Technological Applied Sciences
ISSN: 1308 7223 (NWSATAS)
ID: 2019.14.2.2A0169

Status : Original Study
Received: January 2018
Accepted: April 2019

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DOI	http://dx.doi.org/10.12739/NWSA.2019.14.2.2A0169	
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PRODUCTION OF AA5754/B_4C COMPOSITE MATERIALS BY THE SEMI-SOLID STIRRING METHOD

ABSRACT

Aluminum composites were produced by reinforcing an AA5754 aluminum alloy with B4C particles. The semi-solid stirring and low-pressure solidification methods were used to produce AA5754/B4C composites, and the mechanical characteristics of the samples that were obtained were determined by three-point bending and compression tests. Additionally, microstructure examinations were made by SEM, EDS and XRD, and the sucsesfull producibility of the B4C reinforced aluminium composites with the method that was used was seen.

Keywords: Aluminum, B_4C, Metal Matrix Composite,
Semi-Solid Stirring, Hardness

1. INTRODUCTION

Studies on metal matrix composites (MMC) started in the late 1950s with the purpose of preserving the superior characteristics of metallic materials while improving their structural properties [1]. High-technology ceramics, polymers, metals and composites, which entered the world's economy with a substantial market share in the second half of the twentieth century, are materials with high added value that have high technical performance and content of knowledge, as well as diversity [2]. Studies on continuous development of the efficiency of materials are increasingly abundant in the fields of materials science and engineering [3]. In recent years, MMC has been prevalently research and used in industrial practices. The widespread usage of aluminum as a matrix material is increasing due to its low density and inexpensive costs [4]. Additionally, aluminum is an attractive material for MMC production due to its resistance to corrosion, low electrical resistance and perfect mechanical properties [5 and 6]. Production and usage of MMCs have increased due to technological advancements especially in the automotive industry and space and aviation sectors. MMCs with superior characteristics may be produced by combining two or more materials in the same or different groups including at least one metal and metal alloy with continuous fibers, whiskers or particles, as well as combining their desired characteristics [7, 8, 9 and 10]. MMC materials are advanced-technology materials that may exhibition superior characteristics such as high modulus of elasticity, high tensile, abrasion, compression and creep strength, ability to protect their stability at high temperatures, ductility and toughness, low specific weight, low sensitivity against thermal shocks and high electrical and thermal conductivity. There are three important factors that determine the structures and characteristics of MMCs. These are the matrix material, the reinforcement material and the interface connection. The main

How to Cite:
Yakut, R. and Ürkmez Taşkın, N., (2019). Production of AA5754/B_4C Composite Materials By The Semi-Solid Stirring Method, **Technological Applied Sciences (NWSATAS)**, 14(2):57-67, DOI:10.12739/NWSA.2019.14.2.2A0169.

function of the reinforcement is usually carrying the incoming load and increasing the rigidity, strength and abrasion resistance of the matrix [11]. The function of the matrix to keep the reinforcement elements integrated and protect the material's surface from mechanical damages during the process [12]. The function of the interface connection is that its strength is dependent on the wettability characteristics of the matrix.

2. RESEARCH SIGNIFICANCE

B_4C ceramic powders are mostly preferred as reinforcement materials in production of high-strength aluminum-based composite materials due to their low density, high melting temperature, superior strength characteristics and high modulus of elasticity. However, because of the wetting problem of B_4C, it is highly difficult to mix it into Al. This study aimed to increase the wettability of B_4C in aluminum by heat treatment. Moreover, by using the method of semi-solid stirring, it was aimed to increase strength by forming both mechanical and chemical robust bonds between the matrix and the reinforcement.

3. MATERIAL AND METHOD

3.1. Matrix Material

The matrix material for the production of B_4C-reinforced composite materials was selected as the AA5754 alloy. The density of this alloy is 2.68g/cm^3, it does not have a thermal hardening property, and its hardness and strength values increase as the ratio of magnesium increases. On the other hand, it is an aluminum alloy that has low ductility and has the characteristics of good welding and good malleability. The properties of the AA5754 aluminum alloy are given in Tables 1 and 2 [13].

