BALLISTIC PERFORMANCE OF FRP – STEEL LAYERED STRUCTURES

Wiesław Barnat, Paweł Gotowicki, Paweł Dybcio, Roman Gieleta, Krzysztof Kosiuczenko

Military University of Technology
Department of Mechanics and Applied Computer Science
Gen. Sylwestra Kaliskiego Street 2, 00-908 Warsaw, Poland
tel.: +48 22 6837201, +48 22 6839226, fax: +48 22 6839355
e-mail: wbarnat@wat.edu.pl, pgotowicki@wat.edu.pl, pdybcio@wat.edu.pl
rgieleta@wat.edu.pl, kkosiuczenko@wat.edu.pl

Abstract

In this study, the impact performance of layered structures made of aramid/epoxy, S2 glass/epoxy, Dyneema and steel subjected to high velocity impact is presented. All materials were previously examined using proper techniques of strength tests. The procedure allowed determining Young's moduli, Poisson's ratio, ultimate compression and tension strength, shear modulus. The ballistic test procedure was based on standards for testing panels and armour plates. For the purpose of ballistic tests, standard 5.56 NATO ammunition (183 g) was used. The aim of presented work was to determine ballistic performance of different structures under bullet impact. During the tests, subsequent time moments were recorded using Phantom V12 high-speed camera. When structure penetration did occur, the residual velocity of bullet was measured using PVM-21 lightscreen. Basing on the results, each material performance was evaluated. This paper reviewed a number of mechanisms that influence the ballistic performance of ballistic textiles. The composites reinforced with continuous fibres (aramid, S2 glass) could effectively absorb the kinematic energy of bullet. The efficiency of energy absorption for each types of material in the order from highest is as follows: polyethylene fibres Dyneema HB50, composite reinforced with S2 glass fibres, composite reinforced with aramid fibres.

Keywords: *ballistic performance, NATO 5.56, ballistic test, experimental technique, Dyneema*

1. Introduction

Ballistic performance of different materials is one of the most important information in armour design process. Determining ballistic limit is one of basic tests to determine usefulness of material. Armor systems have been conventionally monolithic, typically composing of a high strength steel plate. However, there is an increasing demand for the materials and multilayer material systems providing maximum ballistic protection at a minimum weight. Ballistic behaviour of textile fibres and fabrics has been investigated experimentally and ballistic behaviour of textile fabric systems has been estimated. The procedure for evaluation of each solution was based on NATO STANAG 2920 [1], MIL-A-46100-D [2] and MIL-Std-662F [3] standards. As well as that, other works concerning ballistic performance of composites were used [4, 5].

2. Test stand

For the purpose of experimental trials a ballistic test stand was used. It was designed in the Department of Mechanics and Applied Computer Science at the Military University of Technology. The stand allows observation of penetration process before and after examined sample. During the tests, the process was recorded using Phantom V12 high speed camera. Velocities before and after the impact were acquired using two PVM-21 lightscreens. Fig. 1-3 show elements of test stand. Fig. 1 presents sample mounted in test stand. Fig. 2 depicts high speed camera inside shield allowing observation. Camera is placed at certain angle and distance Fig. 3 shows a lightscreen measuring projectile velocity after impact. The accuracy of velocity measurement was ±0.2%. For the purpose of presented test, sampling rate for high speed camera was around 10,000 fps. Test stand was designed in accordance with standard [1] to provide proper target retention. During tests no backing material was used. The angles between target surface and strike face of the projectile formed an angle around 2° which makes the impact normal to the target surface. The impact point in each case was located in the centre of sample. Every impact point was at least eight projectile calibres from sample edge.

Experimental research was carried out in Ballistics Laboratory at the Military University of Technology using 5.56 mm ammunition and high precision barrel. Test procedure was based on standards [1-3]. Test programme consisted of 16 trials for different material types and thicknesses. Each trial was registered using high speed camera Phantom V12, projectile velocities were measured using lightscreens. Fig. 4 presents barrel used for the purpose of trials. During tests, standard SS109, 5.56×45 mm round (B-32) was used. The muzzle velocity of projectile was around 950 m/s.

