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INVESTIGATION OF BALLISTIC PROPERTIES OF THREE PHASED FIBER HYBRID COMPOSITE STRUCTURE

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ABSTRACT

The basic mechanisms that are affecting an armor structure during high speed impact are very complicated. Each of these mechanisms with the effect of single or multi-parameter analysis is not possible. Effect of these mechanisms can be interpreted with energy absorbed during high speed impact. In this context, the ballistic study of composite plates manufactured by hand lay-up method, by layered with multi phased of cross-plied polyethylene material SB21 and plane waved Kevlar 129 and E-glass materials. Projectile velocities and back face signatures were measured by ballistic tests. It is aimed to investigate the ballistic properties of the samples that are 2 and 3 phased manufactured with different ballistic materials in different configurations. It is observed that shooting through the Kevlar 129 side caused to more energy absorption of the 3 phased systems respect to SB21 side.
Keywords: *High velocity impact, polymer matrix composite, ballistic properties*

1. INTRODUCTION

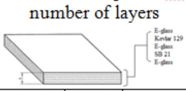
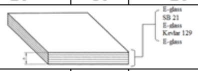
Fiber-reinforced polymer-matrix composites are the most-advanced and commercially-available materials. They are widely used in aerospace and defense-related industries [1]. Many of light-weight ballistic-protection armor systems are currently being made of “ballistic-grade” or “armorgrade” composites [2,3], known to have high specific modulus, high specific strength, high resistance to corrosion, low weight [4-6]. The constructed fibers such as aramid or oriented polyethylene fibers have an outstanding impact resistance [7,8]. The fibers, in the form of either woven fabrics or 0˚/90˚ cross-plied collimated continuous filaments, are embedded in the resin/polymer matrix. As a result of the very low resin content, these composites remain flexible to relatively high laminate thicknesses. Armor-grade composite laminates based on aramid fiber are widely used in hard personnel-armor systems, in ballistic protection by light-weight armored vehicles, helicopters and patrol boats [9,10].

2. MATERIALS AND METHODS

2.1. Composite Hybrid Panels

Our study was consist of two stages. In the 1st stage some group of samples had manufactured laminated as 2 phased with E-glass and Kevlar 129, E-glass and SB21. The number of plies in same lamination construction for each sample had changed with 10, 15 and 20. The number of plies of E-glass got constant as 10. At the 2nd stage, involving present study, some group samples were manufactured as 3 phased with Kevlar 129, E-glass and SB21. Kevlar 129, SB21 and E-glass layers were used like in the same way within the 1st group samples. For the 2nd group with identical pairs there were 6 samples. As the 2nd layers changing Kevlar 129 versus SB21 for the inverse sides of identical pairs, so shooting tests performed from opposite faces of each pair. Also a sample prepared by stitching 40 plies of Kevlar 129 and another sample prepared by hand lay-up procedure with epoxy resin matrix and 40 plies of SB21. Configuration of the panels are shown in Table 1.

Table 1. The Properties of Samples: The configurations of the constructed composite amours

The configuration of composite armor and the number of layers 					Composite sample's mass, g	Sample's thickness, mm	% Volumetric amount of fiber	% Volumetric amount of matrix
E-glass	Kevlar129	E-glass	SB21	E-glass				
10	10	10	10	10	1700	10,5	74,75	25,15
10	15	10	15	10	1950	12	78,75	21,25
10	20	10	20	10	2550	14	79,06	20,94
								
E-glass	SB21	E-glass	Kevlar129	E-glass				
10	10	10	10	10	1700	10,5	74,75	25,15
10	15	10	15	10	1950	12	78,75	21,25
10	20	10	20	10	2550	14	79,06	20,94

2.2. Ballistic Test Setup

Ballistic tests were performed with the approved test apparatus at the facility of Turkish Armed Forces in Afyonkarahisar, Turkey (Fig.1). The exact impact velocity of each projectile was measured with a chronograph before impacting the target. Six shooting tests for each case with different velocities were carried out reference of National Institute of Justice NIJ 0101.04 Level III and by 0˚ NATO Angle. If the bullets can't pass through the ballistic panels after shootings, a trauma is formed in the backing material at certain diameter and depth. The depth of this trauma shows the kinetic energy of the bullet transmitted to the back side of a panel. The bullets with 9 mm diameter were used in the shootings. Standard 0,41 g weight of gun powder in the core of the each bullet were changed for obtaining different shooting velocity.

3. RESULTS AND DISCUSSIONS

Our previous study the 2 phased samples including one phase E-glass with 3 layers, 10 plies each and the other phase is Kevlar 129 layers perforated. Also 2 phased samples of E-glass and SB21 that have alike configuration with E-glass and Kevlar 129 of which are having couple of layers in row with 10 and 15 plies of SB21 perforated. But the third sample that has 2 layers of SB21 with 20 plies each did not perforate [11].

In the present study, for 3 phased samples of which had shots from the face of Kevlar 129 as a second phase lamination after E-glass had success at protection as shown in Fig.2. 3 phased samples of which had shots from the face of SB1 as a second phase of layer in row after E-glass were nearly perforated, as shown in Fig.3. This results show that the ability of energy absorption and spreading this energy to the panel structure is more successful for Kevlar 129 than SB21. Delamination failure affects larger areas on polyethylene materials than fabrics (Table 2 and 3).
For all of the shots, the perforation doesn't occur for the 1st and the 5th shots. Even the system has almost reached the ballistic limit, the complete success has not been achieved because polyethylene SB21 has less energy absorption. By referring to the experimental results, SB21 whose stretching ability is higher in the direction of the material thickness. Damage becomes localized to the immediate area around the point of impact, and the transverse deflection of the fabric is minimal during impact of single Kevlar and UHMWPE yarn at high velocities, the yarn failed in shear. Fabrics with high friction and low effective moduli were observed to dissipate larger amounts of energy.