Table 1. Mechanical characteristics of AA5754 alloy

Heat Treatment	Tensile Strength, Rm MPa	Elongation Strength %	Shear Modulus MPa	Elasticity Modulus GPa
O, H111	215	25	140	68
H22	245	15	150	68
H24	270	14	160	68
H26	290	10	170	68

Table 2. Chemical composition of AA5754 alloy

Weight %	Si	Fe	Cu	Mg	Mn	Cr	Zn	Ti
Minimum	-	-	-	2.6	-	-	-	-
Maximum	0.4	0.4	0.1	3.6	0.5	0.3	0.2	0.15

3.2. Reinforcement Materials

B_4C is as a reinforcement material to increase the abrasion and impact strength of materials due to its lightness and superior mechanical properties. Considering the materials used in ballistic applications, it is seen that ceramic materials such as B_4C constitute alternatives to steel and aluminum in armor plate applications. The characteristics of the B_4C reinforcement material are given in Table 3.

Table 3. Some mechanical and physical characteristics of B_4C materials [13]

Reinforcement Material	B_4C
Density (x10^{3}kgm^3)	2.52
Thermal Expansion Coefficient (10^{-6}C^{-1})	6.08
Melting Point (°C)	2420
Compression Strength (MPa)	2900
Elasticity Modulus (GPa)	460
Knoop Hardness	2800

3.3. Composite Material Production by the Method of Semi-solid Stirring

The temperature of the melting furnace (Figure 1) was kept constant at 720°C. The nitrogen gas setup was placed in a way that would allow provision of nitrogen onto the metal. After the matrix material was put into the SiC pot where melting and stirring processes were carried out, the semi-solid temperature was reached, and the reinforcement material that was heated to 220˚C was added at a rate of 5gr/min. The B_4C reinforcement, which was added into the matrix by using steel rods with specifically-profiled tips, was introduced at a constant temperature. It was achieved to mix the reinforcement into the matrix by low-speed stirring and kneading processes at the semi-solid temperature of the matrix material by using mixers. The mixture, whose temperature increased rapidly after the process of adding the reinforcement material, was homogenized by applying high-rate stirring for a short time. After the stirring and homogenization processes, the lowest temperature interval that would allow fluidity was selected as the casting temperature, the mixture was removed from the melting unit and taken into a steel mold (Figure 2) that was preheated to the temperature interval of 540-550°C. The upper lid of the steel mold that contained the melt was closed, the mold was put under the press tray, and the compression process started in a few seconds. After applying a compression force for 3-4 seconds under 10 MPa pressure, the entire mold was taken out of the press, the composite material was left for 15 minutes to cool in the mold, then taken out of the mold and left for cooling at the ambient temperature. The prismatic composite sample material with metal matrix that came out of the mold is shown in Figure 3. AA5754/B_4C composite materials were produced by adding B_4C into the semi-solid aluminum alloy in rates that are given in Table 4. The temperature values were determined with the type-K thermocouples that were placed into the furnace.

Table 4. Volumetric ratios of the reinforcements in the AA5754 alloy

Composite sample	% Al (cm^3)	% B_4C (cm^3)
100% Al	242	-
20% B_4C-80% AA5754	193.6	48.4

Three samples were cast for each ratio of reinforcement. In order to be able to compare the properties of the composite materials that were obtained to those of the matrix alloy, unreinforced matrix alloy was also produced in the same production conditions, and control samples were prepared.