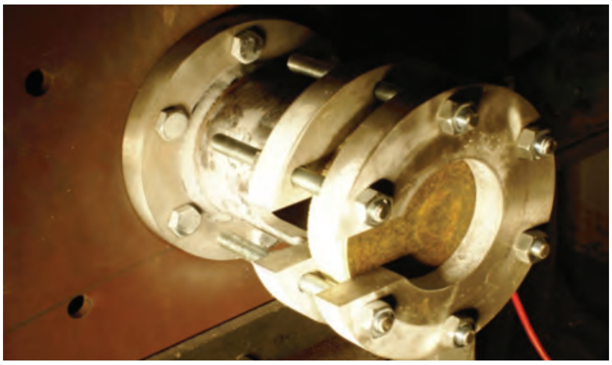

Fig. 1. Outlook of test stand with sample

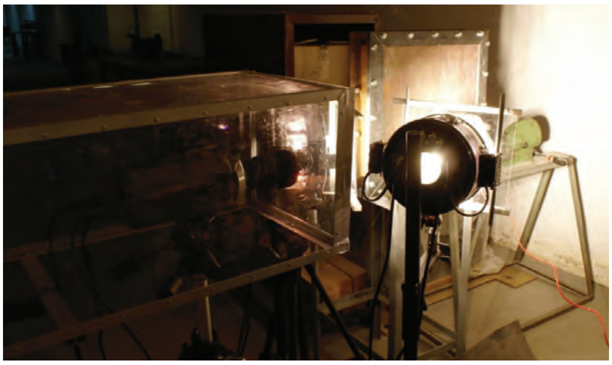

Fig. 2. Overview of test stand – Phantom V12 high speed camera

Fig. 3. Overview of test stand – PVM-21 lightscreen

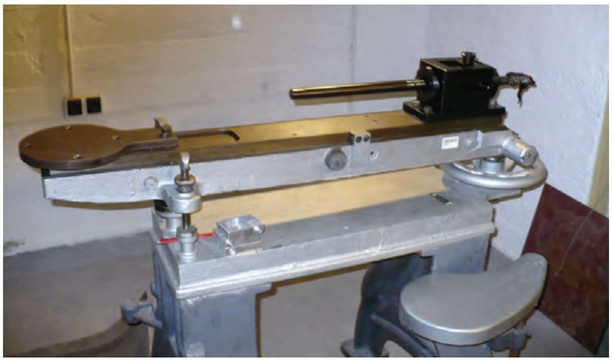

Fig. 4. High precision barrel

3. Materials

For the purpose of analysis 4 types of materials were taken into consideration. The literature study showed that their ballistic performance is the most likely to achieve aim of this study [4, 6]. The materials examined were:

– regular cross-aramid epoxy laminate configuration $(0/90)_n$. The matrix is an epoxy resin laminate. The laminate is reinforced by aramid fabric stitched progressive (producer SAERTEX GmbH & Co. KG) with the following parameters: Style S32AX010-00450-01270-239000, fiber Twaron HM, weight 457 g/m^2, warp/weft 161/161 tex;
– regular cross-aramid epoxy laminate configuration $(0/90)_n$. The matrix is an epoxy resin laminate. The laminate is reinforced by glass fabric stitched progressive (producer SAERTEX GmbH & Co. KG) with the following parameters: Style S32ZX00K-00520-01270-264000, fiber S2 Glass, weight 528 g/m^2, warp/weft 161/161 tex;

– Material Dyneema® HB50. The material consists of layers of polyethylene fibers in the form of tapes of a monotropic several millimetres width plain weave interlaced. The material was treated as an orthotropic material, symmetrical, balanced;
– HTK-900 steel.

All materials were previously examined using proper techniques of strength tests. The procedure allowed determining Young’s moduli, Poisson’s ratio, ultimate compression and tension strength, shear modulus using five tests: tension test in reinforcement direction (ISO 527), in-plane shear test (ISO 14129), out-of-plane shear test (ASTM D 5379) compression in reinforcement direction (ISO 14126) and compression in thickness direction (ISO 14126).

