TESTING THE BALLISTIC RESISTANCE OF COMPOSITE MATERIALS

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Abstract

This article deals with the issue of the ballistic resistance of composite panels, which were made of para-aramid fiber. For the shooting tests was used Twaron CT 747 with epoxy matrix LG 700. This material is used for soft and hard ballistic protection. The composite panels were impacted by the missile 5.56 x 45 mm NATO FMJ M139 and by the missile 5.56 x 45 mm NATO FMJ SS109. To provide the required ballistic resistance in accordance with the US STANDARD NIJ 0101.06, the composite panels were impacted by the missile 7.62 x 51 mm NATO FMJ M80. The ballistic resistance of composite panels was verified through shooting tests in the experimental ballistics laboratory. Based on the ballistic tests, we monitored the extent of the damage, the spread of cracks and delamination of layers, which allowed the evaluation of the damage of these panels. The result of the shooting tests was the determination of limit thicknesses, in which the panels will not be penetrated. These results provide essential aspects for the development of new composite armor.

Keywords: Composite materials, Twaron, ballistic resistance, ballistic fabric, penetration

1. INTRODUCTION

Each army is equipped with ballistic equipments, which protect individuals and military equipment against the destructive effects of ammunition [1]. These ballistic equipments represent an artificial barrier that protects the target against the destructive effects of missiles, shrapnels and cold weapons. They are divided into soft ballistic devices worn on the human body (protective vest) and hard ballistic devices not worn on the human body (ballistic resistance panel) [1-3].

With regard to the development of firearms and ammunition, the demands on the ballistic resistance of these equipments against ballistic threats are increasing. In many cases the level of ballistic resistance is dependent on the weight of ballistic protection, which in turn affects the mobility of the subject on the battlefield [2-5].

There are a number of ballistic materials used for armoring military equipment. Metal materials such as steels, aluminium alloys, titanium alloys and non-metallic materials based on ceramics and ballistic resistant textiles and their combinations are most commonly used for ballistic protection [2,4,6,7]. The efficiency of ballistic materials depends on the method of processing materials, the structure and its properties [5,6]. The steels used for ballistic protection are characterised by a number of advantages. These advantages include the mechanical properties of steel and a wide range of thermal and chemical-thermal treatment. The effectiveness of steel armor depends primarily on strength, hardness, toughness and other characteristics that are given by alloying elements. For steel materials, their toughness decreases with increasing hardness. The main disadvantage of steels is their specific weight, which reduces the level of mobility of military equipment [6,8].

The current trend to reduce the specific weight, to increase ballistic resistance and mobility of military equipments is to use the composite multilayer armor. These armors are usually composed of two or more different materials with specific characteristics. The benefit of material is to reach disruptive new unique product with specific ballistic properties, which is characterised by better characteristics than the original initial material [2,9,10,11]. This combination of steel plates (Hardox®, Armox®, etc.), ballistic ceramics, panels of polyethylene with ultra-high molecular weight (Endumax®, Dyneema®, etc.) and panels made of solid fabrics. The most widely used solid fabrics for the manufacture of soft ballistic protections for the individuals are para-aramids with the trade name Kevlar® and Twaron®. It is aromatic polyamides with high strength. These materials are used for ballistic protection as woven material, which are characterized by high tensile strength, low density and high temperature resistance. They are also characterized by high resistance to chemicals, in addition to strong acids and bases**.** The use of solid fabrics offers a wide application not only for military purposes in the ballistic protection of an individual or a military equipment, but also for the manufacture of protective workwear resistant to fire, stabbing or cutting [1,2,11].

Testing of ballistic resistance of composite multilayer armor combined with ballistic ceramics, solid fabrics and fibers of UHMWPE material will be the subject of further development of composite ballistic protection resistant for missiles in military caliber 7.62 x 51 mm NATO.

The ballistic resistance of the composite panel of different thicknesses was studied in this article. The aim of the shooting experiment was to find the limit thickness of the composite panel resp. the number of layers in which this panel does not penetrate. A composite panel of Twaron CT 747 material was used in the experimental part. The ballistic resistance was shot by the missile 5.56 mm FMJ M139 and by the missile 5.56 mm FMJ SS109. The panel was also shot by the missile 7.62 mm FMJ M80 according to the American standard US STANDARD NIJ 0101.06.

2. MATERIALS AND METHODS

The examined material was Twaron CT 747. The material specifications of Twaron CT 747, which are specified by the manufacturer, are given in **Table 1**.

Table 1 Specification of the material Twaron CT 747

Material	Thickness (mm)	Area density (g/m^2)	Tensile strength module (GPa)	Composite density (kg/m^3)
Twaron CT 747	0.62	410	115	1450

2.1. Manufacture of panel from material Twaron CT 747

For the shooting experiment were made composite panels of Twaron CT 747 with different thicknesses and defined parameters, **Table 2**.

