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Production of Functionally Graded AlB2/Al-4%Mg Composite by Centrifugal Casting

Ömer Savaş
Yıldız Tecnical University, Naval Architect and Marine Engineering Faculty, 34349 Istanbul, Turkey

Ramazan Kayikci
Sakarya Üniversity, Faculty of Technology, Department of Mechanical Engineering, 54187, Sakarya, Turkey

Ferit Ficici
Sakarya Üniversity, Faculty of Technology, Department of Mechanical Engineering, 54187, Sakarya, Turkey

Sakip Köksal
Sakarya Üniversity, Faculty of Technology, Department of Mechanical Engineering, 54187, Sakarya, Turkey

Abstract:

In this study, production of functionally graded AlB_2 reinforced Al-4%Mg composite has been investigated. In-situ high-aspect-ratio flake AlB_2 reinforcement was obtained by the addition of boron oxide to the liquid Al-Mg at 1400 °C. It has been observed that there were two distinct regions without a smooth grading: one is rich of and the other is poor of AlB_2. The results showed that the highest AlB_2 content has been found to be around 10% in external zones, whereas the lowest AlB_2 content has been observed to be 0.02% in the internal zones. Additionally, results showed that, depending on the increase in the reinforcement phase in external zones, up to 20 % increase in the hardness of the composite has been achieved.

Key words: Aluminum boride, AlB_2, boron oxide, functionally graded composites.

1. Introduction

Metal matrix composite have been gaining importance in engineering applications, because of their high specific strength, high modulus and high wear resistance [1-6]. Functionally graded metal matrix composites have a great significance for the use in automobile, aerospace and defence industries. A functionally graded metal matrix composite can be defined as its reinforcement particle's volume fraction varies continuously from the inner to the outer sections of the part. Therefore, their mechanical properties are different from the inner region and outer region accordingly [7, 8].

Until recently, a number of studies on functionally graded metal matrix composites produced by centrifugal casting had SiC, Al_2O_3 and AlB_2 reinforcement particles in various aluminium alloys [7-9]. Production of functionally graded materials under centrifugal force is an effective method. Advantage of centrifugal casting is good mould filling combined with good microstructural control. Aluminium boron master alloys have been used commercially to scavenge transition-metal elements during the production of aluminium electrical wires [10] and is also used for grain refiner as Al-Ti-B in aluminium castings [11]. It is known that the crystal structure of borides is a hexagonal close packed (HCP). Depending on the cooling rate they can be in fine flake shaped structure having few micron thickness with aspect ratio ranging from 30 to 400 [12, 13].

AlB_2 flakes in liquid aluminium alloys can be precipitated during solidification. [14-17]. Thus, the reinforcement phase (AlB_2 flakes) can readily be produced by in-situ fabrication techniques. There are a few study regarding AlB_2/ Al composites for producing functionally graded metal matrix composites [9, 18, 19]. AlB_2 phase have high strength and high modulus and has higher density (3.19 g/cm^3) [18], than liquid aluminium (2.4 g/cm^3) at 700 °C.

In the present work, in-situ AlB_2 flake reinforced Al-Mg matrix composites were in-situ prepared by the reaction of boron oxide (B_2O_3) with liquid Al at a reaction temperature of 1400ºC. Centrifugal casting was applied to the composite to produce functionally graded material FGM.

2. Experimental Procedure

For the fabrication of AlB_2 flake reinforced Al-4%Mg composites were prepared by the reaction of boron oxide (B_2O_3) with Al at a reaction temperature of 1400ºC as explained in detail elsewhere [13]. The composites were placed in a die and the die was heated at 800°C in an

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electric resistance furnace to bring the composites to a semi-solid state ($Al_{(liquid)}$ + $AlB_{2\,(solid)}$). Centrifugal action was then employed with the die containing semi-solid composite to drive the solid AlB_2 particles towards the outer region to produce a functionally graded AlB_2/Al-Mg composite with even higher volume per cent reinforcement. The centrifugation process was carried out under rotation speed of 600 rpm at 800 ºC. A schematic representation of the in-situ production and the following centrifugation process of the functionally graded AlB_2/Al-Mg composite were shown in Fig. 1.