4. Results

As a result for each sample the ballistic performance was evaluated. Sample results of tests are presented in Fig. 5-7. Fig. 5 shows sample No. 1 before and after impact. Fig. 6 presents target sample retension, whereas Fig. 7 shows selected samples after the impact.

a) *b)*

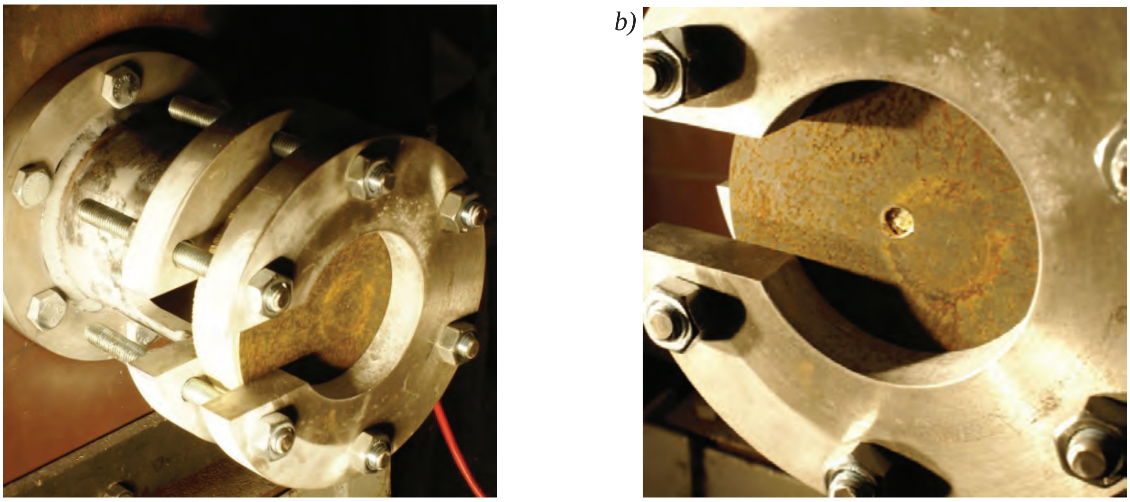

Fig. 5. Sample 1 before (a) and after (b) the test

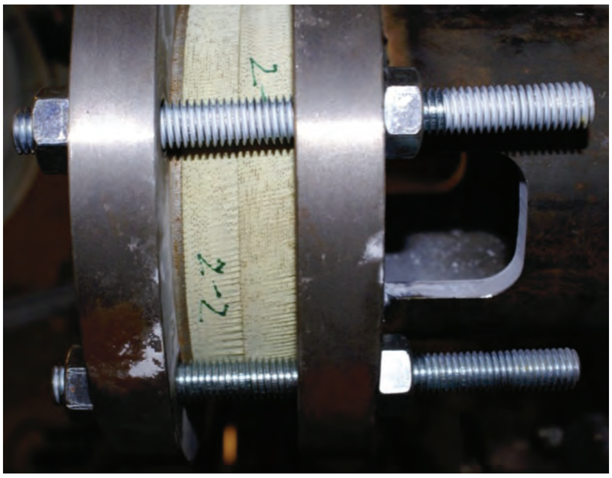

Fig. 6. Sample 2 mounted inside the test stand

Figure 8 and 9 shows sequences acquired using high speed camera for samples No. 2 and No. 1, respectively. In case 1, the penetration of sample did not occur. Fig. 8 presents penetration process for subsequent time moments. There are visible fragments of both sample material and projectile. Fragments of sample material are visible on both sides.

a) b)

