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PRODUCIBILITY OF FUNCTIONALLY GRADED AlB_2/Al COMPOSITE MATERIAL

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Abstract : This study is intended to investigate producibility of functionally graded AlB_2/Al composites which are used in the manufacture of ship machinery parts. AlB_2 particles have been spontaneously formed in liquid matrix as reinforcement. A semi-solid composite ($Al_{(l)}$ - $AlB_{2(s)}$) prepared at 850°C was solidified under a centrifugal force to grade functionally. The properties of composite materials such as hardness and microstructure have been examined. This research provided the following findings, AlB_2 particles can be successfully synthesized with in situ reaction technique in molten aluminum. It was determined that the hardness value of the composites increases with increasing AlB_2 reinforcement content within matrix. Functionally graded AlB_2/Al composite materials can be successfully produced with centrifugal casting technique. It is also determined that AlB_2 reinforcement ratio of the composite materials ranged from 0 to 7 vol. %. In addition, it was observed that the hardness values of the composites increased with the addition of reinforcement ratio.
Key words : AlB_2, Functionally Graded Composite, Ship Machinery

1. INTRODUCTION

Composite materials are new types of materials formed by the combination of two or more different materials in a macro scale. Generally, these composites occur a ductile matrix and a high-hardness reinforcement material [1-3]. Silicon carbide (SiC) and Alumina (Al_2O_3) are preferred as reinforcing phases due to their high wettability of aluminum and low prices.

With the development of modern production processes, it has been shown that various intermetallic compounds can be used as reinforcing particles in the production of AMCs. Since intermetallic particles are formed spontaneously as a result of exothermic reaction in the matrix, it provides both a cheap and easy production route [4,5].

There are very limited studies on aluminum matrix AlB_2 boride reinforced composites materials [6,7]. Composites can be produced easily and cheaply by in-situ production method.

Commercial Al-B master alloys are used as boron donors in the production of AlB_2 composites [8,9]. Commercial Al-B alloys are widely used as grain refiners in the casting of aluminum alloys and in the production of high conductivity conductor wire [10,11]. At room temperature, boron does not dissolve into aluminum matrix and exists as AlB_2 boride compounds as can be seen from the phase diagram. The Al-B Phase diagram has a pertiectic reaction line at about 1000°C.

AlB_{12} structures are transformed into AlB_2 structures by the peritectic reaction. In the production of Al-B master alloys, unstable AlB_{12} structures are also seen in the structure, since sufficient time is not given for this transformation. In composite production, AlB_{12} boride structures are undesirable because they are unstable and brittle. In order to avoid the formation of AlB_{12} structures, it is necessary to synthesize AlB_2 boride structures without nuclear AlB_{12} structures by crossing the peritectic reaction line quickly [8,9,12].

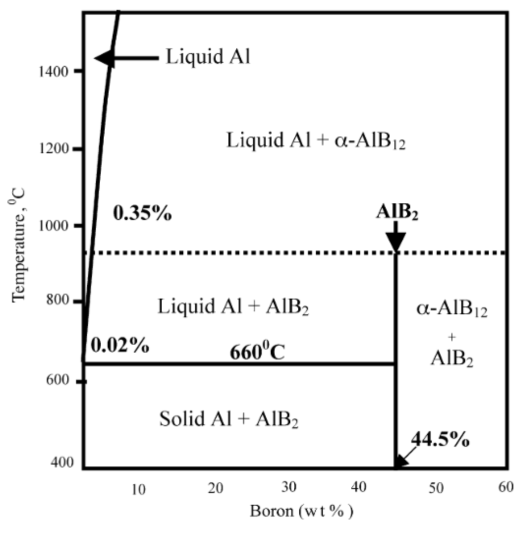

Figure 1 Al–B binary phase diagram

In the literature studies, it is seen that the elastic modulus and wear resistance of the composite materials

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produced depending on the increasing reinforcement ratio increase.

