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INVESTIGATION OF BALLISTIC PERFORMANCE OF LAMINATED HYBRID COMPOSITES

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Abstract: *In this study, the usability of layered hybrid composite as personal armor material has been investigated experimentally. In the scope of study, 4 hybrid composite materials with different thicknesses and number of layers, have been produced by using fabric with two different weaving type as plain and twill. Then, ballistic tests have been performed and the test results have been investigated. First, 2 test samples with [$Glass_{10}$/$Aramid_{10}$/$Carbon_{10}$] lineup and 30 layers have been produced, the ballistic tests have been performed and the results have been investigated. After observing the success of these two test samples, other two test samples have been produced by reducing the number of layers to 21 with [$Glass_{10}$/$Aramid_{10}$/$Carbon_{10}$] lineup. The ballistic tests have been conducted by using Beretta and 9 mm FMJ bullet according with the international standards (NIJ 0101-06). In the ballistic tests, the speed of bullets and the depth of penetration (DOP) accuring on the test samples have been measured and the damages have been assessed.*

Keywords: Hybrid composite, Ballistic performance, Armor material

1. Introduction

A composite material can be defined as obtaining a new material by combining two or more different materials. The purpose is to improve the weak properties of materials and to obtain a new material with better characteristics.

With the expansion of armament, mankind started to use protective armors and shields for defending. They made wars and used weapons and the technology of armors (Yavaş, 2009). Rapidly developing weapons technology has gained a new perspective with the invention of gunpowder and firearms. While the size and the weight of weapons decreased the effect and the range of them increased. Parallel to this, it has been aimed to increase the mobility with lighter body armor systems by investigating flexible materials with light in weight and also, to ensure protection against specific threats.

Temiz (2005), in his experimental study, produced a soft composite structure by using para-aramid and PBO fiber fabrics and a rigid composite structure by using para-aramid and E-glass fiber fabrics hardened with epoxy resin. He performed ballistic tests on these structures and investigated that rigid composite structure couldn’t provide reasonable protection against the bullets used in the test, while soft composite structure exhibit appropriate protection with a higher ballistic resistance.

In a study conducted by Özgültekin (2012), ballistic resistance of polypropylene honeycomb structure reinforced with aramid fiber, carbon fiber and epoxy resin and composite materials produced by using steel sieve wire laminated with epoxy resin were investigated. As a result of ballistic tests, it has been investigated that the combination in which Kevlar is in the rear of the layers, has failed due to the flexible property of Kevlar. Because the bullet has been able to punch the layers as Kevlar has not been reinforced with any other layer. The layered structure combined of three different materials has been investigated to exhibit better results and the test sample in which the Kevlar has been used as middleware material has exhibited a significant resistance to the bullet.

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In this study, to improve the personal protective armors used for defense has been aimed. With this study, experimental background for applications of personal protective armors with lighter and better protective properties has been presented and different ideas for making new armor combinations have been discussed.

2. Methods

In the experimental study, four hybrid composite layered structures were used, that have been produced in Firat University Mechanical Engineering Mechanical Laboratory by using hand lay-up method. In the production process of the test sample, carbon, glass fiber with two different weaving types as plain and twill and aramid fiber with plain weaving type as reinforcement material have been used. As matrix component Hexion MGS L326 Polyester Resin and Hexion H265 Hardener have been used.

After spreading the materials by using hand lay-up method, the mold has been inserted into a hydraulic press and pressed at 30 bar pressure. In the pressing process, the test sample has been cured by increasing the temperature gradually from 20C° to 110C° in 4 hours. The structure of layered hybrid composites used in the ballistic tests is shown in Figure 1. All of the ballistic tests have been carried out in the form of glass fiber, aramid fiber and carbon fiber from the front layer to the rear layer respectively.

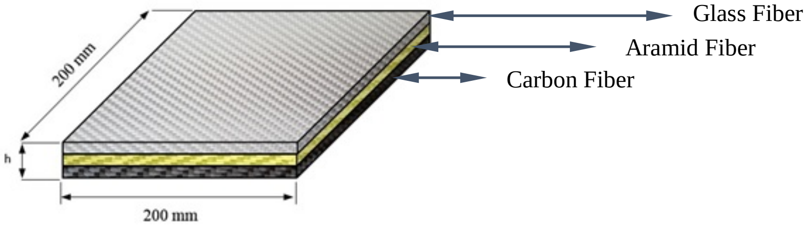

Fig. 1: The schematic of the structure of [Glass/Aramid/Carbon] layered hybrid polyester resin matrix.