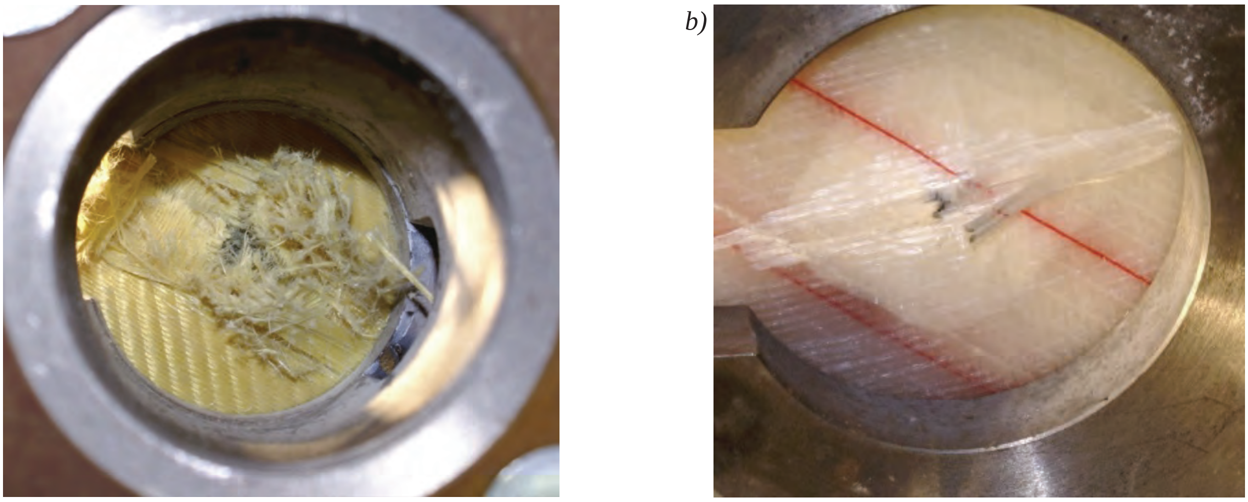

Fig. 7. Sample No. 3 (a) and No. 12 (b) after the test

a) b) c) d) e) f) g) h)