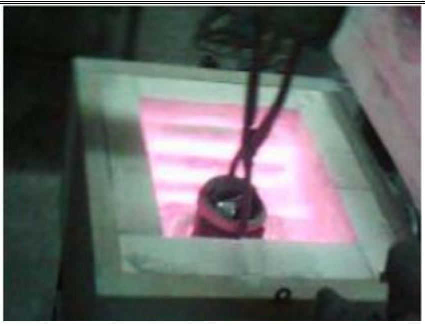


Figure 1. Melting furnace

Figure 2. Female mold

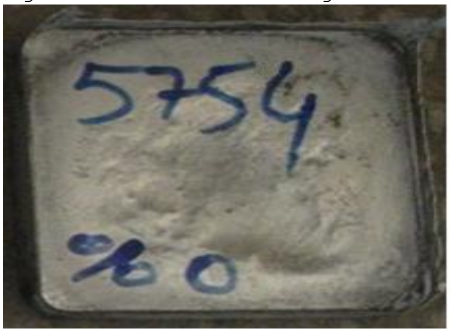


Figure 3. Sample that came out of mold (110x110x20 mm)

The samples for the three-point bending and compression tests were prepared as 7 samples for each process in the wire erosion machine that is seen in Figure 4 at the facilities of Hema Endüstri A.Ş. based on the respective standards of TS-205 and ASTM-E9. The porosity measurement samples are shown in Figure 5, the three point bending samples are shown in Figure 6, and the compression samples are shown in Figure 7.

Figure 4. Preparation of samples with a wire erosion machine

Figure 5. Samples for porosity measurement (20x20x50mm)

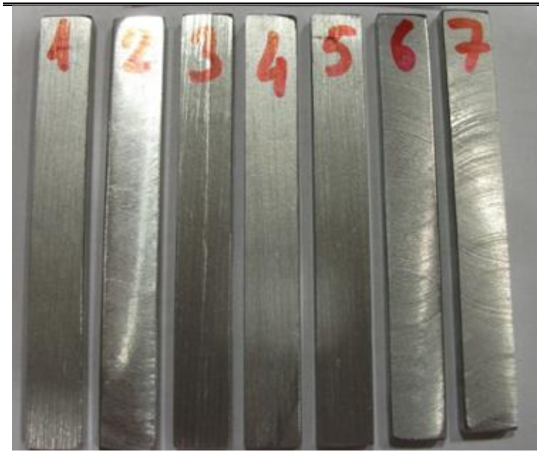


Figure 6. Samples for bending test from three points (4x10x80mm)

Figure 7. Samples for compression test (Ø10x10mm)

4. FINDINGS AND DISCUSSIONS

This study deliberately selected the AA5754 aluminum alloy as the matrix material due to its widespread usage in the field of industry. The B_4C material that was selected as the reinforcement material and had different sizes was mixed into the semi-solid aluminum alloy, and composites were obtained. The effects of the reinforcement ratios in the composites that were obtained on the success of stirring and mechanical properties were examined.

4.1. Results on Specific Weight and Porosity Measurements

The specific weight of the samples that were produced by reinforcement with B_4C particles were calculated based on the Archimedes principle. Table 5 shows the change in the theoretical and experimental specific weight of the composites based on the ratios of the reinforcement particles.

Table 5. Theoretical and experimental specific weights and porosity ratios of samples

Material	% B_4C (by Volume)	Theoretical Specific Weight (g_f/cm^3)	Experimental Specific Weight (g_f/cm^3)	% Porosity
AA 5754	-	2.68	2.67	0.3
AA 5754+20% B_4C	20	2.65	2.48	6.3

With the increase in the volumetric ratios of the reinforcement, reduction was observed in the specific weights of the composite materials. When the theoretical and experimental specific weights of the samples were compared, it was seen that they had high porosity ratios. It is believed that this result was caused by compression under low pressure.

