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FAILURE AND DAMAGE ANALYSES OF AL-7075 MATRIX COMPOSITE REINFORCED WITH SiC_p AFTER BALLISTIC IMPACT

KARAMIŞ M.B[*]., CERİT A.A[**]., NAİR F.[***]

ABSTRACT

Metal matrix composite (MMC) materials used for a wide range of construction elements can also be used in making armour. In this work, failures and damages of Al-7075 material composed of SiC particle reinforcements were investigated after ballistic impact.

Metal matrix composite samples were manufactured by squeeze casting method. The reinforcing particles in the matrix material have 20 % volume fraction and in average size of 350 µm. After the reinforcements were incorporated in to the liquid matrix material at 800 ºC, they were stirred by a rotating rod in order to achieve the homogeneous, mixture in a steel mould having composite target dimension of 120 mm in diameter and 20 mm thickness. The composite materials at 650 ºC were solidified under the pressure of 180 MPa.

The ballistic tests of the composite targets were carried out with the 7.62 mm projectiles having velocities of 800 m/s. The distance between the targets and running position of the projectile were 15 m. Al-5083 materials were used as backing blocks during the ballistic tests.

The macrograph of the craters and holes created by high velocity projectiles are analyzed by light and scanning electron microscopy studies. After the ballistic test, deep craters on the both sides of the target surfaces and some damages such a petalling, bulging and cracking were observed at the entrance and exits of the hole on the targets.

Key Words: Ballistic, Armour, Damages, Metal Matrix Composite

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[*] Professor, Dept. of Mechanical Engineering, Erciyes University, Kayseri, Turkiye
[**] Research Assistant, Dept. of Mechanical Engineering, Erciyes University, Kayseri, Turkiye
[***] Assistant Prof., Dept. of Mechanical Engineering, Erciyes University, Kayseri, Turkiye

1. INTRODUCTION

The new inventions and researches in material science create the new technological developments [1]. Nowadays, the material science is not only an engineering branch but it also interests in to subbranches such as metals, non-metals, chemicals, organics and polymeric science. Composite materials have an importance in the sub group and they have newly and special application areas in the use of engineering components. Now, aerospace, automotive and textile industries consider widely to use by acceptation with importance of composite material such as polymeric and metal matrix composites [2].

As a general definition, the composite materials are obtained by the mixing of two different materials at least, such as, metallic, organic or inorganic materials, one of them is matrix other one is reinforcement. Thus, the new composite material has better properties than those of its components separately. Therefore, the composite material has different physical and mechanical properties from matrix and reinforcement materials. The wide application to make a composite material is the mixing of different materials in the form of fiber or particle in to the matrix material. Thus, mixed but a new composite material is obtained [3-6].

Military transport aircraft are often required to operate in support of peacekeeping and evacuation operations where there is a significant risk from attack. Electronic defensive aids may be employed to counter guided weapons, however, in low intensity conflicts there is a continual threat from sniper fire [7].

Armour protecting panels are used in engines, flight deck, gunner station, transmission areas, pilot seats and cockpits. These panels are applied on Boeing Ch47, Augusta, Sikorsky UH60 Blackhawk and C130 Hercules aircrafts [7, 8].

A number of RAF C-130 Hercules aircraft had armour protection fitted around the cockpit to protect the flight crew. The armour was manufactured by Aero Consultants UK Ltd and consisted of glass ceramic tiles bonded to an aramid composite backing. This was fitted over the existing aircraft structure around the cockpit to protect the crew and the vital aircraft systems. The armour system was not expected to support load and was simply bolted over the existing plywood floor. A typical armour kit covered 18.2 m^2 of the cockpit walls and floor with a total weight of 585 kg.

The armour panels fitted to C130 Hercules aircraft were designed as a removable system that was placed on top of the existing plywood floor panels. Although this allows removal and consequent weight saving when the aircraft is used in peacetime, it represents a considerable parasitic mass from a structural standpoint. When armor installed as a floor system, the backing material would be uppermost with the spall shield at the lower surface. Normal loads on the floor would produce a tensile stress in the lower face of the ceramic and the spall shield. The low toughness of the ceramic and relatively low strength of the spall shield would normally be insufficient to support the floor loads. However, if the spall shield was thickened or made from a stronger material then it would be possible to produce a system of considerable strength. Such a system could permanently replace the existing plywood floor panels and would support all structural floor loads in addition to providing armour protection.

