A study of the ballistic protection mechanism of two kinds of structure against 7.62×54 mm ball ammunition

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Abstract. In this work, the protection mechanism of two kinds of structure was studied using 7.62×54 mm ball ammunition, which still played an important role in the threat spectrum of military vehicles. The tested one structure is consisted with silicon carbide (SiC) ceramic and Ultra-High Molecular Weight Polyethylene (UHMWPE), and the other is UHMWPE only. Silicon carbide ceramic was chose as strike face material for the reason of its widely using in Light Weight Vehicle Armor. And the UHMWPE was widely used for personnel body armor, because of its high protection ability and low density. These two kinds of structure were tested with 7.62×54 mm ball ammunition using a 7.62 mm powder gun launching system. After the ballistic experiment, the target plate was evaluated, and the residual steel core was recovered and measured. It was found that the main effect of ceramic strike face was eroding the steel core, rather than breaking it in the scene of defeating AP round ammunition. Otherwise, there is a critical thickness with the ceramic strike face to erode the steel core in the ceramic/UHMWPE combination, for the reason of the presence of two intermediate parts, the jacket and lead filler, between the core and ceramic target. Furthermore, compared to the ceramic/UHMWPE structure, single UHMWPE laminate is more effective, because that is strong enough to mushroom the core and absorb the energy.

1. Introduction

The ballistic performance of ceramic materials using in armor system has been extensively studied since the 1960s [1-3]. A ceramic armor design usually is consisted of the hard disrupting ceramic strike face plate and the deformable back plate. The purpose of the ceramic is to induce fragmentation in the projectile or induce erosion thereby redirecting and dispersing the kinetic energy. On the other hand, the back plate acts to transfer and absorb the kinetic energy of the residual bullet through inelastic deformation. When a projectile impacts and penetrates the ceramic face, brittle failure produces and leads to extensive fragmentation of the tile. Through this way the energy was dispersed to a widely area. If the fragments are not retained in place then the multi-hit capability of the armor is compromised. So a spall cover was used on the front of the ceramic strike face in order to add some robustness to the structure. And in the most armor systems, this cover is a lightweight fiber-reinforced polymer cladding. In this work the glass fiber reinforced polymer was used.

Since 1960s, the impact response of ceramic armor structure to a range of small calibre ammunition has been studied for many researchers. But most of the work published focused on the penetration mechanisms of the steel-cored armor piercing bullets. In this work, the penetration behavior of the 7.62×54 mm mild steel core ball ammunition was studied, because it’s still an important threat for the military used vehicle. And for the vehicle protection, Silicon carbide (SiC) is broadly used for its high performance, low density and reasonable price. The UHMWPE laminate composite is mainly used for
ultra light weight body armor application for its high ballistic performance against small calibre ammunition and ultra low density. So this work was mainly focused on this two promising material.

The work of Gooch et al. [4], have shown that the presence of the copper jacket, on the APM2 rounds, plays a measurable role in the penetrator-ceramic interaction. More recently, the work of Hazell et al. [5] have shown similar effects with the 7.62 mm M993, tungsten-carbide-cored, rounds. And the study of Ian G. Crouch et al. [6], also have shown that a similar effect is existed in the 7.62mm AK47 MSC round. Both studies observed that the jacket and the filler ahead of the core preload the ceramic, which make the ceramic prematurely fail, thereby offering less resistance to the core of the penetrator.

In this work, two kinds of structure was studied using 7.62×54 mm ball ammunition to find the better structure and to find the usually defeating mechanism of this type ammunition. One structure is consisted of silicon carbide ceramic and UHMWPE laminate plate, and the other is UHMWPE laminate plate only.

2. Experimental set up
The terminal ballistic work was carried out in the laboratory of the Inner Mongolia Metal Material Research Institute, Yantai, China.

2.1. Target materials used
The silicon Carbide ceramics used in the experiment was manufactured by Yangzhou North-SanShan Industrial Ceramics Co. Ltd using Reaction sintered technique. Three specification of discs, respectively 3mm, 4mm, 5mm in thickness, was used with the shape of hexagon and the edge length of 17.5mm. The density of the ceramics was measured from 3.12 g/cc to 3.15 g/cc, using the boiling water method according to Chinese GB/T 1966. The average 3-point flexure strength of ceramic was nearly 400Mpa and the Vickers hardness was nearly 2.4Gpa.

