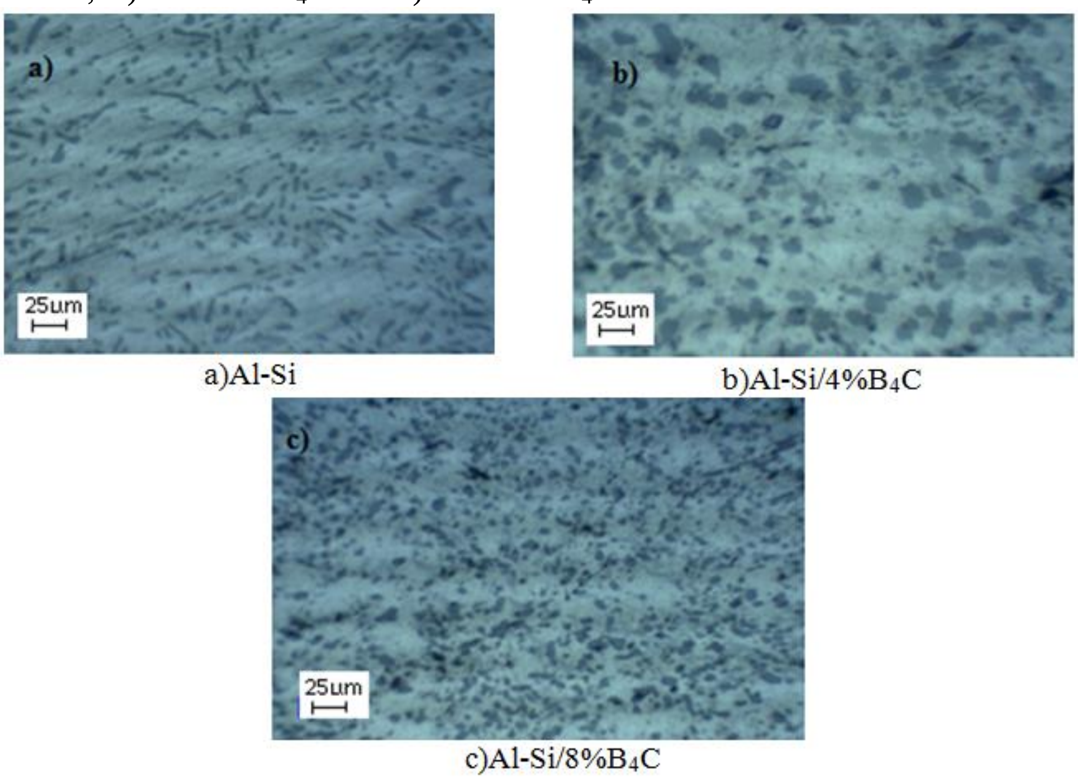


Figure 3: Optical Micrographs of Al-Si/B_4C composites aged at 220^oC for 2 hr a) Al-Si, b) Al-Si/4%B_4C and c) Al-Si/8%B_4C