The armour manufacturer proposed a modified armor system with an aluminium face bonded to the glass ceramic in place of the GFRP spall shield [7].

The fiber reinforced composites have also some advantage such as higher strength, young modulus and lower weight while they have relatively higher cost. On the one hand, the particulate reinforced metal matrix composites (MMCs) have advantages such as higher young modulus, strength, hardness and wear resistance in comparison with the monolithic metal equivalent. However, they have some disadvantages such as lower toughness, higher cost, more difficult machining, etc according to their component. It is understood that there is not sufficient research about the ballistic behaviours of these two structures. Therefore the purpose of this study is to investigate the damages created by projectile on the Al matrix composite material [6].

2. EXPERIMENTAL WORK

2.1 Materials

In this study, Al-7075 aluminium alloy widely used for ballistic applications was chosen as the matrix material. The chemical composition of the matrix material is given in Table 1. For reinforcement of the matrix material, SiC particles having average size of 350 μm with 3,1 gm/cm^3 density was used as 20% volume fraction.

The manufacturing process of the composite was the squeeze casting method. Firstly, the molten Al material was poured at 800º C in to the steel mould with 120 mm in diameter made from H13 steel. And then SiC particles were mixed with molten material by stirring in the mould. The stirring process was continued until the molten material reaches to nearly solidification temperature. Following the stirring process, the mixed material was pressed in the mould (squeeze casting) under the pressure of 180±10 MPa. The pressing load was applied until the material was solidified completely. The thickness of the composite sample was 20±3(mm).

2.2 Ballistic Tests

The ballistic tests were carried out on the composite sample appropriate to the NIJ test standard. In the test, G3 type long barrel rifle with AP 7,62x51 mm armor piercing projectiles were used. The projectile average speeds were 800±20 m/s.

While distance between rifle barrel and the composite target were 15 m, the temperature of military polygon and humidity were 21º C and 65% RH, respectively. The test stand and the distances are given schematically in Fig. 1.

Al-5083 backing plate with 800x200x20 mm in dimensions was used for supporting the composite target and to evaluate the damage mechanism and type on the target. If the projectile passed to the target by drilling, the backing plate was utilized for obtaining information about the ballistic capacity of the target.

3. RESULTS AND DISCUSSIONS

The microstructure of the composite material manufactured for this study can be seen in Fig. 2. It is clear that the SiC particles are dispersed homogenously in the structure. This is very important factor for the ballistic performance of the target.

To evaluate the impact behaviour of the reinforced samples together with backing and unreinforced Al-7075 materials, during the ballistic tests, the backing plate and base material mentioned above were subjected to the projectile impact under the same condition with the target samples. An impact deformations on the backing plate and base material can be seen in Fig. 3. When the near edge area of the projectile holes are examined, the petalling, which is caused by the punching effect of the projectile due to the swelling of the edge material on the hole entrance, can be observed clearly on the both samples (fig.3 a and b), This swelling area has also some cracks caused by the rapid material deformation as circular from the impact axis to free area. Since the projectile behaves like a piercing punch, the material compressed during the piercing is swelled as petal near edge of the hole entrance. Fig.3 c shows the back side of the backing plate used with Al-base material tests. It is clear that the projectile passed through both Al base sample and backing plate. The back side of the backing plate has large swelling without any cracking because of toughness of the material.

During the projectile movement, some material through out the thickness of the composite target is compressed by the punching effect in the radial direction of the hole. Because, the body material present on the hole center before the impact is deformed rapidly by exceeding the yielding stress of the matrix material [9]. If the target material is not softer relatively, similar to backing material, some craters can be observed on the impact area of the projectile. Some cracks at the back side of the impact area may be occurred because of the impact effect.

The damages on both sides of the Al-7075 composite target containing 20 % SiC can be seen in Fig. 4a and b. It can be seen from the figure that the target could stop the projectile with both some craters on the impact area and some cracks on the back side of the impact axis. The impacted projectile to the target can be seen already in the body (Fig. 4a) with the projectile jacket, made from cupper alloy, on the steel core. In comparison with the backing material damage, it can be seen that while the crater and cracks are occurred on the composite material, only petalling is created on the backing material without any cracking (fig.3). Because, the SiC particles cause the brittleness of the composite material and yielding can not be observed on the metal matrix composites after the projectile impact. Therefore, the radial cracks are observed by the impact effect of the projectile on the back side of the composite target because of using the backing plate (Fig. 4b).