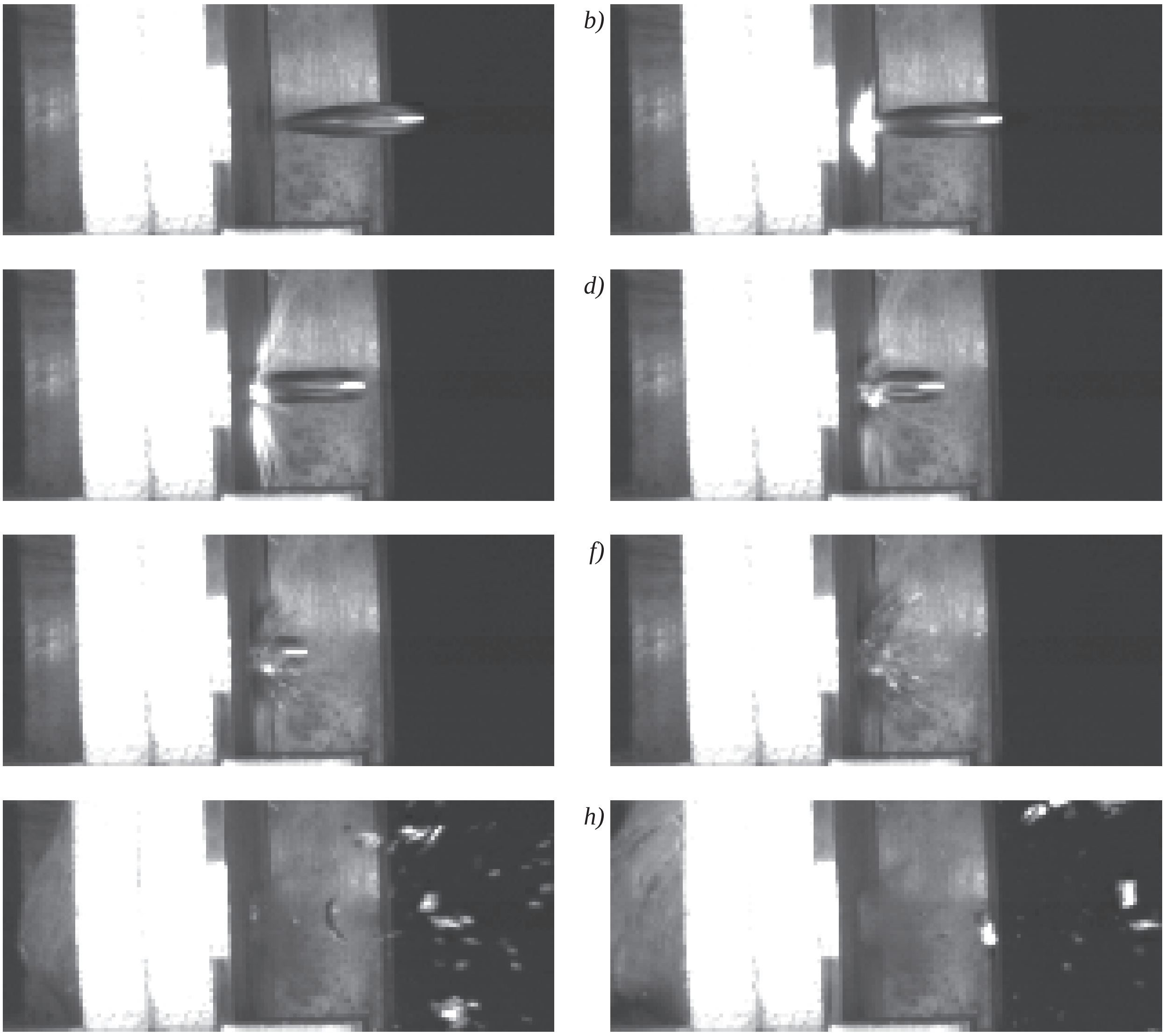

Fig. 8. Subsequent moments of the impact for the sample No. 2: 0.0 μs (a), 5.3 μs (b), 10.6 μs (c), 15.9 μs (d), 21.2 μs (e), 26.5 μs (f), 111.4 μs (g), 143.2 μs (h)

On the other hand, Fig. 9 shows projectile deceleration process for subsequent time moments. Visual inspection of sample after impact showed no perforation. Visualisation of penetration process will be used for verification and validation of numerical models. It also gives information about specific failure mod of each material. In Fig. 8, there is visible HB50 material with elongated fibres at time 111.4 μs and 143.2 μs. This failure mechanism shows good energy-absorbing properties due to large material area taking part in projectile deceleration.