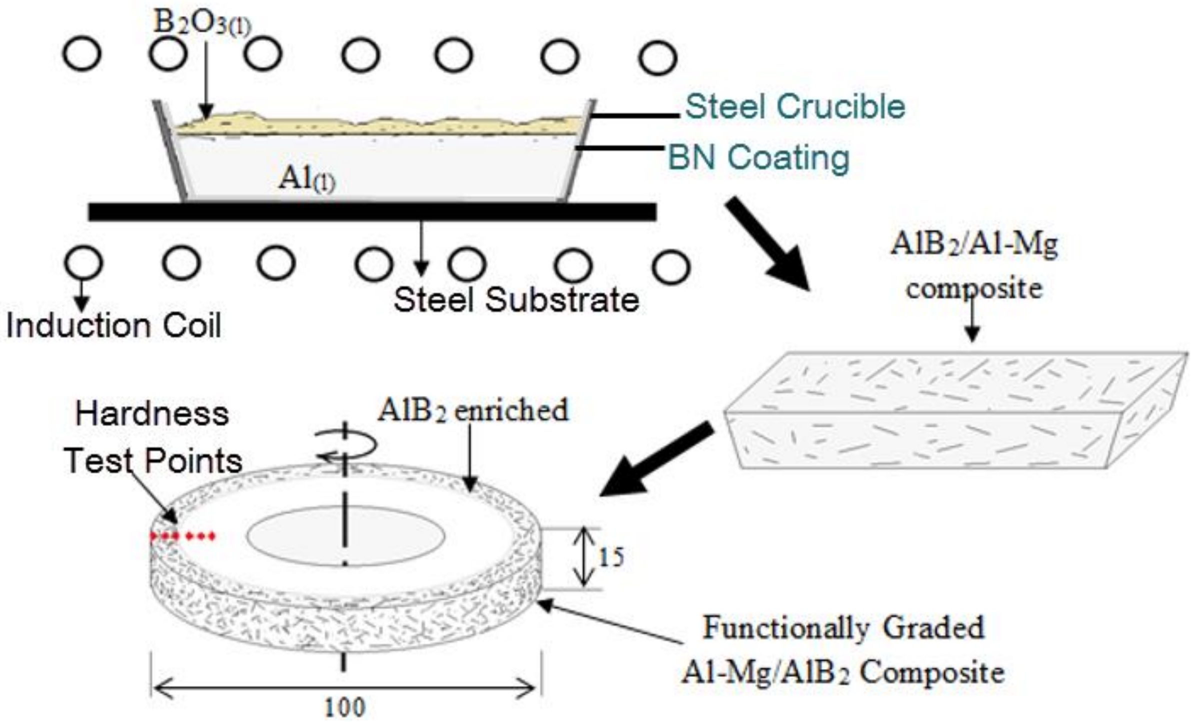

Figure 1. Schematic illustration of AlB_2 /Al-Mg composites production route.

Since boron cannot be quantified by Energy Dispersive Spectrometer (EDS), measurement of total weight per cent of boron in the AlB_2/Al-Mg composites were carried out by a wet chemical analysis method, as explained elsewhere [13]. For examination, Small samples were extracted from the AlB_2/Al-Mg composites. For the microstructure analysis the samples were ground up to 1200 grid by using SiC paper followed by polishing, using 0.2 µm diamond paste. For detailed evaluation of the boride structure, the samples of composites were deep etched using % 10 HCl solution followed by an examination with JEOL JSM 6060LV scanning electron microscope (SEM). Brinell hardness (BHN) of the composites was measured after polishing to a 1 µm finish. Hardness of composites was measured with 2 mm ranges on the composites from outside to inside as seen Fig 1.

The hardness values of the samples were measured using a 2.5 mm diameter ball at load of 31.25 kgf for 10 sec. The composites were solutionized at 540 °C for 4 h followed by water quenching at 60 °C, waiting at room temperature for 12 h, and aging was carried out at 190 °C for 10 h.