Further more, although the backing plate is put on the backside of the target, the large swelling also became with some cracking at the back side of the impact axis (interface between target and backing plate) even tough the projectile passes to the target (Fig. 5a). Because, the compression waves and stress occurred very fastly on the impact zone cause to the swelling and cracking of the backside of the brittle target relatively and to big crater at the front of the relatively soft backing material (Fig. 5b). In addition, the projectile velocity differences in allowance (780 -820 m/s) occurred during the firing may cause to different damages although the tests were carried out with backing plate.(cracks in fig.4 and penetration in fig.5)

During the movement of projectile in the composite body, the SiC particles can scratch the projectile surface and the speed of the moving projectile is decreased by this strong friction in the body. It is understood easily that the higher volumetric fraction of SiC particle causes stronger friction between projectile and hole surface. Therefore, if the target has SiC particles higher volumetric fraction, the target gets brittle but the projectile moving in to target body is slowed and its body is deformed, scratched and its direction may also be changed by the SiC particles.

This strong friction between projectile and target body causes to the leaving of the projectile jacket at the hole entrance. Since the SiC particles lead to increasing of composite strength and brittleness, the deformation capability of the target decreases and the brittle cracking at the impact area is occurred during the projectile impacting. Therefore the projectile and/or its jacket is caught, but the projectile impact energy is converted to cracking at the impact area instead of plastic yielding (swelling) (Fig. 6a). Sometimes, the projectile jacket is caught by the strong body material at the entrance of the hole, while the projectile core is stopped at the body depth (Fig. 6b).

The hole surfaces, where the high velocity friction occurs, can be rapidly melted by the excess heating caused by the friction. The molten matrix materials with some SiC particles are adhered to the projectile surface and also cause to decrease the projectile velocity. The hole section created by the projectile is given in Fig. 7. It can be seen from the section that the entrance surface area rubbed with a higher velocity projectile is bright and it has some melted and rapidly solidified areas (Karamış area [10,11]) and there are also craters on the both sides of the hole.

Another target damages created on the Al-7075 matrix composite reinforced by 20% SiC can be seen in Fig. 8. on the entrance and the exit sides of the target supported by the backing plate. While the big crater and some cracking are observed on the entrance side of the hole, the rising area with deeper cracking is occurs on the back side of the hole.

If the impacting is established on the target without backing plate, the damages occurred at the entrance and exit side of the hole are severe as can be seen in Fig. 9. Because, in the case of using backing plate, some of the impact energy is consumed by the backing material while the energy is reacted to the target itself. Therefore, the target without backing plate experiences severe damages than that of the other one.

4. Conclusions

The results derived from this study can be summarized as follows;

1. Al-7075 is a suitable material for producing Metal Matrix Composite reinforced with SiC particles.

2. When the projectile impacts with a high speed (i.e. 800 m/s) to an aluminium material, petalling is occurred at the surrounding of the hole created by projectile. On the other hand, if the impacting is created on an Al matrix composite reinforced by SiC particles with 20% volume fraction, the big crater with some cracking on the front side of the hole is occurred, while the swelling with cracking is observed on the back side of the hole.
3. During the movement of the projectile in the composite body, the SiC particles scratch the projectile surface and strong friction occurs between the projectile and the hole surface. This strong friction causes to decrease the speed of the projectile during its move in the hole.
4. The Al-matrix material and some SiC particles adhere to the projectile surface and they also decrease the projectile velocity. On the entrance side of the hole, the bright melted areas can be observed due to the relatively higher velocity friction.
5. The composite target can stop the projectile. However, the composite target can be cracked and some damages occur near the impact area, due to the relatively lower toughness and deformation capability caused by SiC particles.

