Fabrication of AA6061/B4C Composites and Investigation of Ballistic Performances

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Abstract—**In this study, mechanical properties of B4C particulate reinforced AA6061 matrix composites produced by powder metallurgy were investigated and their ballistic performances were examined. AA6061 matrix particles have been mixed with B4C particle for 45 minute and cold pressed under 400 MPa. The pressed compacts have been sintered at 550 ^{o}C for one hour, and then were extruded at the same temperature. In order to improve rigidity, the T6 precipitation processes were applied to the composite samples. The ballistic performance of composite samples against 7.62×51 mm shootings were examined. Extruded plate samples have shown significantly high ballistic performance against 7.62×51 mm shootings. It is proved that the ballistic performance is increasing by using dual plate composite system against 7.62×51 mm shootings.**

Keywords-AA6061; B4C; composite materials; powder metallurgy; ballistic performance

I. INTRODUCTION

The demand for less dense and high stiffer materials is increasing day by day. Metal matrix composites (MMCs) are among the advanced composite materials and their applications are increasing due to their superior mechanical properties [1]. Aluminum matrix composites (AMCs) are among the MMCs are used in advanced applications due to their good wear resistance, thermal stability, high fatigue resistance, hardness and strength properties [2-3]. Because of these advantages, AMCs are mostly used in the automotive, aerospace, marine, sports and defense industries [4-5]. In AMCs are used in different types reinforcing elements such as B4C, SiC, Al2O3, TiC and MgO [6-10]. As a reinforcing element, B4C is a material that exhibits excellent physical and mechanical properties with its high melting point and hardness, resistance to impact and abrasion, and excellent resistance to chemical substances and neutron absorbing ability [11-12].

It is known that the ballistic protection ability of metal armors can be effectively improved by covering with a ceramic plate layer since the last century. Therefore, ceramic armors such as Al2O3, SiC, B4C and TiB2 have shown promising ballistic protection. However, they have disadvantages such as high cost, machining difficulty, low fracture toughness and low resistance to multiple bullet impacts. For this reason, composite structures and composite materials are needed which can overcome the disadvantages of ceramic armor [13]. Zhou et al. investigated the ballistic resistance of B4C/2024Al composite materials produced by pressure infiltration method against 7.62 mm armor piercing bullets [13].

The purpose of this study is to investigate the ballistic properties of AA6061 alloy and AA6061/B4C composite materials in combination. In the experiments, AA6061 matrix reinforced B4C reinforced composite materials were produced by hot extrusion method and ballistic tests were carried out.

II. EXPERIMENTAL PROCEDURES

A. *Work Piece Material*

B4C powders of 0-5% by weight with AA6061 powders were mixed in a Turbola T2F type three-dimensional mixer for 45 minutes. The blended powders were pressed uniaxially at 300 MPa with the cold pressing mold. After pressing, powder metal block samples with a full diameter of 100 mm and a length of 100 mm were obtained (Figure 1). The powder metal block samples were extruded at a rate of ¼ after sintering in an open atmosphere at 550 °C for 1 hour using Protherm PLF 120/12 type furnace. The sections of the specimens after pressing and extrusion process are given in Figure 2. T6 aging heat treatment was applied to increase the strength of composite plates. The obtained B4C aging samples were heated in the oven to a temperature of 530 °C using a heating rate of 10 °C/min, followed by dissolving for 1 hour, followed by rapid cooling by supplying water. The water-cooled samples were individually artificially aged for 8 hours at a heating rate of 10 ° C / minute to a temperature of 175 °C.

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B. Material Characterization

The density measurements of the produced AA6061/B4C composite materials were made using the Sartorius brand scale with a sensitivity of 0,1 mg according to the Archimedes principle. Microstructure studies of the samples were made on a Leica DM4000M optical microscope. Hardness measurements were performed by applying a 2.5 mm ball tip and 31,25 kgf load to the EMCO TEST Duravision 200 brand hardness tester.