4.2. Mechanical Test Results

4.2.1. Three-Point Bending Test

In this study, 3 samples were produced for each of the AA 5754+20% B_4C composite material, and for comparison, the unreinforced AA5754 material. The samples that were produced were subjected to bending tests from three points. The bending strengths of the samples were calculated based on the equation that is found in the (ASTM B528-05) standard.

$$TRS=\frac{3PL}{2t^2w} \quad (1)$$

In the equation:
P: Force that is applied on the sample at the time of breaking (N)
L: Distance between the supports (mm)
t: Sample thickness (mm)
w: Sample width (mm)
TRS: Bending strength (MPa)

As a result of the three-point bending tests, the mean bending strength values of the AA5754/B_4C composites with 20% B_4C reinforcement and the unreinforced AA5754 samples were respectively 122.3N/mm^2 and 268.2N/mm^2. As the ratio of reinforcement increased, the bending strength decreased. Therefore, mechanical strength decreased due to the addition of the reinforcement.

4.2.2. Compression Experiments

The AA5754/B_4C composites and the unreinforced AA5754 aluminum alloy samples were subjected to compression tests. The mean compression strength of the unreinforced samples was measured as 210N/mm^2. As a result of the test on the composites that were produced by adding 20% B_4C on the AA5754 alloy by volume, the mean compression strength value was calculated as 519.7N/mm^2. Addition of the B_4C reinforcement led to an increase in the compression strength.

4.2.3. Microstructure Examinations

Understanding whether or not a mechanical or chemical bond has been achieved between the reinforcement phase and the matrix in composite materials is possible by examining whether or not the reinforcement phase is homogenously distributed in the reinforcement phase. The microstructures of the experiment samples were examined by taking their SEM images at different magnification rates. This study used the AlMg3 (AA5754) alloy.

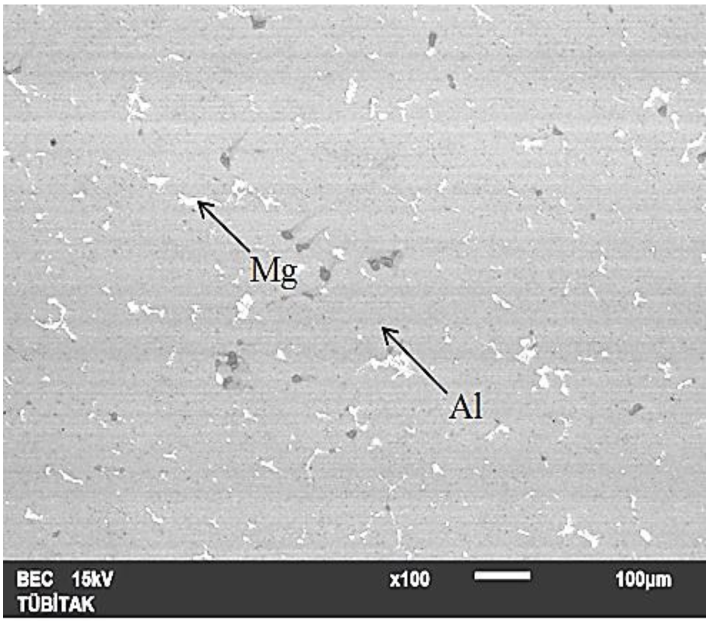
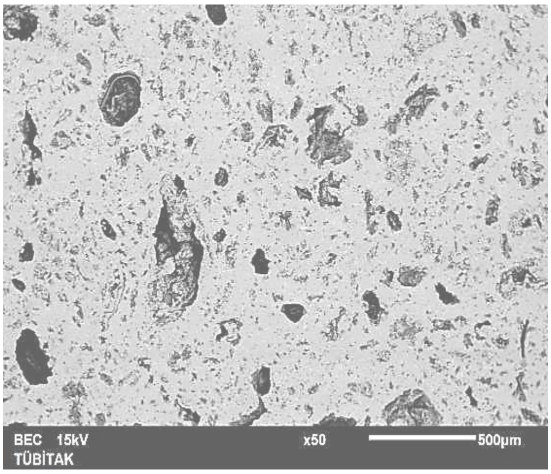