However, with the increasing reinforcement ratio, it is observed that the composite becomes the fracture toughness decreases significantly. It is observed that the service life of the machine parts, which are exposed to repeated loads, is significantly reduced due to the low fracture toughness. Increasing both fracture toughness and wear resistance can be achieved with functionally graded composite materials [8, 14-16].

There have been studies on the production of AlB_2/Al composites in previous studies [6,7]. However, there is no study that AlB_2/Al composites materials are used in the production of ship machinery parts.

In this study, it was intended to produce functional graded AlB_2 reinforced aluminum matrix composite by centrifugal casting method. After AlB_2 boride structures were synthesized inside liquid aluminum, the semi-solid "$Al_{(l)}$ + AlB_2(s)" solution have been solidified under a centrifugal force to achieve a gradual increase in reinforcement rates. In addition, techniques such as optical microscope, XRD (x-ray diffraction model), scanning electron microscope (SEM) and Brinell Hardness (BHN). has been applied to characterize composites.

2. EXPERIMENTAL WORKS

The production of composites was carried out in 3 stages. In the first stage, Al-B melt was formed at 1200 °C. In the second step, AlB_2 structures were synthesized by crossing the peritechic reaction line quickly. In the last stage, liquid aluminum containing solid AlB_2 structures was solidified under a centrifugal force.

In the first stage, Al-3B master alloys, which are used as grain refiners in the casting of aluminum alloys, were used as a boron source in the formation of the Al-B melt. Considering the Al-B two phase diagrams, it is seen that the boron solubility at 1200 ºC is around 1.5 wt.%. Therefore, the Al-B master alloy was diluted using ETİAL 8 ingots with a purity of 99.6%. Alloys prepared in small ingots were melted in an electric resistance furnace in steel crucibles. In order to synthesize the AlB_2 structures, the Al-B melt in the steel crucible at 1200 ºC was taken from the furnace and solidified by placing it in water in order to quickly cross the peritectic reaction line. Afterwards, the cast ingot was taken into a steel crucible with a diameter of 80mm and a height of 100 mm. The alloy was melted at about 900 ºC to form a semi-solid melt "$Al_{(l)}$ + $AlB_{2(s)}$". The semi-solid was solidified under centrifugal force using a centrifugal casting mechanism so that AlB_2 was functionally graded in centrifugal force.

The composites were characterized by Scanning Electron Microscopy (SEM) using a JEOL JSM6060LV type device and X-ray diffraction (XRD) using Cu -Kα radiation. Reinforcing ratios of the composites were estimated using the peak density ratios of the phases obtained from the XRD studies. The AlB_2 particles were extracted from the composite by dissolving the Al matrix using a 37 %HCI solution to take SEM images. The hardness of the composites was determined using a Brinell hardness tester with a 2.5 mm diameter balls at a load of 31.25 kg for 20 s.

3. RESULTS AND DISCUSSION

It is given that a photographic image of the AlB_2/Al functional graded composite produced by centrifugal casting method in Figure 1. In order to examine the macro scale, the composite material was cut at a certain cross-section with the help of a band saw. The cut surface was etched with HCl solution after metallographic preparation. It is noteworthy that there are two different layers clearly separated from each other in the cross-sectional view of the composite. The outer part of the composite ingots appears to be covered with a dark layer. It is seen in Figure 1 that the layer surrounding the outer part of the composite is dark in color and the layer surrounding the inner part of the composite is light in color. The dark layer on the composite is about 2mm wide, and the light layer is approximately 20mm wide.

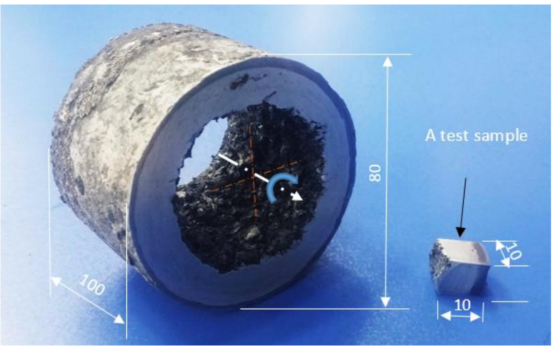

Figure 2 A photography of AlB_2/Al functional graded composite

X-ray diffraction (XRD) analysis results taken from the dark layer and the light layer inner are given in Figure 3a and 3b, respectively. In Figure 2a, it is seen that Al and AlB_2 peaks are present in the XRD pattern taken from the dark layer. However, in Figure 3b, it is seen that only Al peaks are present in the XRD pattern taken from the light layer.

