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Transparent armour materials

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Abstract

The ballistic performance of transparent ceramic and glass materials was investigated. Various types of layered sandwich composites were compared from the ballistic resistance viewpoint. Layered sandwiches from soda-lime silicate float glass and also sandwiches with sapphire top layer were prepared. Their ballistic resistances against two types of 7.62 mm caliber armour-piercing (AP) ammunition of protection level 3 according to NATO Standardization Agreement STANAG 4569 were investigated. For the ballistic performance assessment depth of penetration (DOP) test method and ballistic mass efficiency of sandwich (BME_S) criterion were used. From economical, technological, optical and ballistic point of view as optimal solution sandwich structure consisting of sapphire front-face layer, float glass internal layers and polycarbonate backing layer was found. Specific solution is shown in the article.

Keywords: Armour; Al_2O_3; Glass; Hardness; Optical properties; Ballistic performance

1. Introduction

Ceramic materials have been frequently and successfully used in armour configurations all over the world. Comparison of weights of steel and ceramic composite armours, which resist to the same type of ammunition, shows that by using ceramic composite armours the mass can be reduced significantly. For armour application whole scale of oxide and non-oxide ceramic materials, such as boron carbide (B_4C), alumina (Al_2O_3), silicon nitride (Si_3N_4), silicon carbide (SiC), titanium diboride (TiB_2), a composite of Si and SiC (SiC–Si), etc., is considered. Besides terminal ballistic properties also price, availability, production technology and workability decide about their particular uses. From economical and technological point of view optimum material is alumina. Alumina is also the most common type of ceramics used for armour production.[1–4]

Ceramic composite armour is typically designed to protect against armour-piercing (AP), high kinetic energy projectiles, mainly in the small arms and heavy machine gun category. These AP projectiles are purely inertial rounds, which cores are most commonly made of hard steel (HV_5 848–870), of moderate density (7.85 g cm^{-3}) or harder tungsten carbide (WC) of higher densities (13.5–15.0 g cm^{-3}) and hardness (HV_5 1347–1394). The hard core is generally encased in a thin jacket of a more ductile metal for interior ballistic or aerodynamic considerations, but penetration performance is controlled by the core properties. Such projectiles typically have a length to diameter (L/D) ratio in the range 3:1 to 5:1 with moderate muzzle velocities of less than 1000 m s^{-1}. The generally accepted high-end caliber is 14.5 mm, typified by Soviet KPV family of heavy machine guns. Overall, these projectiles tend to produce a total kinetic energy in the order of magnitude 10^3–10^4 J.[5] Classification of the ammunition according to the protection levels is defined in the STANAG 4569.[6]

1.1. Configuration of ceramic armours

Production technology and difficult workability of ceramic materials lead to their application in armours mainly in flat plates form. Flat plates are constructed from variously shaped tiles. Square or hexagonal shaped tiles are commonly used (see Fig. 1). Their size is proportional to expected calibre of used ammunition. For armours resisting to 7.62 caliber ammunition the tiles of standard dimensions 50 mm × 50 mm are commonly applied. For higher calibres larger tiles are recommended.

Using of ceramic plates for curved surfaces is more complicated. These cases are commonly solved by using ceramic parts embedded in metal, polymer or inorganic matrix. Armours consisting of ceramic balls and cylinders are optimal. Structure of such armours is shown in Fig. 2. Ceramic balls or cylin-

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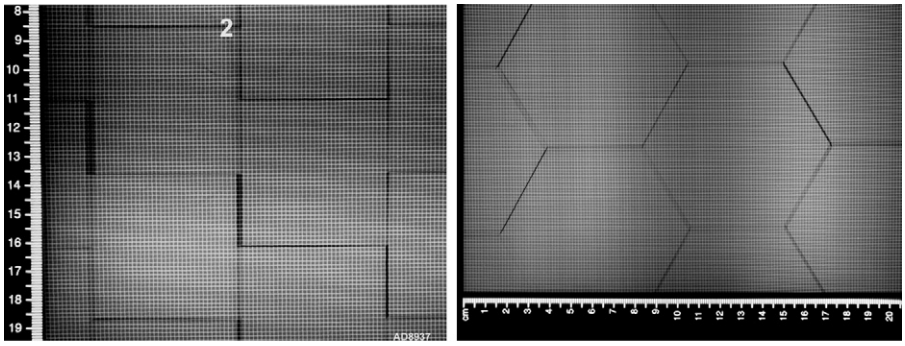

Fig. 1. Typical shapes of ceramic tiles.