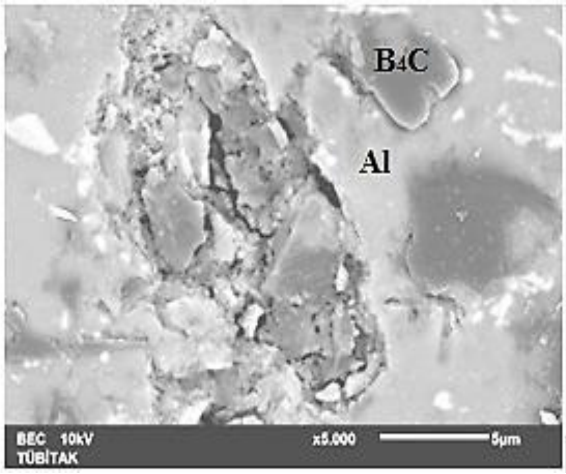
Figure 8. Microstructure of unreinforced AA5754 matrix (x100)

Figure 8 shows the microstructure of the unreinforced AA5754 alloy. Regions of homogenously distributed Mg are seen in the aluminum. Mg reduces the surface tension of aluminum in liquid form and increases the wettability of the reinforcement material that is added. Magnesium forms a eutectic composition with aluminum at the ratio of 33%. It reduces the specific weight of the alloy that it enters as its specific weight is low. Precipitation hardening occurs in alloys that contain more than 6% Mg. Magnesium hardens the alloy and increases its strength. Precipitation hardening does not happen in lower ratios. Aluminum alloys that cannot be hardened by heat treatment are produced. Mg also increases the resistance of aluminum against saltwater corrosion.

Figure 9 shows the SEM microstructure images of the AA5754/B_4C composites that were added B_4C by 20%. Figure 9 (a) and (b) shows that the reinforcement material was homogeneously distributed in the prepared composites, and the x50 and x5000 images demonstrate that the B_4C particles were sufficiently wetted by aluminum. It may be observed in the images that the B_4C particles surrounded well by aluminum, and there were no pores or flocculation. This proves that a mechanical bond was formed between the reinforcement material and the matrix. As gas absorption was high due to the longtime of stirring, micro gaps were formed in the structure, and the B_4C particles gathered in these gaps. Moreover, as a result of the EDS analysis that is shown in Figure 10, it was seen that the interface between the reinforcement and the matrix included reaction products in the AA5754/B_4C composites, which proved that there was chemical bonding.



a) AA5754/B_4C composite (vol 20%, x50)

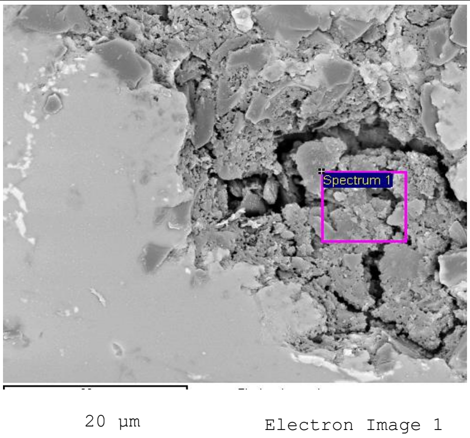


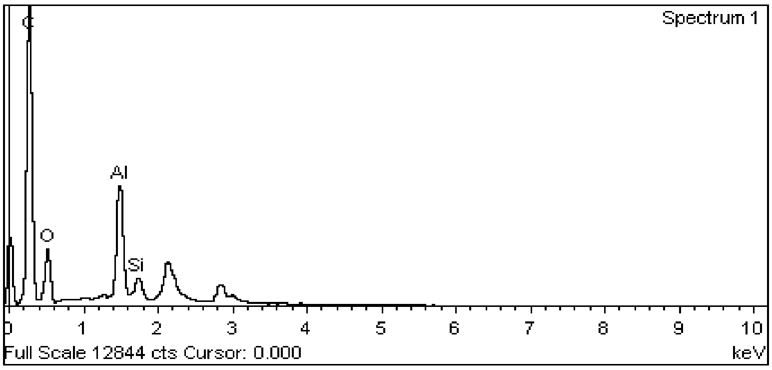
b) AA5754/B_4C composite (vol 20%, x5000)