Table 2 Parameters of the composite panel Twaron CT 747 with matrix LG 700

Composite panel	Dimension (mm)	Number of layers	Thickness (mm)	Weight (kg)
Twaron CT 747 with matrix LG 700	300 x 300	60	32.4	3.80
		30	15.5	1.80
		20	10.6	1.15
		20	10.1	1.10
		10	5.5	0.65

The ballistically resistant Twaron CT 747 material was cut to the required size. Composite panels were produced by using the vacuum infusion, which is well described in the sources [12,13]. The preparation of the material for vacuum infusion and their subsequent vacuuming is shown in **Figures 1** and **2**. The matrix was used for the production of the composite panel. The matrix was consisted of the epoxy resin LG 700 and the hardener HG 700. The epoxy resin was mixed with hardener in a weight ratio of 100:30. All panels were cured at room temperature 22 °C for 24 hours. After curing and removal, the composite panels were cut with using abrasive machining waterjet to reach the final dimension of 300 x 300 mm. Five composite panels of 60, 30, 20, 20 and 10 layers were produced by vacuum infusion. The panel thickness with a total of 140 layers was 74.1 mm and its weight was 8.5 kg, see **Table 2**. The manufacturing process was repeated for all composite panels.

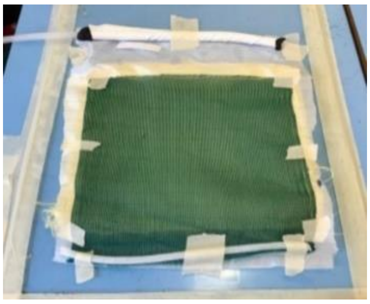

Figure 1 Preparation materials Twaron CT 747 for vacuum

Figure 2 Vacuum infusion process

2.2. Shooting experiment

To verify the ballistic resistance of composite panels was established a shooting experiment in accordance with the NATO military standard AEP-55 STANAG 4569 – Protection Levels for Occupants of Logistic and Light Armoured Vehicles [14]. This experiment was performed in the experimental ballistic laboratory at a reduced distance of 25 m.

To perform the shooting experiment was used the shooting station, which was consisted of the mobile shooting stool (STZA 12M1) with the universal breech (Prototypa-ZM, UZ-2002) and the exchangeable ballistic barrel (Prototypa-ZM, type: 5.56x45 mm NATO EPVAT and 7.62x51 mm NATO EPVAT). Ballistic radar (Prototypa-ZM, DRS-01) and optoelectronic gates (Kistler, 2521A) were used to measure the velocity of the missile on the flight path. For recording the effects on the target during the shooting experiment was used the high-speed camera (Photron, SA-Z) with reflectors for illuminating the scanned scene and for evaluating the effect was used recording devices. The technical equipments for the shooting experiment are shown in **Figure 3**.

a) b) c) d)

Figure 3 Technical equipments a) shooting stool with breech and barrel b) optoelectronic gates c) optoelectronic target d) high-speed camera

The arrangement of the technical equipments for the shooting experiment are shown in **Figure 4**. For the shooting tests the composite panel (sample) was fixed in the double frame.

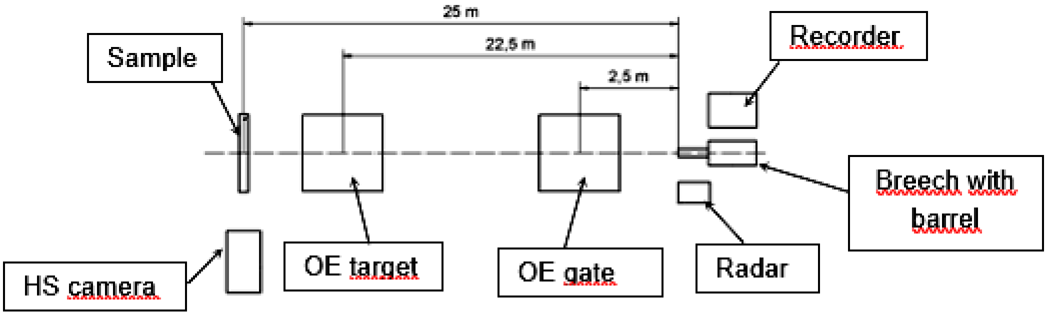

Figure 4 The arrangement of the technical equipments

For testing ballistic resistance of the composite panel was used rifle cartridges, which are shown in **Table 3**. These rifle cartridges were chosen based on NATO military standard AEP-55 STANAG 4569 for ballistic protection level 1 [14].