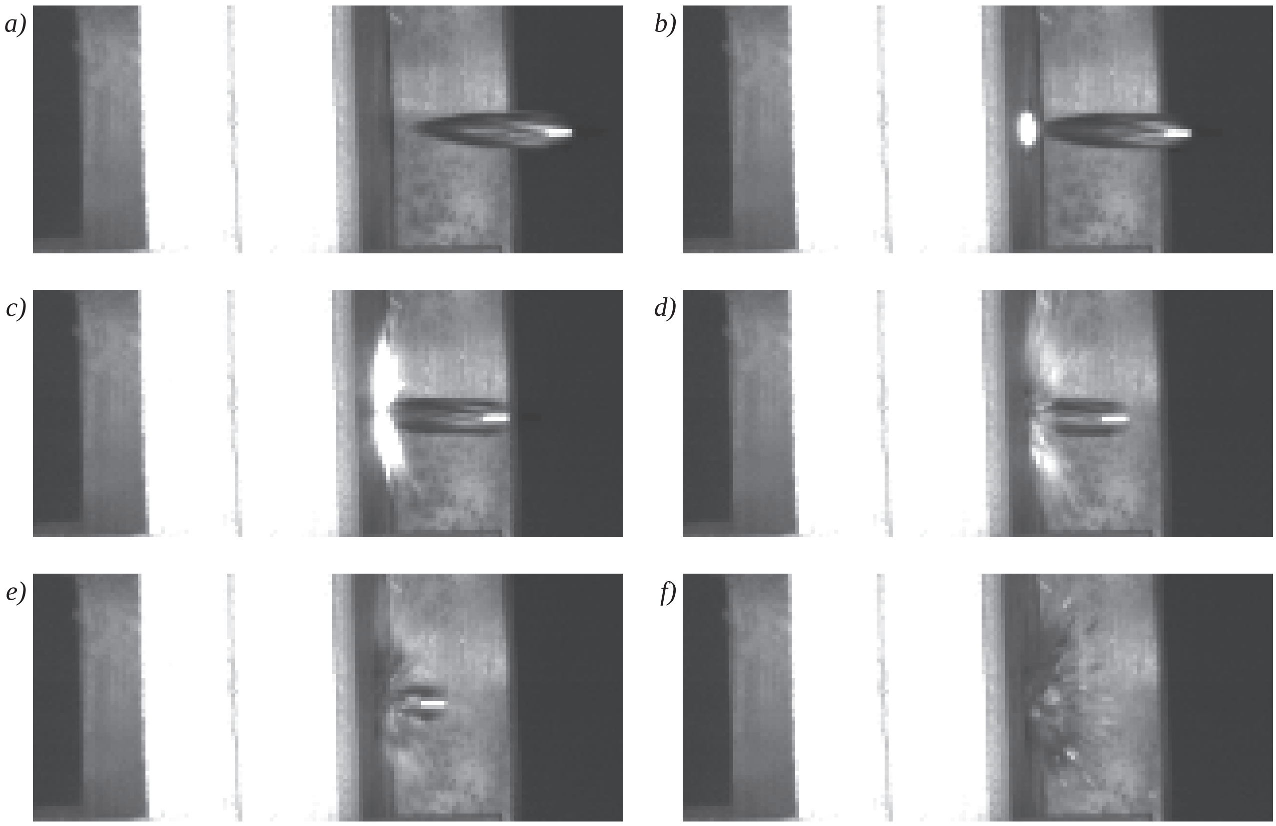

Fig. 9. Subsequent moments of the impact for the sample No. 1: 0.0 μs (a), 5.3 μs (b), 10.6 μs (c), 15.9 μs (d), 21.2 μs (e), 26.5 μs (f)

Table 1 presents results obtained during trials. For each case the layout of sample materials and thicknesses of each layer are given. When penetration of sample occurred, residual velocities of projectiles are given. The muzzle velocity of projectile was also measured, reaching 950 m/s with accuracy ±10 m/s. However, in case 12, the measurement of velocity was inconclusive. Each case is a possible solution for lightweight protective panel that can be used in light-armoured vehicles.

5. Conclusions

16 various samples were examined during the experimental tests. Each of them can be used in special vehicle design process. This paper reviewed a number of mechanisms that influence the ballistic performance of ballistic textiles. The composites reinforced with continuous fibres (aramid, S2 glass) could effectively absorb the kinematic energy of bullet. The efficiency of energy absorption for each types of material in the order from highest is as follows: polyethylene fibres Dyneema HB50, composite reinforced with S2 glass fibres, composite reinforced with aramid fibres.

For each types of material and adopted thickness, the combination of layers allowing total absorption the kinematic energy of ammunition was found. In terms of fulfilment the technical requirements and standards for protective layers which could be used in special cars there are a few possible solutions. The most interesting systems using polyethylene HB50 and S2 glass for protection against SS109 bullet striking construction with velocity 950 m/s.

Tab. 1. Test results for samples 1–16

Sample No.	Layers from muzzle										Penetration (yes/no)	Residual velocity [m/s]
	Layer 1		Layer 2		Layer 3		Layer 4		Layer 5			
1	HTK	3	Aramid	15	Aramid	15	Aramid	10	Aramid	10	no	—
2	HTK	3	Aramid	15	Aramid	15					no	—
3	HTK	3	Aramid	10							yes	502
4	HTK	3	Aramid	10	Aramid	10					yes	219
5	HTK	3	Aramid	10	Aramid	15					yes	—
6	Aramid	15	Aramid	15							yes	650
7	HTK	3	S2	15	S2	15					no	—
8	HTK	3	S2	10	S2	15					no	—
9	HTK	3	S2	10	S2	10					no	—
10	HTK	3	S2	15							no	—
11	HTK	3	S2	10							yes	117
12	S2	10	S2	15							yes	—
13	HTK	3	Aramid	10	S2	10					no	—
14	HTK	3	S2	10	Aramid	10					no	—
15	HTK	3	S2	10	HB50	5					no	—
16	HTK	3	Aramid	10	HB50	5					no	—

References

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