3. Results And Discussion

The mixture of boron oxide and Al-4%Mg alloys was melted and heated to 1400 °C for 1.5 h to maximize the boron solubility in the liquid Al-Mg alloy as explained in detail in a previous work [10]. During synthesizing a portion of boron oxide, chemical reaction of Equation (Eq.) 1 occurs at the interface between the molten alloy and boron oxide resulting in boron in liquid solution and aluminium oxide mixed with remaining (unreacted) boron oxide on top of the melt [11, 12]. In Eq. (1), α represents aluminium boron solid solution at 298 degree K. ΔG and ΔH are the Gibbs free energy and the enthalpy of the reaction respectively.

$$2Al + B_2O_3 \rightarrow \alpha - Al_2O_3 + 2[B] \qquad (1)$$

$$\Delta G^0_{298^\circ} = -416.9\ kJ/mol$$
$$\Delta H^0_{298^\circ} = -402.7\ kj/mol$$

Results from wet chemistry analyses showed that the amount of boron in the as-cast (unfiltered) casting was

1.2 wt % as all the boron atoms within the Al-B alloy can be considered to be boride compounds as reported in previous studies [9, 14]. The volume content of the boride phase within the matrix was calculated as 2.6 %. The microstructure of 2.6 vol. % AlB_2/Al-Mg composite material is given in Fig. 2.

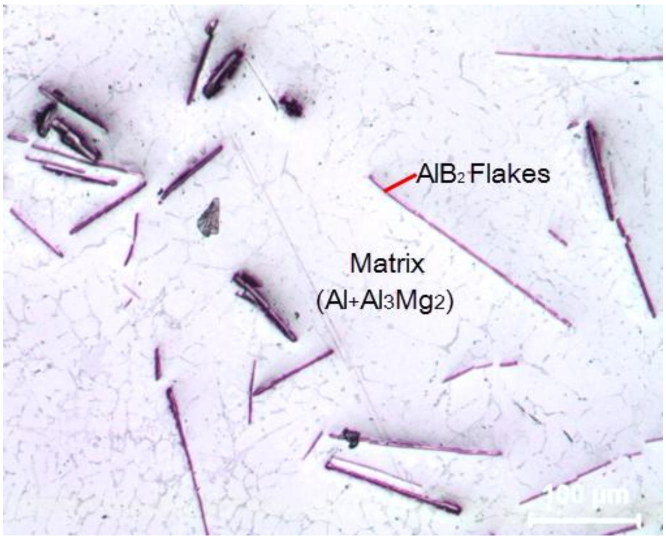

Figure 2. Microstructure of the in-situ 2.6 vol. % AlB_2/Al-Mg composite material

In Fig. 2, it can be observed that the in-situ AlB_2 boride particles with flake crystals and the β- Al_3Mg_2 phases with needle-shape form are distributed uniformly in the aluminium matrix.

A sample of 2.6 vol.% AlB_2 reinforced aluminium composite was deep-etched to extricate boride flakes from the aluminium matrix. Fig. 3 shows a SEM image of %2.6 vol. AlB_2/Al-Mg composite. As seen in the SEM image, AlB_2 structures have a fine flake shape and a high aspect ratio (width/thickness). This result is in good agreement with previous reports on AlB_2/Al [13, 14, 16].

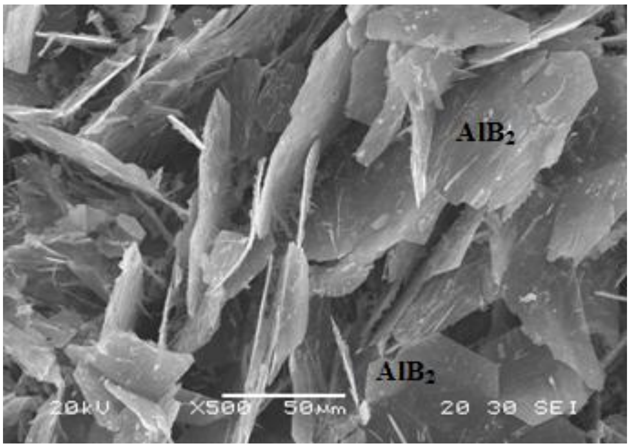

Figure 3. SEM image of the deep etched AlB_2/Al-Mg composite

The 2.6 % vol. AlB_2/Al-Mg composite was heated for centrifugal casting to 800 ºC to produce functionally graded (FG) composites material. After the centrifugal casting process the composite was cooled to room temperature for examinations. A cross section of the FG composites after deep etching with 10% HCl solution for 30 sec is shown in Fig 4. It has been observed that there were two distinct regions; the darker region which is named the external zone, the lighter region which is named the internal zone.