Table 3 Rifle cartridges according to NATO AEP-55 STANAG 4569, ballistic protection level 1

Cartridge type	Missile type	Missile weight (g)	Serial number	Manufacturer	V_{proof}* (m/s)
5.56 x 45 mm NATO	FMJ M193	3.55	138 FNB 07	FNH	937
5.56 x 45 mm NATO	FMJ SS109	4.00	25 SB 15	S&B	900
7.62 x 51 mm NATO	FMJ M80	9.55	1/82	S&B	833

* the impact velocity of the missile required by the standard, accepted range of individual velocity ± 20 m/s

3. RESULTS AND DISCUSSIONS

The following chapter is devoted to the results of the shooting tests. In terms of ballistic resistance verification, the panel was shot by the missile 5.56 mm M193 and SS109. To ensure the ballistic resistance according to the US STANDARD NIJ 0101.06, Level III, the composite panel was shot by the missile 7.62 mm FMJ M80.

3.1. Twaron CT 747 with matrix LG 700

The tested sample was the composite panel made of Twaron CT 747 with matrix LG 700. The thickness of this panel of 140 layers was 74.1 mm, and its weight was 8.5 kg, see **Table 2**. According to the NATO military standard AEP-55 STANAG 4569, three missiles were shot into the panel in sequence, see **Table 3**. **Figure 5** shows the position of the shots and it also shows the strike and back face of the composite panel with the number of 140 layers. Here it is evident that the total kinetic energy of the missiles was dissipated to delamination of the individual layers of the composite panel. There was no penetration of this panel.

Figure 5 Strike and back face of the panel Twaron CT 747 with matrix LG 700, 140 layers

Due to the non-breaking of the back layer (**Figure 5**), the Twaron CT 747 composite panel with matrix LG 700 was reduced to 90 layers and its thickness and weight also reduced. The purpose of this reduction was to find a limiting thickness without penetration of this panel. The thickness after reduction was 47.9 mm and its weight was 5.6 kg. To verify the ballistic resistance, two missiles 7.62 mm FMJ M80 were shot into this panel (**Figure 6**). After hitting the missiles on the back side of this panel was formed the plastic deformation, which indicates a traumatic effect. According to the US STANDARD NIJ 0101.06, the maximum value of the trauma effect is allowed up to 40 mm [15]. This deformation indicates that it is the limit thickness.

Figure 6 Strike and back face of the panel Twaron CT 747 with matrix LG 700, 90 layers

The results of the shooting experiment are given in **Table 4**. In **Table 4** the impact velocities of the missiles v_{25} are recorded by using ballistic radar (Prototypa-ZM, DRS-01), their kinetic energy, when the missiles hit the panel E_{K25} and the output velocities v_{out} are recorded by using a high-speed camera (Photron, SA-Z).

Table 4 Measured impact and output velocities of rifle missiles

Sample	Number of layers	Missile type	V_{25} (m/s)	V_{out} (m/s)	E_{K25} (J)
Twaron CT 747 with matrix LG 700	140	5.56 mm FMJ M193	946.4	0	1567.6
		5.56 mm FMJ SS109	915.5	0	1676.2
		7.62 mm FMJ M80	825.1	0	3250.6
	90	7.62 mm FMJ M80	829.8	0	3287.8
		7.62 mm FMJ M80	839.1	0	3361.6

4. CONCLUSION

In this study was investigated the ballistic resistance of the composite panel from the material Twaron CT 747 with matrix LG 700. This panel with different thicknesses was shot by the rifle missiles, see **Table 3**. The aim of this study was to determine the limit thickness for ballistic resistance guaranteed by US STANDARD NIJ 0101.06, level III. From the shooting experiment were obtained the following results:

The composite panel made of Twaron CT 747 with matrix LG 700 of 140 layers with the thickness 74.1 mm was not penetrated by the missile 7.62 mm M80. The deformation on the back side of this panel did not appear, so it was not possible to determine its limit thickness. The weight of this panel was 8.5 kg. The panel was reduced to 90 layers to determine the limit thickness. The thickness of the panel was 47.9 mm and its weight was 5.6 kg. After impact of the missile 7.62 mm M80 with an impact velocity of approximately 830 m/s, a plastic deformation was formed on the back of this panel, which indicates that this is its limit thickness. The composite panel Twaron CT 747 with matrix LG 700 matrix after reduction with the total thickness of 47.9 mm complies with ballistic resistance to the American standard US STANDARD NIJ 0101.06, level III.

This knowledge gained from the experimental part will be used for further development of armor in the military industry with regard to ballistic protection. To increase the ballistic resistence we will focus in the publication of further articles on multilayer composite armor, which will be composed of para-aramid fabric, ultra-high molecular weight polyethylene (UHMWPE) and a ceramic plate.

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