Figure 9. SEM microstructure images of AA5754/B_4C composites

Spectrum processing:
Peaks possibly omitted: 2.139, 2.840, 3.020, 3.694 keV
Processing option: All elements analyzed (Normalised)
Number of iterations = 4
Standard:
C CaCO3 1-Jun-1999 12:00 AM
O SiO2 1-Jun-1999 12:00 AM
Al Al2O3 1-Jun-1999 12:00 AM
Si SiO2 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
C	65.80	76.12
O	17.90	15.54
Al	13.34	6.87
Si	2.96	1.46
Totals	100.00	

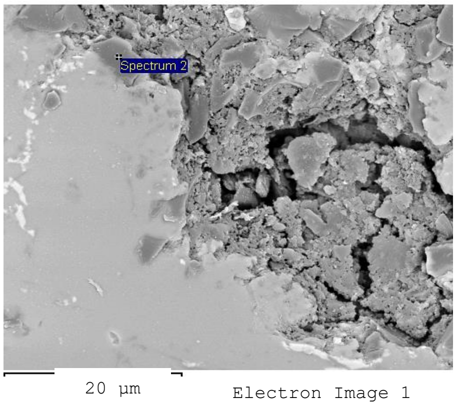


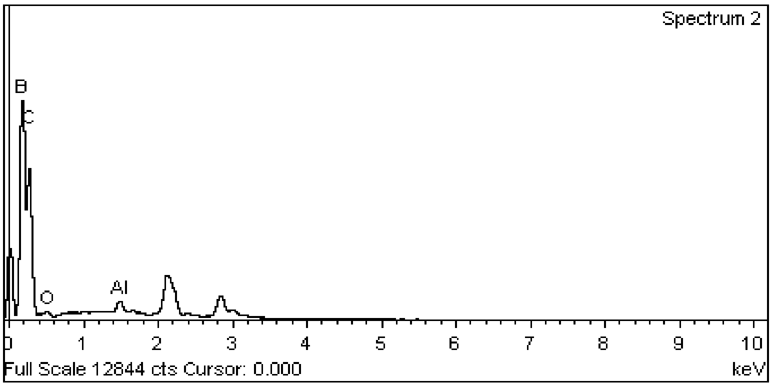


(a)

Spectrum processing:
Peaks possibly omitted: 2.140, 2.425, 2.842, 3.023 keV
Processing option: All elements analyzed (Normalised)
Number of iterations = 4
Standard:
B B 20-Jul-1999 12:00 AM
C CaCO3 1-Jun-1999 12:00 AM
O SiO2 1-Jun-1999 12:00 AM
Al Al2O3 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
B	47.26	50.16
C	51.23	48.95
O	0.87	0.62
Al	0.64	0.27
Totals	100.00	





(b)

Figure 10. EDS analyses on the a) matrix material and b) reinforcement region in the AA5754/B_4C composites with 20% reinforcement

The XRD analyses that were carried out on the AA5754/B_4C composites with 20% reinforcement revealed reaction products mainly consisting of Al_3BC and B_2O_3 in the interface between the reinforcement and the matrix, and these reactions showed a chemical bond between the components (Figure 11). It was also seen in the XRD analysis results that are shown in Figure 12 that the heat treatments that were applied to increase the wettability of the B_4C powders by aluminum were successful. In this analysis, it was observed that $B(OH)_3$ reaction products formed on the B_4C powders.