Ballistic tests have been carried out by considering some standards. In the expermental study, National Institute of Justice (NIJ) has been taken as reference in the tests of the ballistic performance of composite samples. According to NIJ 0101.06 Level II-A standard, in the shots from 5 m by using 9 mm FMJ bullet, the bullet speed has to be 373 ± 9.1 m/s (NIJ 0101.06). According to NIJ 0101.06 standard, to consider the test sample successful, the bullet used in the test have to stay in the test sample and the depth of penetration have to be maximum 44 mm. For the depth of penetraion above 44 mm, the test sample is considered to be unsuccessful even if it is not punctured. The speed of the bullet has been determined by using Chrony F1 Master choronograph in the tests. The ballistic tests have been performed by the same person to make sure that carrying out the tests in the same condition. The experimental setup is shown in Figure 2.

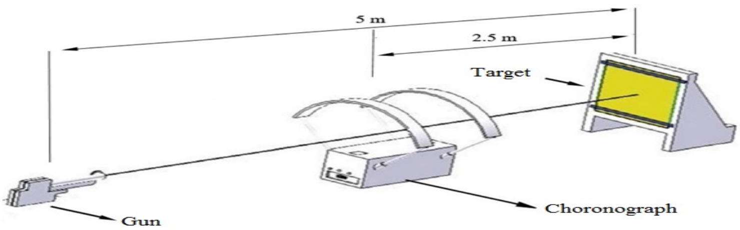

Fig. 2: The ballistic test system.

3. Findings

In this study, the ballistic tests of produced samples with the reference of NIJ 0101.06 standard have been performed. In the first stage of the study, two 30 layered hybrid composite structures with [Carbon(plain)$_{10}$/Aramid(plain)$_{10}$/Glass(plain)$_{10}$] and [Carbon(twill)$_{10}$/Aramid(plain)$_{10}$/Glass(twill)$_{10}$] lineup have been produced and the ballistic tests have been performed. The photos of the 30 layered test samples after the ballistic tests are shown in Figure 3 and Figure 4. After the ballistic tests, the test samples have been checked whether they are successful or not.

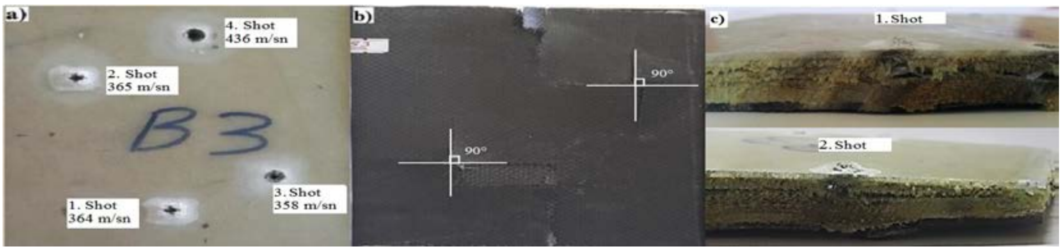

Fig. 3: B3 [Carbon(plain)$_{10}$/Aramid(plain)$_{10}$/Glass(plain)$_{10}$] test sample.

In the tests, the average bullet speed of the shots to B3 test sample with [Carbon(plain)10/Aramid(plain)10/Glass(plain)10] lineup has been determined 381m/s and the average depth of penetraion is 7.93mm. The depth of penetraion of the test sample indicates that the sample is in the ballistic limits without perforation. This test sample provides protection according to NIJ Level II-A standard. Fiber damage has been occurred in both horizontal and vertical directions becaouse the carbon fiber fabric has been in the rear of the test sample in plain type.

Fig. 4: B4 [Carbon(twill)$_{10}$/Aramid(plain)$_{10}$/Glass(twill)$_{10}$] test sample.

In none of the shots to B4 test sample, perforation has happened and this sample is successful. Carbon fiber fabric used as supporting plate at the rear of the test sample has not been damaged. B3 test sample has been determined 384 m/s and the average depth of penetration is 5.49 mm. This test sample provides protection according to NIJ Level II-A standard.

With protection property, another important factor in ballistic armor design is lightness property. Taking account of lightness property, after observing the success of firs two test samples, in the second stage other two test samples have been produced by reducing the number of layers to 21 and the ballistic tests have been conducted. The photos of the 21 layered test sample after ballistic test are shown in Figure 5 and figure 6.