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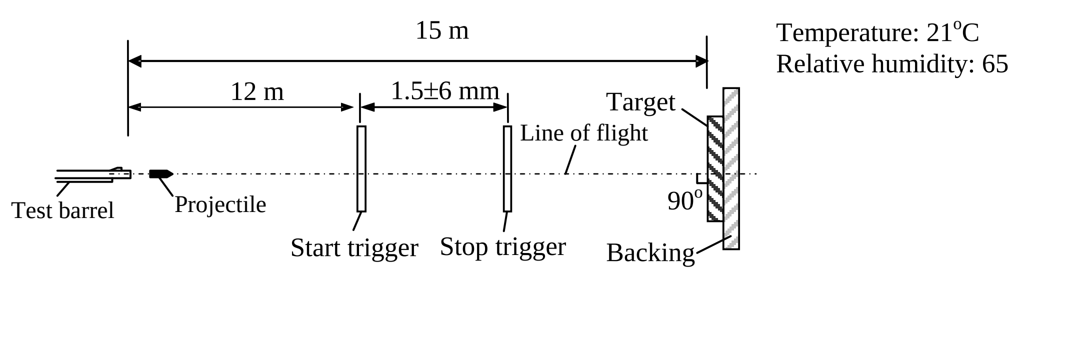
Table1. The chemical composition of the materials

Material	% Si	% Fe	% Cu	% Mn	% Mg	%Cr	% Zn	% Ti
Al-7075 (Composite Matrix)	0.4	0.5	1.2-2	0.3	2.1-2.9	0.18-0.28	5.1	0.2
Al-5083 (Backing Block)	0.4-0.7	0.4	0.1	0.4-1	4.0-4.9	0.05-0.25	0.25	0.15

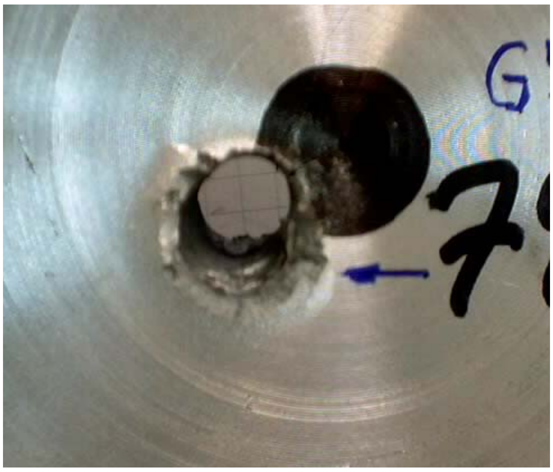


Rifle Type	**Projectile Type**	**Projectile velocity, m/s**	**Angle of incidence**	**Target material**
G3 (Germany Assault Rifle)	**AP** 7.62x51 mm (Armor Piercing)	800	90º	MMC (Al-SiC)

Figure 1. Ballistic test configuration and conditions

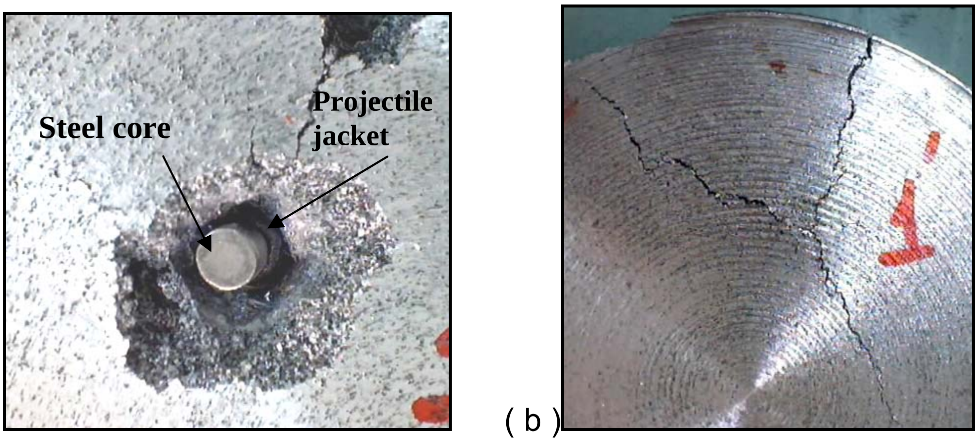
Figure 2. Composite structure

a) 

b) 