The XRD patterns in Figure 3 show that the composite is composed of only aluminum and AlB_2 phases. According to the XRD peaks above and Ref. [8,9,12], possible chemical reactions in Al-B solution are as follows:

$$B + 3Al \rightarrow AlB_2 \qquad (1)$$

This result demonstrates that the Al-B solution nucleates the AlB_2 phases without nucleating the AlB_{12}

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phases by crossing the peritectic reaction line at a sufficient cooling rate. Observation of the AlB_2 phase in the dark layer indicates that the AlB_2 particles are gathered on the outer wall of the composite with the effect of the centrifugal force. According to the peak intensities, it clearly shows that the dark layer contains 8 wt.% AlB_2, and the light layer does not contain AlB_2 particle.

Therefore, the dark and light layer is named as AlB_2-reinforced and non-reinforced layers, respectively.

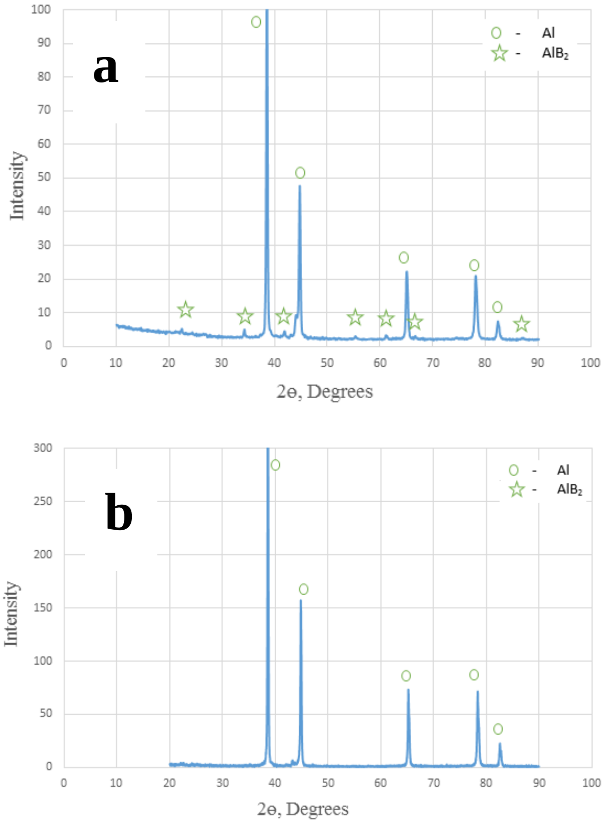

Figure 4 The XRD patterns taken from a) AlB_2-reinforced and b) non-reinforced layers of the composite

Figure 5 shows in the microstructure image taken from the AlB_2-reinforced and non-reinforced layers. Similar to the XRD results, AlB_2 particles are seen in AlB_2-reinforced layer, but there is no AlB_2 particle in non-reinforced layer.

It has been observed that the AlB_2 particles are the appearance of a long bar and exhibit homogeneous distribution in the aluminum matrix. Figure 5 is shown that the width of the AlB_2 particles is approximately 25µm and exhibits a random distribution.