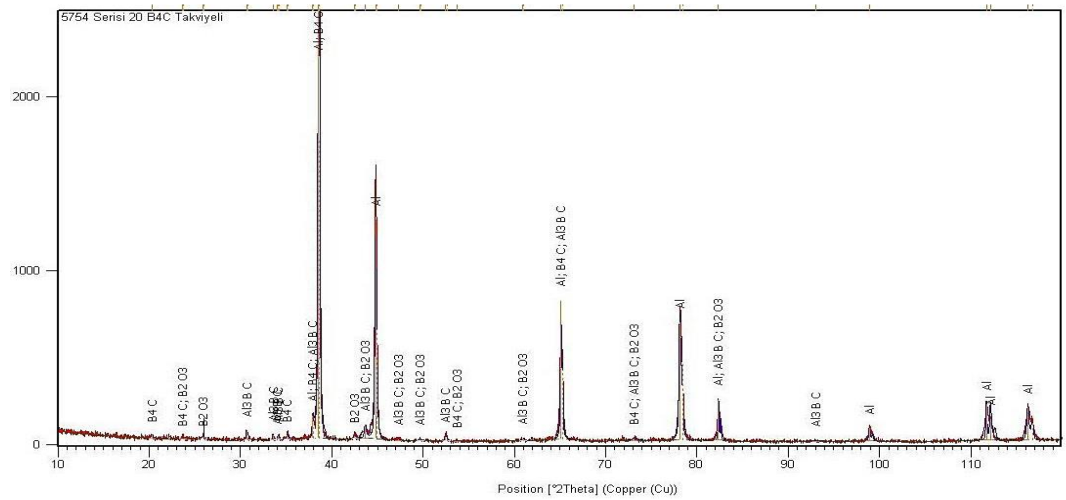


Figure 11. XRD analysis on AA5754/B_4C composite

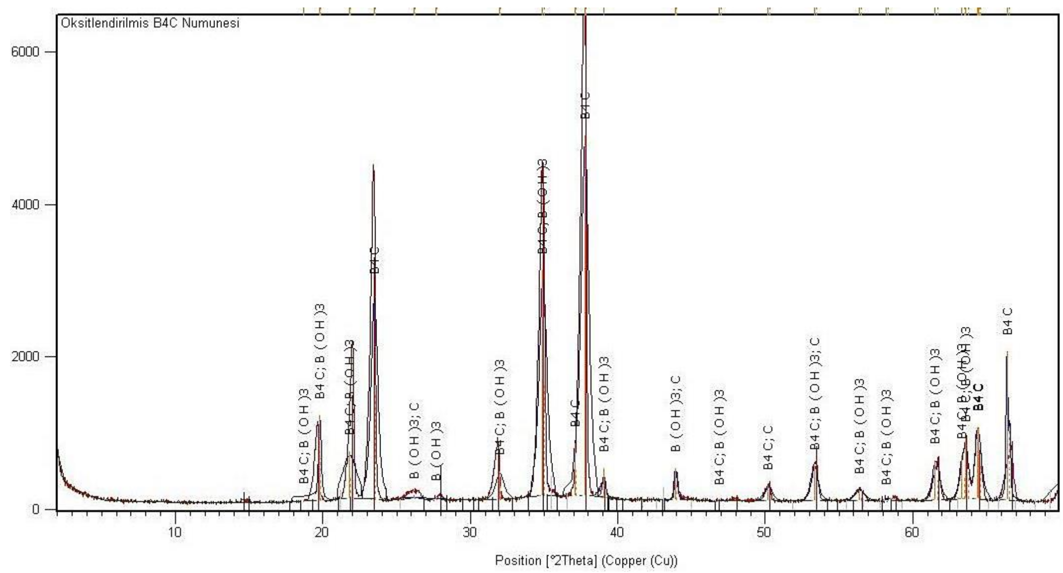


Figure 12. XRD analysis on B_4C powders that were heat-treated

5. CONCLUSION

The results that were obtained are summarized below.

- The heat treatment applied to the B_4C particles resulted in the formation of oxide layers on the particles and improved the wetting of the reinforcing particles by aluminum.
- By using the method of semi-solid stirring, the reinforcements were homogenously mixed into the matrix material, and problems such as flocculation, separation, rejection of the reinforcement out of mixture were not observed.