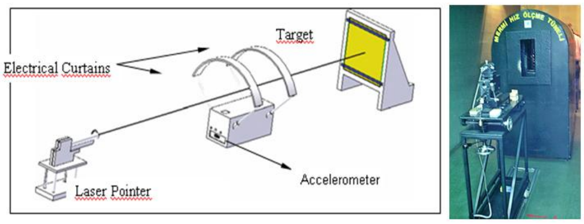


Fig.1. Ballistic test setup in the TAF facilities

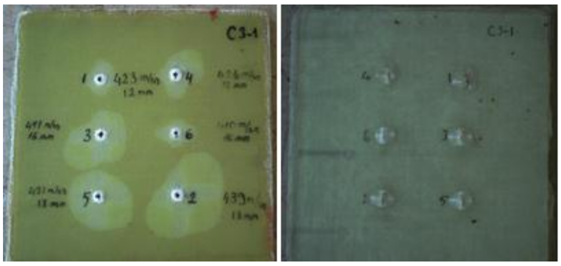


Fig.2. The sample of [[(E-Glass)$_{10}$ + (Kevlar 129)$_{10}$ + (E-Glass)$_{10}$ + (SB21)$_{10}$ + (E-Glass)$_{10}$]$_{60}$] material by which the shot tests were performed.

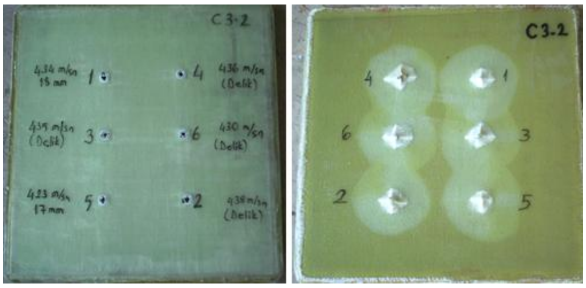


Fig.3. The sample of [[(E-glass)$_{10}$ + (SB21)$_{20}$ + (E-glass)$_{10}$ +(Kevlar 129)$_{20}$ + (E-glass)$_{10}$]$_{70}$] material by which the shot tests were performed.

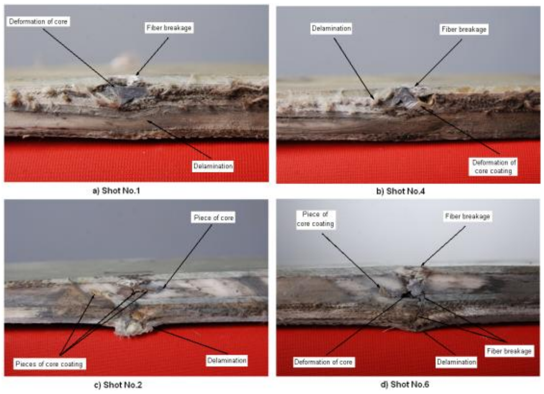


Fig.4. (a), (b): The cross-sectional images of the material in Fig.2
(c), (d): The cross-sectional images of the material in Fig.3.

Table 2. The test results of the shot tests for the sample of epoxy-resin-having [[(E-Glass)$_{10}$ + (Kevlar 129)$_{10}$ + (E-Glass)$_{10}$ + (SB21)$_{10}$ + (E-Glass)$_{10}$]$_{60}$] material

Shot No	V_m (m/sec)	E_K (Nm)	Debris Depth (mm)	Back Face Signature / Delamination Height (mm)	Back Face Signature / Delamination Diameter (mm)	Results
1	423	664.721	12	0.12	30	NIJ III-A
2	439	715,958	13	3,13	30	NIJ III-A
3	451	755,634	16	3,20	30	NIJ III-A
4	426	674.183	12	0,12	30	NIJ III-A
5	431	690.102	13	3,24	30	NIJ III-A
6	410	624.491	10	0,14	30	NIJ III-A

Table 3. The test results of the shot tests for the sample of epoxy-resin-having [[(E-glass)$_{10}$ + (SB21)$_{20}$ + (E-glass)$_{10}$ + (Kevlar 129)$_{20}$ + (E-glass)$_{10}$]$_{70}$] material

Shot No	V_m (m/sec)	E_K (Nm)	Debris Depth (mm)	Back Face Signature / Delamination Height (mm)	Back Face Signature / Delamination Diameter (mm)	Results
1	434	699,742	18	5,68	31	NIJ III-A
2	438	712,700	-	7,62	37	Perforation
3	435	702,970	-	6,68	37	Perforation
4	436	706,206	-	5,83	37	Perforation
5	423	664,721	17	5,25	31	NIJ III-A
6	430	686,903	-	6,76	37	Perforation

Polymeric composites are generally brittle and they absorb the energy in the elastic region only. In the test shots the primary fibers has breakage as long as they have reached their elongation value under the sudden impact. The layers close to the impact point have lower elastic properties for the reinforced composite samples. Therefore the stresses out of the plane are so sensitive when the load is applied. The type of ballistic damages may differ according to the structural properties of the test samples, the geometry, the speed and the mass of the bullet [12-14].

The deformations such as delamination, fiber breakage, interlayer separation, back face signature and matrix cracking occur in the laminated-composite samples after the shots. The normal stresses occurring between the layers cause the formation and the growth of these delamination as the bullet penetrates into the composite structure [15-17]. Moreover reduced material thickness in the direction of the bullet at the back side of the sample, where the perforation is not seen, results in lowering the reaction resistance against the bullet [18].

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