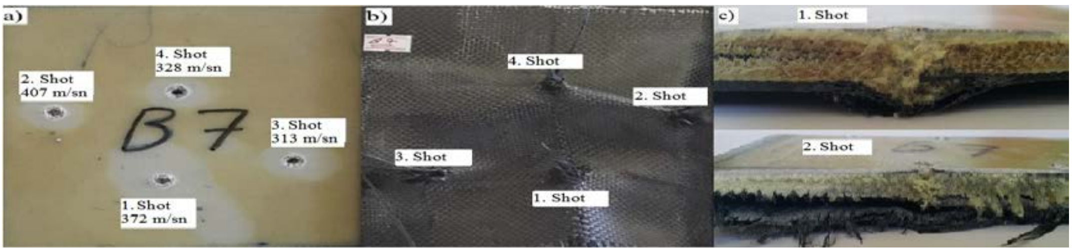

Fig. 5: B7 [Carbon(plain)$_7$/Aramid(plain)$_7$/Glass(plain)$_7$] test sample.

The bullet speeds of shots to B7 test sample have been between 313 m/s and 407 m/s. All of these shots have resulted with perforation and the samples have been unsuccessful.

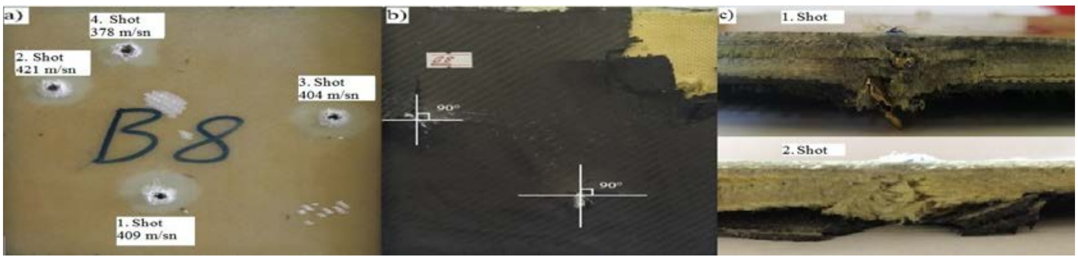

Fig. 6: B8 [Carbon(twill)$_7$/Aramid(plain)$_7$/Glass(twill)$_7$] test sample.

Perforation has been occurred in the Shot-1 and Shot-2 of 4 shots to B8 test sample with speed of 409 m/s and 421 m/s respectively. In the shots no puncture has occurred due to the carbon fiber fabric in the rear of the test sample is in twill type, fiber damage has been occurred in both horizontal and vertical directions. Carbon fiber plate has ruptured with Shot-2. In the Shot-1 damage has been occurred in fiber fabric due to twill weaving type and also, perforation has been observed. The average bullet speed has been 391 m/s and the average depth of penetration has been 8.75 mm of all shots accept Shot-1 and Shot-2 in which perforation has been occurred.

4. Conclusions

In this study, test samples have been produced to investigate the usability of layered hybrid composites as personal armor material. Ballistic tests of these samples have been performed with the reference of NIJ.0101-06 standard and the results of the tests have been investigated. The structural configuration of the test sample and the evaluations of the ballistic test results are given in Table 1.

Tab. 1: The ballistic test results

Test Sample	Material	Layer Number	Thickness (mm)	Mass (gr)	Evaluation Criteria
B3	***[Carbon(plain)$_{10}$/Aramid(plain)$_{10}$/Glass(plain)$_{10}$]***	***30***	***9***	***550***	***II-A***
B4	***[Carbon(twill)$_{10}$/Aramid(plain)$_{10}$/Glass(twill)$_{10}$]***	***30***	***9.5***	***598***	***II-A***
B7	***[Carbon(plain)$_{7}$/Aramid(plain)$_{7}$/Glass(plain)$_{7}$]***	***21***	***6***	***372***	***Puncture***
B8	***[Carbon(twill)$_{7}$/Aramid(plain)$_{7}$/Glass(twill)$_{7}$]***	***21***	***7***	***432***	***Puncture***

B4 with [Carbon (Twill)10/Aramid(Plain)10/Glass(Twill)10] lineup has been observed to be the most successful of 30 layered test samples in the ballistic tests.

After observing success of 30 layered hybrid composites in the ballistic tests, the layer number has been decreased to 21 from 30 and the ballistic tests have been performed for these samples.

None of the 21 layered test samples have been successful in the ballistic tests.

By considering the results of all test, twill weaving fabrics have been determined to have better ballistic resistance from plain weaving fabrics.

The damage types have been investigated after the ballistic tests and damage of fiber and separation of layers have been observed to be the most common damage types.

Behind the protection property, another important factor in the design of armor material is lightness property. The successful test samples of the ballistic tests in this study can be recommended to study to reach an optimum weight and thickness with better ballistic resistance by reducing the number of layers for new armors.

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