THE OPTIMIZATION OF FIBER-REINFORCED BACKPANEL AS A SUBSTRATE FOR CERAMIC/COMPOSITE BALLISTIC INSERTS FOR PERSONAL PROTECTION

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Pure fiber-reinforced polymer composites can give protection only of a certain level of ballistic threat i.e. only of small arms ammunition. For higher ballistic threat of high energy projectiles, ballistic inserts of ceramic tiles/composite back panel are used. Such inserts are usually composed of ceramic tiles, facing the impact, laid on fiber-reinforced polymer back panel where the hardness of the ceramic is the main factor contributing to the ballistic strength of the inserts. The purpose of the back panel is to keep the tiles stuck together and to be strong/rigid enough to keep the backface blunt trauma effect of the inserts under the allowed upper limit of 44 mm (1,73 inch).
In this study we used pure (99,5%) alumina 5 x 5 x 0,9 cm ceramic tiles and different types of back panel high-performance composites reinforced with aramid (Kevlar), ballistic nylon, ultra-high molecular weight polyethylene (UHMWPE, Dyneema) and glass fibers. The purpose of the study was to find the optimal back panel construction in terms of its trauma performance, weight and price level. It was shown that the lowest trauma effect could be achieved with aramid composites, the lowest weight with UHMWPE, the cheapest – with glass but with a sacrifice of the weight and ballistic nylon backpanel was somewhere between aramid and glass panels in terms of its weight and price level.

Key words: trauma effect, ballistic strength, bullet penetration, ballistic fabrics, aramid, alumina tiles

1. Introduction

High performance polymeric fibers play a very important role in light-weight armor material used to protect personnel either through armor worn on the body (inserts, vests, helmets) or through armor attached to the interior of personnel transport vehicles in air, on land or water. Pure fiber-reinforced polymer composites can give protection only of a certain level of ballistic threat i.e. only of small arms ammunition.

For higher ballistic threat of high energy projectiles, ballistic inserts of ceramic tiles/composite back panel are used. Consideration of ballistic protection system must take into account several factors: the type of the ballistic treat, the ability to manufacture the armor system and the properties of the armor system components. These factors include treat level, multihit performance, environmental conditions, space limitations, manufacturing challenges, cost and weight limitations, physical properties of facing material and backing material and overall ballistic performance of the system.

Oxide ceramics, in particular alumina ceramics have a high level of physical properties that are suited for armor application. Alumina ceramics are of low cost and can be manufactured using a variety of methods i.e. slip casting, pressing and injection molding, without any expensive equipment.

Despite the elevated density (up to 3,95 g/cm3), alumina ceramics can be used for ballistic protection.

Evaluation of ballistic performance of ceramics has been a difficult task due to a number of variables, like type of treat, projectile velocity, projectile geometry, nature of ceramics , target configuration in terms of front and backing material and their thickness i.e. areal weight, angle of impact and support condition affecting the results. The purpose of this paper is to investigate the material type, thickness i.e. areal weight and cost level for a backpanel used as a substrate for ceramic tiles.

2. Experimental procedure

Composite back panels are made of aramid, ultra-high molecular weight polyethylene, nylon and glass fiber composites. The size of the panels was 250 x 300 x 8 mm. This is the standard size for front and back inserts of ballistic vests. Ceramic tiles alumina content was 99,5 % and their size 50 x 50 x 9 mm, which means 30 tiles were used per panel. The tiles are stuck onto the panel by flexible adhesive. The properties of used ceramic tiles are listed in table 1.

Table 1. Physical properties of the ceramic tiles

Property	**Unit**	**Value**
Density	g/cm3	3.87
Residual porosity	%	< 2
Medium grain size	μm	10
Vickers hardness	GPa	15
Young's modulus	GPa	365
Bending strength 4-point	MPa	280
Compressive strength	MPa	2200
Fracture toughness	$MPa \cdot m^{1/2}$	3.6
Sound velocity	m/s	10300

Shooting weapon in all cases was Kalashnikov rifle, 7,62 x 39.mm. The panels are tested from 10 m distance using standard ammunition. The effect of the projectile is shown in Figure 1. It can be seen that the hit tile is completely destroyed although there is not penetration. The fragments from the projectile as well as from the ceramic are kept by the back panel which deforms under the impact. The main criteria for evaluation of the panels was the backface blunt trauma effect of the inserts (backpanel + ceramic tiles). In accordance to the NIJ 0101.04 ballistic standard maximum allowed upper limit of the blunt trauma effect is 44 mm (1,73 inch).

Figure 1. The effect of the high energy projectile on the insert

The results of the test are listed in table 2.

Table 2. Blunt trauma effect of the ballistic inserts constructed from ceramic tiles/composite back panel, 8 mm thick

	Construction of the insert	Blunt trauma effect, mm
1.	Ceramic tiles/UHMWPE fibers reinforced back panel	36
2	Ceramic tiles/nylon fibers reinforced back panel	42
3	Ceramic tiles/aramid fibers reinforced back panel	28
4	Ceramic tiles/glass fibers reinforced back panel	43*

* Since there was partial penetration of the ceramic fragments through the glass fiber panel the test is repeated on 10 mm thick glass fiber panel

3. Discussion

For the same thickness of 8 mm the lowest trauma was shown by the aramid fiber panel, the second best is the PE fibers panel and the worst – ballistic nylon panel. Glass fiber panel with thickness of 8 mm is not appropriate as a back panel, but 10 mm thick panel can be used with sacrifice of the weight. Although ballistic strength of the insert is mainly determined by the ceramic tiles, back panel ballistic strength can have its share to the overall ballistic strength of the insert. It was shown by the glass fiber panel, which has the lowest ballistic strength compared to other tree panels

As for the weight of the panels it corresponds to the specific weight of the fibers, that is, it increases in the following order: PE, nylon, aramid and glass.

From the price level point of view, starting with the cheapest the panels follow this order: glass, nylon, aramid and PE.

4. Summary

The lowest trauma effect is shown by the aramid fibers, the second best are PE fibers followed by the nylon and glass fibers. The lightest panel is that made of PE fibers, the second best is nylon fiber panel followed by aramid and glass fiber panels. The cheapest of all panels is that made of glass fibers, the followed by the nylon, aramid and PE fibers respectfully.

5. References

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