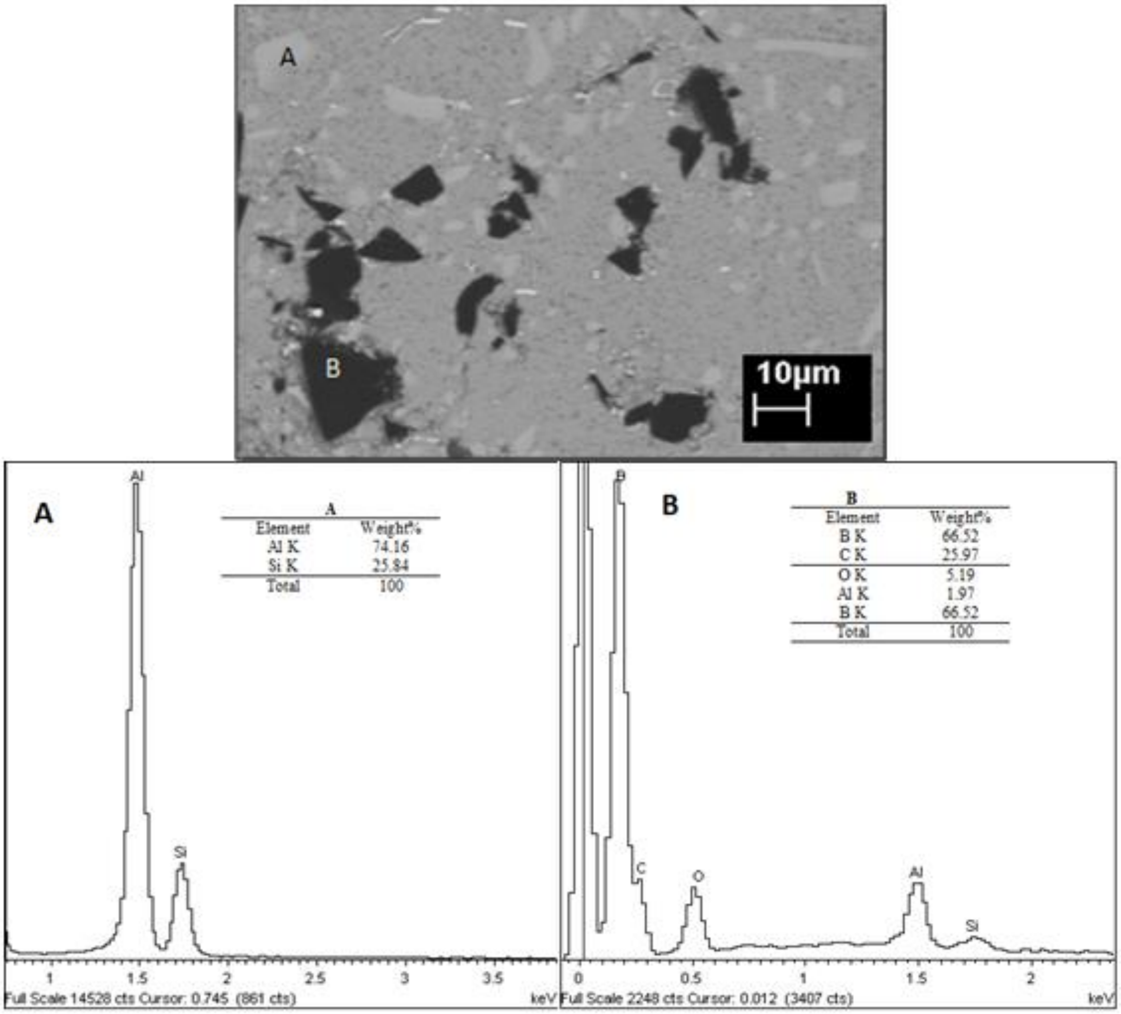


Figure 4:The SEM image and EDX spectrum of Al-Si/ 4% B_4C composite after ageing at 180^oC for 2hr

The SEM image in Figure 4 indicates that B_4C particles dispersed well throughout the matrix of the Al-Si and most of them located adjacent to Si. The existence of B_4C is confirmed by EDX results such as in Figure 4 which is represented by black regions. The white regions are Si phase which was embedded in α-Al matrix. This was also confirmed by the EDX result in Figure 4. Generally, the irregular shape B_4C particles as shown in Figure 4 were smaller in size as compared to the average original size of 15.22 µm. This was due to stirring action performed during casting process. The carbon peak presents in the EDX spectrum perhaps come from graphite crucible used in melting whereas might come from oxide formed on the surface of the sample.

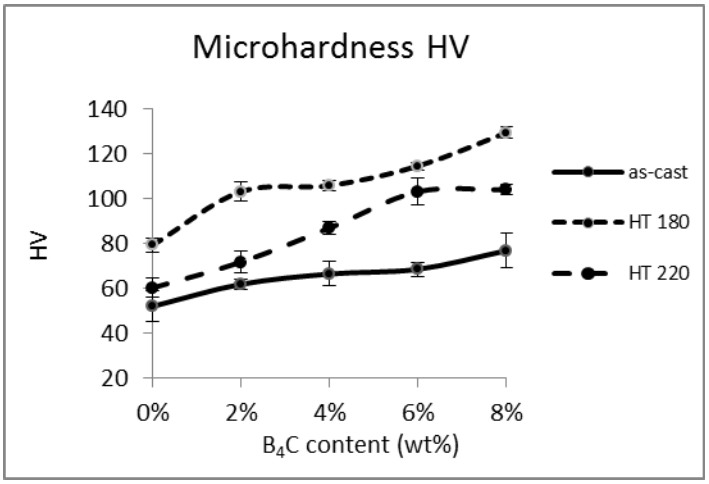


Figure 5: Variations of microhardness of Al-Si/B_4C composites with B_4C content for as-cast, aged at180^oC, and 220^oC for 2hr

Figure 5 shows the microhardness as a function of B_4C contents in the composites where microhardness of the as-cast Al-Si/B_4C composite as well as the composites aged at 180 and 220^oC increased with B_4C content. However the hardness of the composites aged for at 180^oC 2 hr was higher than that of the one aged at 200^oC for a similar ageing time regardless of B_4C content. The hardness of as-cast composite without B_4C was 52 HV and increased to 78 HV when containing 8 wt% B_4C. Ageing at 180^oC had increased the hardness from 79 HV for composite without B_4C to 130 HV for the composite with 8 wt% B_4C. However, the composite without B_4C which were aged at 220^oC has hardness of 72 HV and increased to 104 HV after aging at 220^oC. Higher hardness values for the composites containing B_4C imply that the presence of B_4C particles has contributed to the improvement in hardness of Al-Si alloy matrix by creating more deformation sites [4] besides B_4C is a hard ceramics [2]. Harder reinforcing materials in the matrix enhance the work hardening rate of the matrix and higher constraint to the localised matrix during deformation thus increase hardness [4]. Higher hardness of the composite will gives better strength and better elastic properties. At the same time, heat treatment process also helps in improving the overall hardness of the composites by reducing number of pores, removing trapped gas and transforming needle-like Si to spheroidal Si.

CONCLUSION

The Al-Si/B_4C composites which were fabricated by stir casting technique have well distributed B_4C particles in the matrix. Morphological study shows that the needle-like Si in the composites has changed to spheroid when subjected to ageing treatment even though with the presence of B_4C particles. The hardness of Al-Si/B_4C composites increased with B_4C content. Further increased in hardness was observed when the composites were aged at 180^oC for 2 hr which may be due to the spheroidization of Si.

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