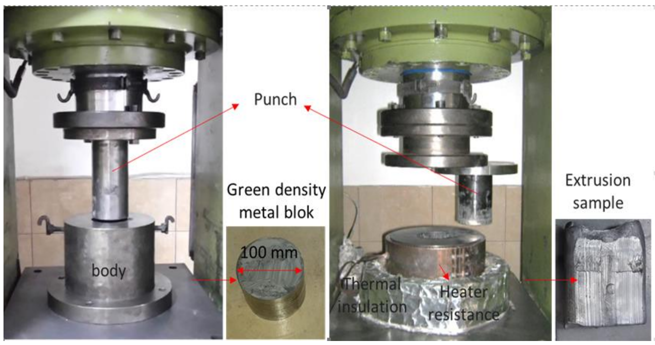

Figure 1. In the production of composite materials (a) cold pressing mold (b) extrusion mold

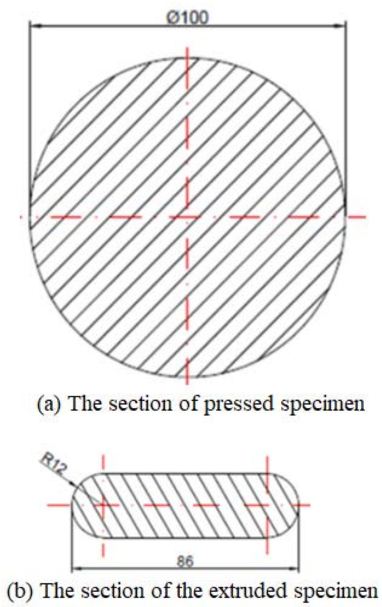

Figure 2. The section view of the samples

C. Ballistic Experiments

Ballistic experiments of the produced composite materials were made according to National Institute of Justice (NIJ) standards for type III threats [14]. Ballistic test specimens prepared in dimensions of 80 × 120 mm were fixed to the target and shot at a distance of 10 m. The tests were carried out using G3 rifles and 7.62 mm × 51 mm M80 type bullets. The overview of the ballistic test setup is presented in figure 3.

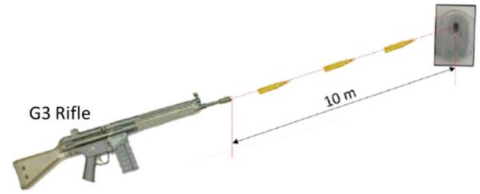

Figure 3. Overview of the experimental setup used for the ballistic testing

The schematic view and dimensions of the projectile used in the ballistic tests are given in Figure 4.

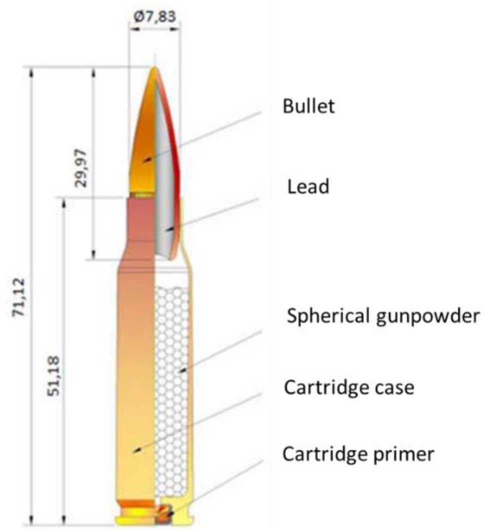

Figure 4. Schematic view of the 7.62 mm × 51 mm M80 type bullets and dimensions were given in mm.

III. Experimental Results and Discussion

Density and porosity measurements after extrusion were carried out. Theoretical densities were also calculated depending on the matrix and amount of reinforcement. When the theoretical density and the experimental density are compared, the densities have increased to over 99%. In other words, at a very small proportion of the pores, about 1%, were observed. While an average of 99.26% density was obtained in AA6061 material, an average 99.22% density was obtained in B_4C reinforced composites. Figure 5 shows optical microscope images taken from the post-extrusion surface of AA6061 matrix 5% B_4C reinforced composite material. The AA6061 material was found to have a structure that was so porous that it would almost disappear. When we look at 5% B_4C reinforced composite material, it is observed that B_4C particles are homogeneously distributed in the matrix structure. When we look at the hardness values obtained from unreinforced and 5% reinforced composite materials, the average hardness value of AA6061 is 55 HB while the average hardness value of 5% B_4C reinforced composite materials is 56,6 HB. Depending on the amount of B_4C, it was observed that the hardness value increased with respect to the untreated materials. In a similar study, the authors found that hardness increases with the increase in the amount of B_4C [15]. B_4C particles are thought to be an important factor in increasing the stiffness of the composites by forming tensions in the matrix structure.