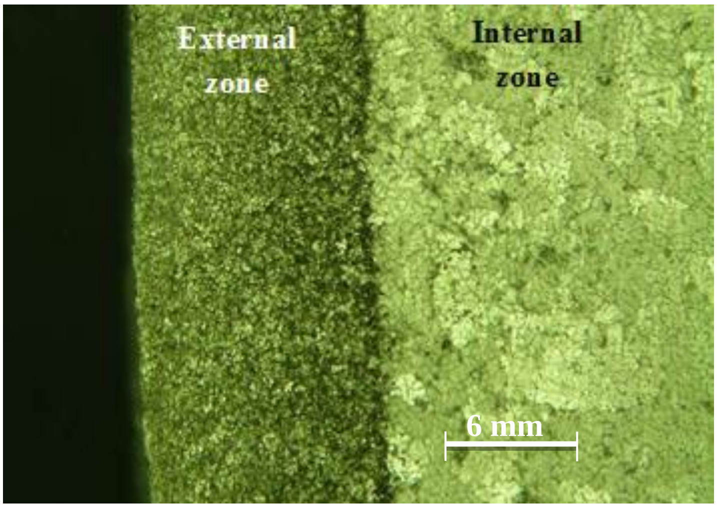

Figure 4. A cross section of the functionally graded AlB_2/Al-Mg composites

The microstructures of the darker and the lighter regions are shown in Fig 5. As the seen in Fig. 5a that there are numerous of AlB_2 reinforcement particles embedded in the aluminium matrix, whereas, there are almost no AlB_2 particles within the Al-Mg matrix in the internal zone as seen Fig 5b. These results show that all the AlB_2 flakes have been segregated by the centrifugal force at 800 °C as also reported in previous work [9,18]. Results from wet chemistry analyses showed that volume fraction of AlB_2 flake in the external zone increased significantly. The mean volume fraction of AlB_2 flake in this region has been measured as 10 vol. %. On the other hand in the internal region it was 0.02 vol. %.

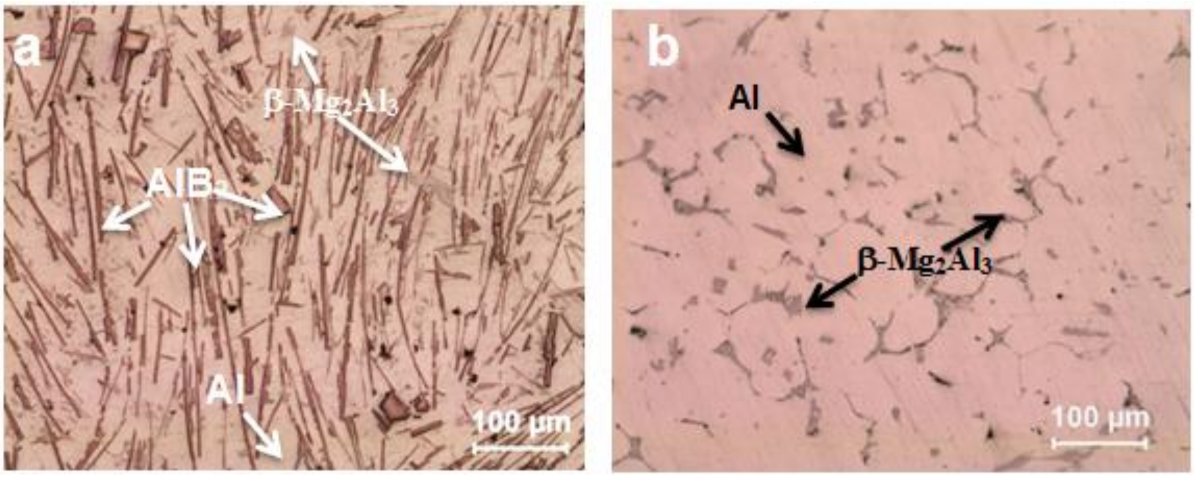

Figure 5. Microstructure of composite of a) external zone and b) internal zone.

Examination with optical microscope shows that the average thickness of AlB_2 is less than 1 µm. The measured average AlB_2 width distribution histogram is seen in Fig. 6. As seen from these histograms that, the average width of AlB_2 flakes is 170 µm, the width of the flakes vary between 40 µm and 350 µm and has demonstrated a normal (Gaussian) distribution within the matrix.