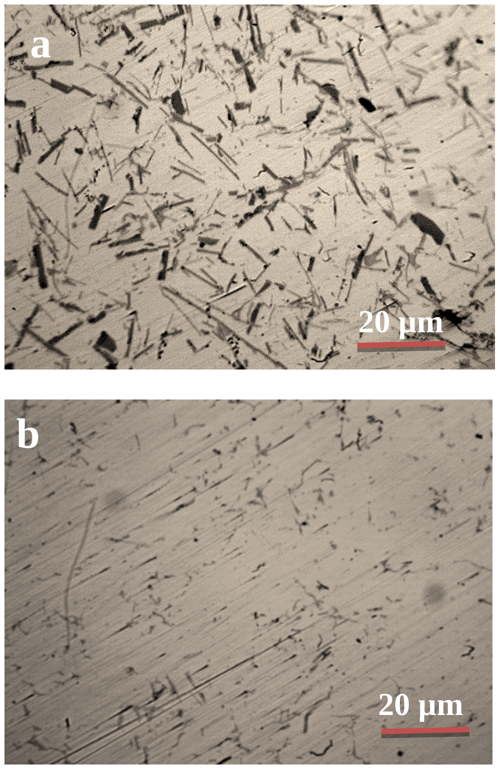

Figure 5 Optical microscope image taken from a) AlB_2-reinforced and b) non-reinforced layers of composite

In order to see the morphology of the AlB_2 particles, a sample taken from the AlB_2-reinforced layer was etched with HCl acid for 60 seconds and SEM images were taken. A SEM image of the rich region is given in Figure 6. It is seen that the AlB_2 particles are hexagonal and plate-shaped. It is seen that the width of the hexagonal plates is about 25 microns and their thickness is less than 1 micron. In addition, although HCl acid dissolved the aluminum matrix easily, it wasn't cause any degeneration of the AlB_2 structures in seen SEM image.

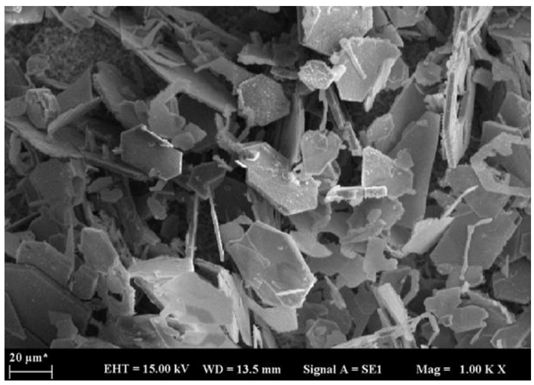

Figure 6 A SEM image of AlB_2 particles

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Table 1. AlB_2-reinforced and non-reinforced layers of composite

Layer of composite	Brinell hardness values (HB)				
	1. Measure	2. Measure	3. Measure	4. Measure	Mean
AlB2-reinforced	77.01	75.15	92.30	84.26	82.25
Non-reinforced	50.01	55.52	52.85	49.17	51.55

Brinell hardness values from AlB_2-reinforced and non-reinforced layers of composite are given in Table 1. It is given the Brinell hardness measurement values taken from AlB_2-reinforced and non-reinforced layers of composite and their averages in Table 1. It is observed that the hardness value of the AlB_2-reinforced layer is higher than the non-reinforced layer. It is further seen that the average hardness value of the non-reinforced layer is 51,5 HB, and the average hardness of the AlB_2-reinforced layer is 82.25 HB. This result shows that the addition of 8wt.% AlB_2 to the aluminum increases its hardness more than 1.5 time.

4. CONCLUSIONS

In this study, production of the AlB_2/Al composites graded functionally by centrifugal casting have been investigated. The results of this study can be summarized as follows:

- The synthesis of AlB_2 particles was achieved by solidifying the Al-B solution prepared at 1200 ºC in water environment. AlB_2 particles were determined to be hexagonal plate-shaped and 25 µm wide.
- It has been shown that functionally graded AlB2 reinforced aluminum matrix composite has been successfully produced by centrifugal casting method. It has been determined that produced composites have two layers reinforced with AlB2 and non-reinforced. It was determined that the AlB2-reinforced layer contained 8wt.% AlB2 particles.
- It was observed that hardness value of AlB2-reinforced layer was higher than non-reinforced layer. It was determined that the hardness value increased from 51.55 HB to 82.25 HB with the addition of 8wt.% AlB_2 in the aluminum matrix.

5. ACKNOWLEDGMENTS

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