The Ultra-high molecular weight polyethylene (UHMWPE) fiber-reinforced composite is a promising material for ballistic protection due to its high strength and low density. UHMWPE laminate was manufactured with a hot press method. And the UHMWPE fiber tenacity was not less than 38CN/dtex and a water-based polyurethane resin was used.

The ceramic plate for the test was mosaic structure with the hexagon ceramic disc and using glass fiber reinforced polymer to retain the discs. The areal density of the ceramic plate is ranged from 23.4 kg/m² to 27.9 kg/m².

2.2. Projectile used
The projectile used is Chinese 7.62×54 mm ball ammunition. The bullet has a nominal mass of 9.6 g and the original length and diameter are measured to be 33 mm and 7.86mm respectively. As can be seen from Figure 1, the core had a slightly truncated, blunt tip. The soft jacket is made of thin, copper-plated, mild steel and the lead completely fills the space between the jacket and the Mild Steel Core. The hardness of the steel core was measured to be HRB 95 and the chemical composition was measured and list in Table 1.

![Figure 1. bullet used in the experiment.](image)

**Table 1.** chemical composition of bullet core. (Unit:%)
| Element | C | Si | Mn | Ni | Cu |
|---------|---|----|----|----|----|
| Content | 0.18 | 0.24 | 0.70 | 0.008 | 0.024 |

2.3. Ballistic experiment

The ballistic experiments were held with a powder gun launching system. The distance between the target and the gun muzzle is 10 m and a aluminum foil screen target bullet velocity measurement system was used 3 m front the target. The experiment setup is illustrated in Figure 2.

Two different structures (see Figure 3) were investigated with full-change ammunition at 0° normal angle. The nominal bullet velocity is 828 m/s at a distance of 25m from the muzzle.

Structure A: Ceramic + UHMWPE (with ceramic thickness be varying); Structure B : UHMWPE only.

![Figure 2. Schematic of experimental set-up.](image)

![Figure 3. Tested two kinds of structure.](image)

2.4. Core recovery and measurement

In order to reveal the defeating mechanism, the core was recovered, in most cases, which is embedded in the UHMWPE back plate. The final length of the recovered cores was measured to the nearest millimeter, since the tips of the eroded cores were very irregular. The final mass of the recovered cores was also measured to the nearest 10th of a gram.

3. Computational modeling

A modeling study using ANSYS AUTODYN was carried out to inform the defeating mechanism of different type structure against the 7.62 × 54mm MSC ball ammunition.
The frequently used JH-2 material model, which was developed by Johnson and Holmquist [7] in 1990s, was used to analysis the impact response of ceramic targets. For the reason of no material data for the tested ceramic, it was chosen to adopt the material data of SiC in AUTODYN material database. The orthotropic equation of state model, orthotropic Yield strength model and orthotropic softening failure model was selected to model the ballistic response of UHMWPE laminate plate. The material data proposed by Lassig T et al. [8] was used in the simulation of this work.

Because the material and hardness of the steel core were similar to AK47 MSC ammunition, the bullet (including jacket, lead and core materials) was simulated using Johnson-Cook strength and failure models previously published by Carbajal et al. [9]. The core, jacket, lead filler and ceramic were modeled using SPH (smooth particle hydrodynamics), otherwise the UHMWPE laminate back plate was modeled using Lagrange dynamic. A 2D axial symmetrical set-up was used with a particle size of 0.1 mm.