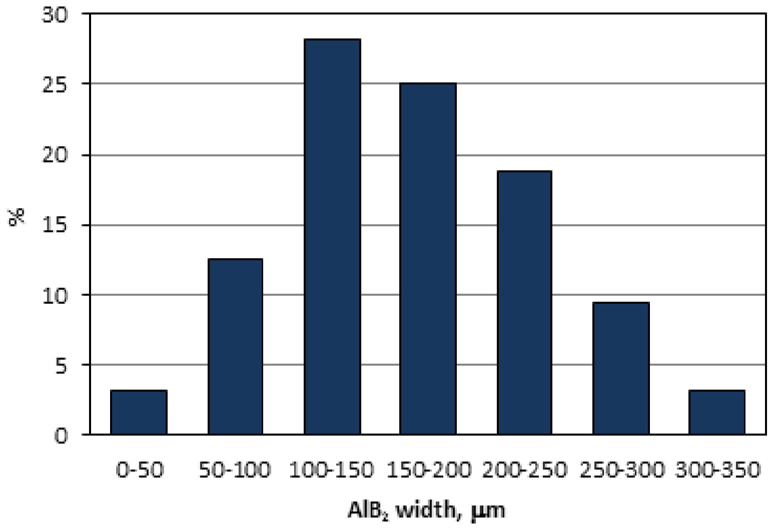

Figure 6. AlB_2 flake width histogram

Measured Brinell hardness as a function of radial distance along the centrifugally cast composite is given in Fig. 7 for the functionally graded AlB_2/Al-Mg composites. A significant increase in hardness of external zone was observed. It can be seen that the Brinell hardness value increased with solution heat treated composites. The functionally graded AlB_2/Al-Mg composites the external zone has the highest hardness with 90 HB. These results show that the hardness of Al-Mg alloys were significantly increased by the addition of 10 % of AlB_2 flake. This result is in good agreement in a number of experimental works reported for AlB_2/Al type composites [9,15,18-22].

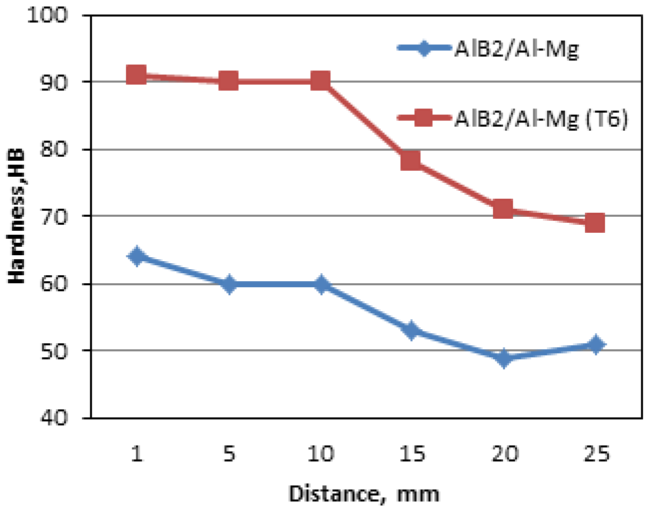

Figure 7. Measured Brinell hardness (HB) as a function of radial distance along the centrifugally casting composite

4. Conclusions

1- AlB_2 Reinforcing particles were produced by chemically reacting aluminium alloys with boron oxide at 1400 °C for 1.5 h. It was observed that the AlB_2 flakes in Al-Mg alloy have average 170 micron width, fine flake shape and volume fraction of AlB_2 flake is 2.6 vol.% in as cast condition.

2- Results showed that volume fraction of AlB_2 flakes in external zone significantly increased under centrifugal force. The average volume fraction of AlB_2 flakes in the external region was 10 vol.%. However in the other region was decreased to almost zero.

3- These results show that the functionally graded AlB_2/Al-Mg composites in external zone have the highest hardness with 90 HB. These results show that the Brinell hardness of Al-Mg alloys were significantly increased by the addition of 10 % of AlB_2 flake.

Acknowledgements

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References

[1] Taya M., Arsenault R.J., 1989, "Metal Matrix Composites: Thermo-Mechanical Behavior", Pergamon Press.