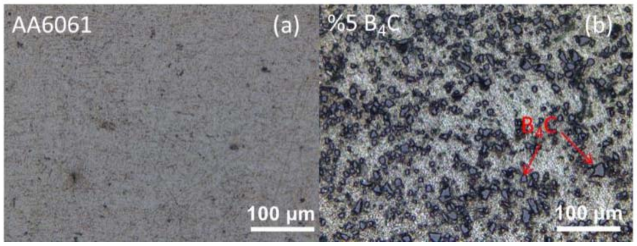

Figure 5. Optical microscope image of (a) AA6061 and (b) 5% B4C composite material

The ballistic tests were performed using the G3 rifle with 7.62 mm bullets. Composite materials produced by extrusion and rolling were placed on top of each other and ballistic test was carried out with 7.62 × 51 mm projectile. In the ballistic test, two extruded materials (AA6061 and 5% B_4C) were shot first without using any adhesive at the interface. A macro image of the composite material after the shot is given in Figure 6. AA6061, which is the material of the first contact with the bullet, was found to have formed a thin hole at the entrance, and the bullet was stuck in the hole at the exit. The exit of the bullet was blocked by 5% B_4C composite material deformation. At the front of composite material with 5% B_4C, it was seen that there was a pit inward due to the pressure force generated by the bullet (Figure 7).

Figure 6. Sample with 7.62 × 51 mm bullet shot with G3 rifle placed side by side after extrusion

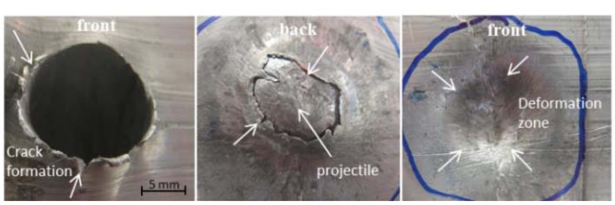

Figure 7. Macro picture of a sample shot with gunshot 7.62 × 51 mm with a G3 rifle placed side by side after extrusion

When looking at the cross-section of the specimen after the test, it was seen that the bullet had collapsed at the end of the material and could not go out. Therefore, it has proved that it can be used as ballistic protective armor material by putting the AA6061 and the 5% B_4C extrusion plate on top of 50 mm in total thickness. When we look at Figure 8, it is seen that the bullet moves as ductile in AA6061 material. The bullet remains between the AA6061 and the 5% B_4C specimen with the effect of the other 5% B_4C reinforced material without exiting the material.

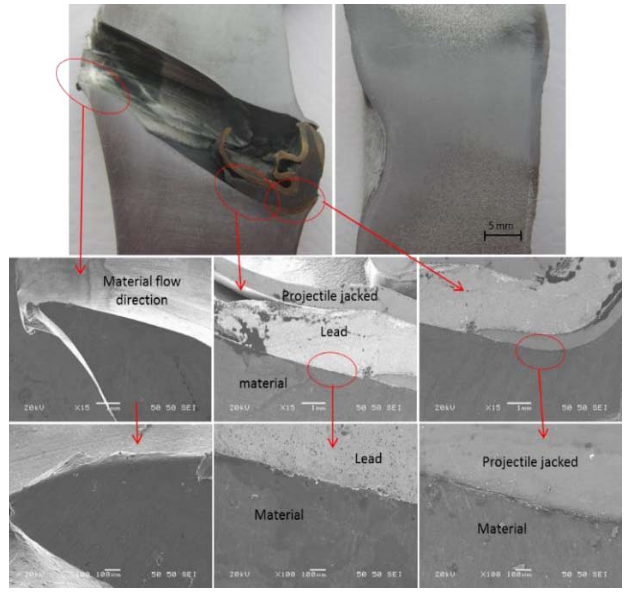

Figure 8. SEM pictures of the specimen of 7,62 × 51 mm bullet shot with G3 rifle placed side by side after extrusion at different magnifications

Figure 9 shows the SEM image taken from the armour and the projectile interface. The EDS results taken from point 1 are evidenced the remain of the projectile and the results of point 2 are indicated the jacket of the projectile while point 3 is matrix material. EDS results of the impacted specimen are presented in Fig.10 (a), (b) and (c). it can be seen from the SEM image, the projectile was stopped in the armour and collapsed at the first layer of the laminated structure. it was also observed a strong bonding between the jacket of the projectile and armour.