- When the SEM images of the microstructures were examined, with the effect of the processes of semi-solid stirring and solidification under pressure, the B_4C reinforcement particles were surrounded by the matrix material well, and a mechanical bond was established
- It was observed that the interface properties were improved in the composites that were produced, but in connection to the high porosity values that occurred, the improvements in the interface properties could not be sufficiently reflected on the mechanical properties.

ACKNOWLEDGEMENTS
This work is supported by the Coordinator of Trakya University's Scientific Research Project (TUBAP Project No: 2013/12).

REFERENCES
[1] Toptan, F., (2011). Production of High Wear Resistant B_4c Particle Reınforced Aluminum Matrix Composites. PhD Thesis. İstanbul: Yıldız Technical University Institute of Science and Technology.
[2] Pul, M., Calin, R., and Citak, R., (2011). An Investigation of Surface Quality of Turning in Al Matrix MgO Reinforced Composite Materials. Journal of the Faculty of Engineering and Architecture of Gazi University: Vol::26, No:1, pp:81-88,
[3] Aksöz, S., Özdemir, A. T., Bostan, B., (2012). Alloyed AA2014 Aluminum Powders Synthesized with Carbon and Determined Properties. Journal of the Faculty of Engineering and Architecture of Gazi University, Vol: 27, No: 1, pp: 109-115.
[4] Arslan, D., Gürü, M., (2013. Production of Boron Carbıde by Mechanochemical Method and Investigation of Usability on the Aluminum Based Composite Material. Journal of the Faculty of Engineering and Architecture of Gazi University, Vol: 28, No: 4, pp: 875-883.
[5] Tosun, N., Kuru, C., and Altıntaş, E., (2010). Investigation of Surface Roughness in Milling with Air and Conventional Cooling Method. Journal of the Faculty of Engineering and Architecture of Gazi University, Vol: 25, No: 1, pp: 141-146.
[6] Tuncer, N., Taşdelen, B., and Arslan, G., (2011). Effect of Passivation and Precipitation Hardening on Processing and Mechanical Properties of B_4C/Al Composites, Ceramics International, Vol: 37, No: 7, pp: 2861-2867.
[7] Ekici, E., (2012). The Manufacture of Aluminium Matrix Composites with B_4C Reinforcing Element and Addition of Graphite and the Analysis of Mechanical Features and Their Machinability on Milling. PhD Thesis. Ankara: Gazi University Institute of Science and Technology.
[8] Groover, M.P., (2010). Fundamentals of Modern Manufacturing, Materials, Processes and Systems 4^{th} Edition. U.S.A.
[9] Yalçın, E.D., (2010). Investigation of Joinability AA 7075 and AA5754 Aluminum Alloys by Friction Stir Welding Method. Master Thesis. Karadeniz Technical University Institute of Science and Technology.
[10] Singla, M., Dwivedi, D. D., Singh, L., and Chawla, V., (2009). Development of Aluminium Based Silicon Carbide Particulate Metal Matrix Composite. Journal of Minerals & Materials Characterization & Engineering, Vol:8, No:6, pp:455-467
[11] Atik, E., Ünlü, B.S., Sen, O., and Çavdar, U., (2006). Investigation of Wear Strength and Mechanical Properies of

Particle Reinforced AlSi12CuNiMg Composites. C.B.U. Journal of Science, Vol:2 No:2 pp:75-87

[12] Kılıç, C., (2008). Sıkıştırma Döküm Yöntemi İle Üretilmiş ve Soğuk Haddelenmiş AlMg3/SiCp Kompozitinin Aşınma Özelliklerinin İncelenmesi, Master Thesis. Trakya University Institute of Science and Technology.

[13] Ürkmez, N., (2004). AlMg3/SiCp Kompozitlerinin Üretimi ve Mekanik Özelliklerdeki Değişimlerin İncelenmesi. PhD Thesis. İstanbul: Yıldız Technical University Institute of Science and Technology.