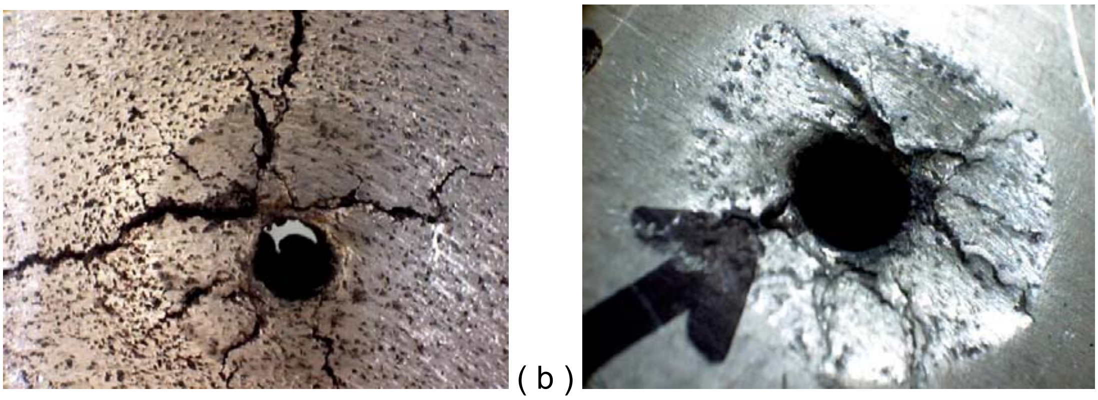
c) 

Figure 3. The deformations on the a) front side of the backing plate, b) front side of the unreinforced Al-7075, c) back side of the backing plate used with unreinforced Al-7075



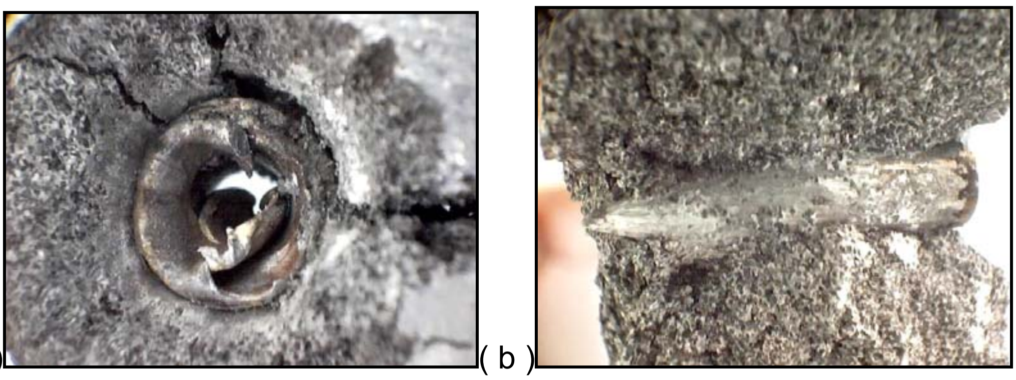
(a) (b)

Figure 4. Damages on the Al-20%SiC Composite target a) front surface b) back surface



(a) (b)

Figure 5. a) Damage on the back surface of the Al- 20%SiC Composite target,
b) Damage on the front surface of the Backing Plate



(a) (b)

Figure 6. a) The projectile jacket caughted by the target,
b) The projectile core caughted by the target

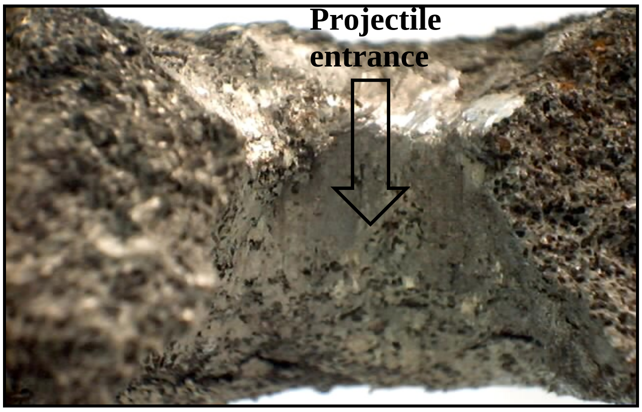


Figure 7. The hole created by the projectile

(a) 

(b) 

Figure 8. The damage on the Al- 20%SiC Composite target a) entrance of the projectile, b) exit of the projectile

Figure 9. The damage on the Al- 20%SiC Composite target without backing block