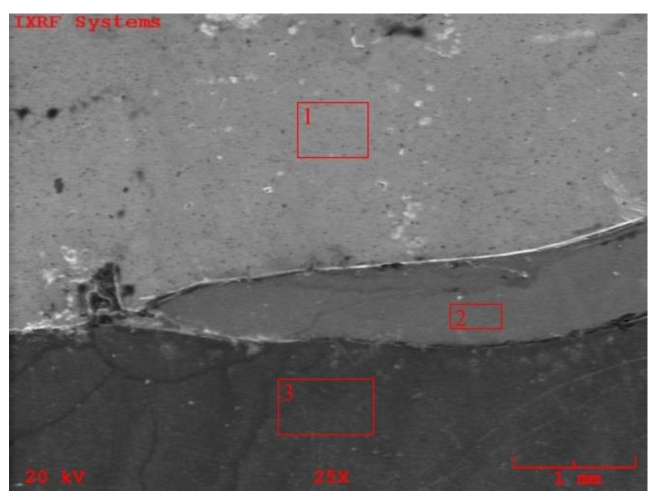

Figure 9. SEM image of the specimen after ballistic impact

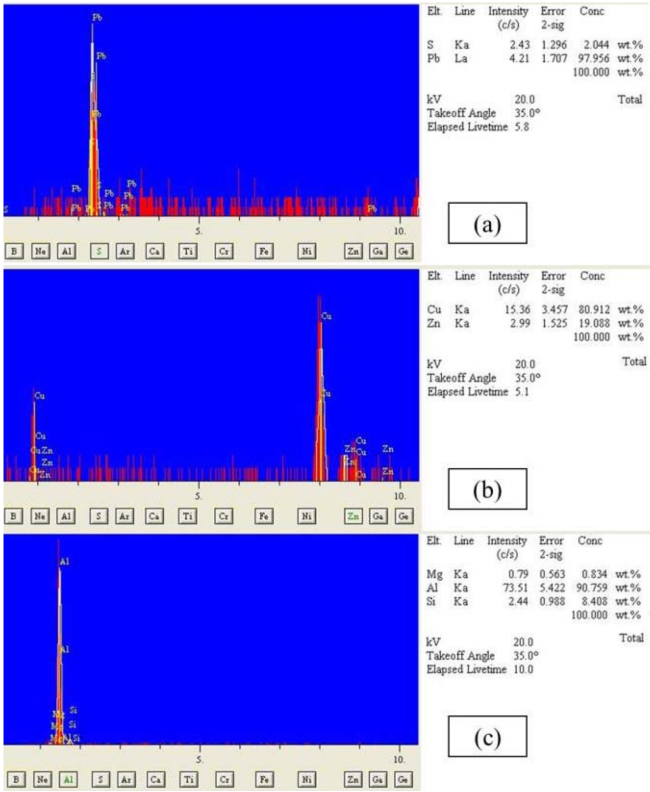

Figure 10. EDS images taken from number 1 (a), number 2 (b) number 3(c)

IV. CONCLUSIONS

The results obtained from studies on the production of the B_4C reinforced AA6061 matrix composite materials by TM method and the examination of the mechanical properties and ballistic performance are summarized below:

1. Density exceeding 99% was obtained after extrusion treatment.
2. When we look at the 5% B_4C reinforced composite material, it was observed that B_4C particles were homogeneously distributed in the matrix structure.
3. The average hardness value of AA6061 was calculated as 55 HB, and the average hardness value of 5% B_4C reinforced composite materials was calculated as 56.6 HB.
4. When we look at the cross-sectional view of the specimen after the test, it is seen that the bullet has collapsed at the end of the material and cannot go out. Therefore, it proved that AA6061 and 5% B_4C extrusion sheet with a total thickness of 50 mm put on top of each other can be used as ballistic protective armor material.

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