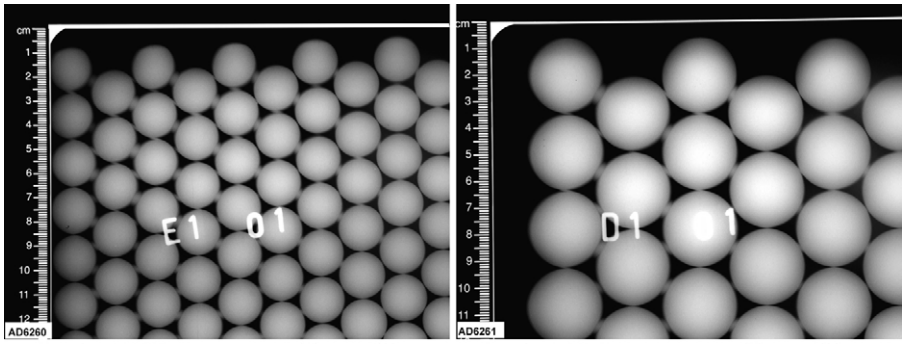

Fig. 2. Ceramic balls in armour structures.

ders size have to be comparable with expected calibre of used ammunition. Good bonding of ceramic parts with matrix represents a serious problem.

For correct function of ceramic armour a backing stiff layer is essential. Aluminium alloys and steels are commonly used as the supporting layer. Ballistic laminates based on glass fibres (E a S2 glass), aramid and polyethylene are used in lightweight applications. Polyurethane or polysulfide glue is successfully used for bonding.

1.2. Transparent armours

The main limiting factors for armours are weight and thickness. For high protection level relatively high armour thickness is needed, which subsequently results in high armour weight. It is also well known that with increasing thickness of transparent material the light transmission decreases. If high protection level is requested, installation of these armours into armoured vehicles and objects is problematic because of their high thickness and weight.

The problem of high thickness and weight of transparent armours is presently solved by research and development of new transparent ceramics of high hardness such as aluminium oxynitride (AlON), spinel ($MgAl_2O_4$) and sapphire (Al_2O_3 single crystal). Available production technologies of these materials in EU countries do not meet the criteria for requested properties (dimensions, transparency, etc.) and their purchase in USA is very expensive or even unfeasible (AlON).[4]

1.3. Transparent ceramic armours

Construction of transparent armours follows the principles well established for the opaque ones. Armour against advanced threats has typically structure shown in Fig. 3.

The front-face layer should be as hard as possible to damage the projectile in maximum range. In ideal case it should be harder than the projectile core. At present some kinds of hardened glass or glass ceramics are used, but in fact, this layer represents a weak point of present transparent armours.

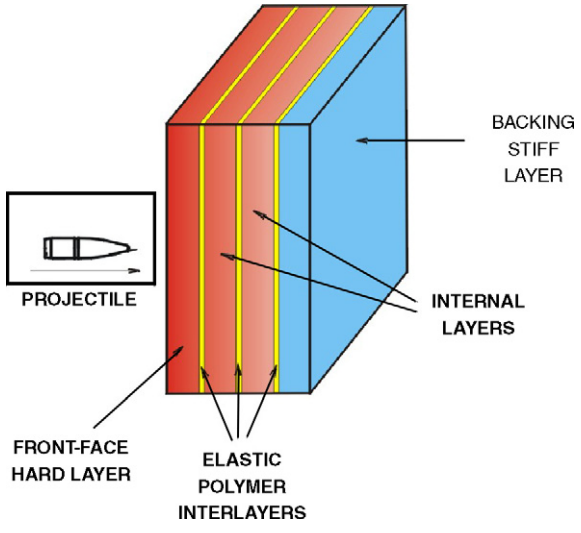

Fig. 3. Schematic structure of transparent armour against advanced threats.