[2] Miracle D.B., (2005),” Metal matrix composites – From science to technological significance”, Composites Science and Technology, 65:2526–2540.

[3] Rohatgi P.K., Cast Metal Matrix Compozites: Past, Present ve Future, American Foundry Society, Silver Anniversary Paper, Div. 2. AFS Transactions, 01-133 (2001) 1-25.

[4] Rawal Suraj P.,(2001)” Interface Structure in Graphite-fiber-reinforced Metal–matrix Composites”, Surface And Interface Analysis,31: 692-700.

[5] Miracle, D. B., (2001-b) “Aeronautical Applications of Metal-matrix Composites”, ASM International, 1043-1049.

[6] Prasad S.V., and R. Asthana (2004),” Aluminum Metal–matrix Composites for Automotive Applications: Tribological Considerations” Tribology Letters, 17 (3): 445-453.

[7]Attia, A.N. (2001), “New Phase Reinforcement for Composite Materials” Materials and Design, 22(6): 459-466.

[8] Leon L. Mishnaevsky Jr, (2006), “Functionally Gradient Metal Matrix Composites: Numerical Analysis of the Microstructure–strength Relationships” Composites Science and Technology 66: 1873–1887.

[9] Melgarejo Z.H., Suarez O.M., Sridharan K., (2006), ”Wear Resistance of a Functionally-graded Aluminum Matrix Composite”, Scripta Materials 55: 95-98.

[10] Cooper P.S, Kearns, MA., (1996), ”Removal of Transition Metal Impurities in Aluminium Melts by Boron Additives”, Materials Science Forum, 217–222:141–146.

[11] Sigworth,G.K., Kuhn,T. A., (2007), “Grain Refinement of Aluminium Casting Alloys”, AFS Transaction, 115: 1−12.

[12] Hall A.C, (1995), “Pathways Family of Low Cost, High Performance, Metal Matrix Composites Based on AlB_2 in Aluminium”, B.S Thesis., The University of Tulsa.

[13] Savas, O., Kayikci, R., Koksal, S., (2012) “Application of Taguchi Method to Investigate the Effect of Some Factors on In-situ Formed Flake Structures of Al/ AlB_2 Composite”, Advanced Composite Letters, 21:44-50.

[14] Deppisch, G. Liu, J.K. Shang, J. Economy, (1997),” Processing and Mechanical Properties of AlB_2 Flake Reinforced Al-alloy Composites”, Material Science Engineering A, 225:153-161.

[15] Ficici F., Koksal S., Kayikci R., Savas O., (2011), "Investigation of Unlubricated Sliding Wear Behaviours of In-Situ AlB_2/Al Metal Matrix Composite" ,Advanced Composites Letters , 20:109-116.

[16] Deppisch G., Liu A., Hall Y., Xu A., Zangvil J.K., Shang J. Economy, (1998),” The Crystallization and Growth of AlB_2 Single Crystal Flakes in Aluminum”, Journal of Materials Research, 13(12): 3485-3497.

[17] El-Mahallawy, M. A. Taha, A.E.W. Jarfors, H.Fredriksson (1999),” On the Reaction Between Aluminium, K_2TiF_6 and KBF_4”, Journal of Alloys and Compounds, 292:221–229.

[18]Melgarejo Z.H., Suárez O.M., Sridharan K., (2008), “Wear Behavior of Functionally Graded Al-Mg-B Composites Fabricated by Centrifugal Casting,” Composites Part A: Applied Science & Manufacturing, 39(7):1150–1158.

[19] Duque N.B., Melgarejo Z.H., Suarez O.M., (2005), “Functionally Graded Aluminum Matrix Composites Produced by Centrifugal Casting”, Materials Characterization, 55:167–171.

[20]Calderon, H. E., Suarez, O. M., (2008), ” Thermomechanical Effects on Aluminum Matrix Composites Reinforced with AlB2 Particles”, Journal of Composite Materials, 42: 2651-2672.

[21] Suarez, O. M., (2003), “Precipitation Hardening of a Novel Aluminum Matrix Composite”, Materials Characterization 49:187–191.

[22]Kubota M., Sugamata M., (2008), “Reaction Milled and Spark Plasma Sintered Al-AlB_2 Composite Materials” Reviews on Advanced Materials Science, 18:269-275.