4. Results and discussion

4.1. Ballistic experiment results

| Impact event | Target ID | Ceramic thickness [mm] | UHMWPE thickness [mm] | Areal density [kg/m²] | Damage | Measured parameters |
|--------------|-----------|------------------------|-----------------------|-----------------------|--------|---------------------|
|              |           |                        |                       |                       |        | Impact Velocity [m/s] | Final core length [mm] | Final core mass [g] |
| 1            | C3+12-1   | 3mm                    | 12mm                  | 23.4                  | PP     | 836                 | 17.5                  | 4.56                  |
| 2            | C3+12-2   | 3mm                    | 12mm                  | 23.5                  | PP     | 845                 | 17.9                  | 4.65                  |
| 3            | C4+12-1   | 4mm                    | 12mm                  | 26.7                  | PP     | 834                 | 17.2                  | 4.56                  |
| 4            | C4+12-2   | 4mm                    | 12mm                  | 26.7                  | CP     | 838                 | NA                    | NA                    |
| 5            | C5+10-1   | 5mm                    | 10mm                  | 27.9                  | PP     | 835                 | 16.2                  | 4.2                   |
| 6            | C0+20-1   | 0                      | 20mm                  | 20.3                  | PP     | 830                 | 17.5                  | 4.7                   |
| 7            |           |                        |                       |                       | PP     | 824                 | 18.0                  | 4.7                   |

The ballistic test results of this experiment were listed in table 2 and some of the tested target was showed in Figure 4. In the scene of Complete Penetration (CP), no final core was recovered, so that it was marked as NA in the core length and mass data. As the purpose of this study was determining the trends in ceramic composite against 7.62 × 54mm MSC ball ammunition, the size and the number of shots per target plate were not consistent. Nevertheless, the experiment results still have a pattern. And it should be noticed that, due to the use of single plate data points in places, conclusions drawn from the results presented here are only indicative of general behavior, rather than absolute predictions of ballistic response.

The impact experiments can be grouped so that a different set of variables could be investigated at any one time. The objectives of each set of impacts were as follows:

#1-9: The effect of ceramic thickness was studied.

#7-12: The efficiency of ceramic was evaluated by comparing with UHMWPE laminate structure.
From the test results, it could be seen that UHMWPE plate was more effective than ceramic/UHMWPE composite with a lower areal density.

**Figure 4.** The typical ballistic results of ceramic/UHMWPE composite.

### 4.2. the effect of ceramic thickness

For the impact even with partial penetration (PP) result, the bullet core was embedded in the UHMWPE back plate. The bullet core was recovered and measured with the result listed in table 2 and the shape showed in figure 5.

Analysis the measured data listed in table 2, it was found that the thicker the ceramic, the greater level of erosion. For a ceramic with thickness less than 4 mm, very little erosion of the core had occurred in this studied situation. And the core length showed a similar phenomenon, with that the recovered core length was nearly the same for a ceramic with thickness 3mm and 4mm. However, the recovered core length was 12 mm for a ceramic thickness of 5 mm.

It can also be seen from the shape of recovered core that it was mainly mushrooming but erosion by the target for the impact of ceramic thickness with 3 mm and 4 mm or the UHMWPE only scene. Otherwise the core was highly erosion by the ceramic for the thickness with 5 mm.

**Figure 5.** Recovered cores from ballistic tests, (a) original core; (b) recovered from C3+12; (c) recovered from C5+10; (d) recovered from C0+20.

### 4.3. the effect of the jacket and filler

As mentioned earlier, it has a low effect of thin ceramic on the impact of 7.62 × 54mm ball ammunition, which is not like the 7.62 × 54mm API ammunition. For the purpose of finding the reasonable explanation of this, the computational modeling work was carried out. The results of the computations with the jacket and filler are shown in Figure 6. The figure indicates that the presence of the lead filler and the jacket pre-damages the ceramic and acts to penetrate into it before core arrival. At the same time, due to the deformation of the UHMWPE back plate, the confining force on the damaged ceramic is decreasing. So in the scene of thin ceramic thickness, the bullet core is nearly erosion.
5. Conclusions
From the impact experiments and computational simulations illustrated above, the following conclusions can be drawn:
(a) The main effect of ceramic strike face was eroding the steel core, rather than breaking the core in the scene of defeating AP round.
(b) In the scene of defeating 7.62 × 54mm ball ammunition, the presence of the lead filler and the jacket tends to pre-damage the ceramic face plate. So there is a critical thickness with the ceramic strike face to erode the steel core in the ceramic/ UHMWPE structure.
(c) UHMWPE laminate composite is more effective than the ceramic faced structure to defeat the 7.62 × 54mm ball ammunition.

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