Experimental Study on Ballistic Performance for Multi-hole Armor Steel Plates Against the 7.62mm Armor Piercing Projectile

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Abstract. The ballistic performance of multi-hole and non-hole armor steel plates has been comparatively tested in the outdoor shooting range. Under conditions of 100m shot distance, 76° normal angle, the multi-hole and non-hole armor steel plates with thickness of 4mm, 5mm and 6mm all appeared typical ricochet phenomenon against the 7.62mm armor piercing projectile. The weight of multi-hole plates compared to the weight of non-hole plates can be reduced by 26.24%. Under conditions of 100m shot distance, 0° normal angle, the 6mm combined with 5mm thickness multi-hole armor steel plates and the 15mm thickness non-hole armor steel plates could both effectively protect the 7.62mm armor piercing projectile. While, the weight of multi-hole plates compared to the weight of non-hole plates can be reduced by 40.85%. The multi-hole armor steel plates have extremely broad application prospects for battlefield protection of light armored vehicles.

1. Introduction

The ceramic composite armor is extensively adopted on light armored vehicles protection for small and middle-caliber armor piercing projectile in many countries. The ceramic composite armor is able to enhance the protection performance, and to meet the vehicle's weight loss requirements, but the manufacturing process is very complex, and the cost is relatively high. The high hardness armor steel plate can enhance the armor protection performance, but seriously affects the mobility of vehicles. Compared with ceramic composite armor and high hardness steel plate, the multi-hole armor steel plate provides a good ballistic performance and economy, and can achieve significant weight loss. This is important remarkably for light armored vehicles to improve the battlefield survivability.

At present, the study of the multi-hole armor steel plate is mainly focused on the material simulation, structural design, simulation of ballistic performance, and so on. But there are few reports on the experimental study of ballistic performance. In this paper, the ballistic performance of typical structure multi-hole armor steel plates was studied by means of service shot test. The results show that the multi-hole armor steel plates have the equivalent or better ballistic performance than the high hardness armor steel plates with the same thickness, but the weight can be reduced by 40.85%. The multi-hole armor steel plates are very suitable as a cost-effective means for the protection of light armored vehicles.
2. Materials and Methods

2.1. Materials
The hot-rolled armor steel plates with a size of 500 mm×350 mm were first perforated in the same manner as shown in Table 1 and Fig.1. Then, the multi-hole armor steel plates were subjected to flatting treatment, and the flatness is not more than 3 mm/m. Finally, the multi-hole armor steel plates were pressure quenched and tempered heat treatment at low temperature, and the Brinell hardness were all HB 500 above. The difference values of surface indentation hardness for each piece of the multi-hole armor steel plates were not more than 0.2mm.

| size (mm×mm×mm) | program 1 | program 2 |
|-----------------|-----------|-----------|
|                 | aperture Φ (mm) | hole center distance T (mm) | aperture Φ (mm) | hole center distance T (mm) |
| 6×500×350       | 5         | 10        | 7         | 12        |
| 5×500×350       |           |           |           |           |
| 4×500×350       |           |           |           |           |

The schematic structure of the multi-hole armor steel plate after perforating and heat treatment is shown in Figure 1.

![Figure 1 Schematic Graph of Structure for the Multi-hole Armor Steel Plate](image)

2.2 Methods
The multi-hole armor steel plates with thickness of 4 mm, 5 mm, 6 mm and (5 + 6) mm were used as target plates. While the non-hole armor steel plates with thickness of 4 mm, 5 mm, 6 mm and 15 mm were used as comparative test target plates. The Brinell hardness of both targets was above HB500. The ballistic test was conducted in the outdoor shooting range. The 7.62mm caliber ballistic gun and 7.62mm armor piercing projectile (AEP-55, 7.62×54R B32 API) were employed. The velocity of projectile from the muzzle at 25m was controlled in range of 800 ~ 815m/s. The projectile of velocity beyond this range was determined to be invalid. The distance between the muzzle and the target was 100m. The target plate was mounted firmly on a target frame with an adjustable obliquity angle. The high strength steel plate with thickness of 2.5mm was acted as the aftereffect plate. The distance between the target plate and the aftereffect plate was 50mm. The ballistic test arrangements are shown in Figure 2.
3. Results and discussion

3.1 Results
The major results of ballistic performance tests are shown in Table 2. The rate of weight loss for multi-hole plates compared to non-hole plates with the same thickness is also calculated and listed in Table 2.

| NO. | thickness of target /mm | structure | normal angle /° | protection effects | rate of weight loss | comparisons |
|-----|-------------------------|-----------|-----------------|--------------------|---------------------|-------------|
| 1   | Ø5T10                   |           |                 | ricochet           | 19.30%             |             |
| 2   | Ø7T12                   |           |                 | ricochet           | 26.24%             | non-hole plates with thickness of 4 mm |
| 3   | no holes                | Ø5T10     | 76              | ricochet           | 26.24%             | non-hole plates with thickness of 5 mm |
| 5   | Ø7T12                   |           |                 | ricochet           | 19.30%             |             |
| 6   | no holes                | Ø5T10     | 76              | ricochet           | 26.24%             | non-hole plates with thickness of 6 mm |
| 7   | Ø7T12                   |           |                 | ricochet           | 19.30%             |             |
| 8   | (6+5)                   | Ø5T10     | 0               | effective protection | 19.32%             | non-hole plates with thickness of 15 mm |
| 9   | no holes                | Ø5T10     | 0               | effective protection | 40.85%             |             |

3.2 Discussion

3.2.1 Ballistic performance of the multi-hole armor steel plate with single layer
The ballistic performance test results of multi-hole armor steel plates with thickness of 5 mm are shown in Figure 3.

![Figure 3](image)

Figure 3 Macromorphology of the 5 mm Thickness Multi-hole Armor Plate after Ballistic Tests. (a) Facing Bullet Plane of the Target, (b) Bullet Marks on Hole Gap Area, (c) Bullet Marks on Hole Edge Area
As can be seen from Figure 3, the 5 mm thickness multi-hole armor steel plate appears a typical ricochet phenomenon at the shot condition of 76° normal angle.

It can be seen from Figure 3 (b) and (c) that, under the above shot conditions, the 7.62mm armor piercing projectiles ricochet over the multi-hole armor steel plate, whether the projectile hits hole gap area or hits hole edge area. The multi-hole armor steel plate is scratched only and not broken through. The spoon shaped bullet marks are generated on the plate. At the same shot conditions, for plates of thickness of 4mm, 5mm and 6mm with multi-hole or non-hole, the results of ballistic tests indicate that all the plates appear typical ricochet phenomenon. The main reason for the phenomenon is the obliquity effect of the target plate, while the projectile deflection effect from the hole edge is not significant.

3.2.2 Ballistic performance of the two-layer multi-hole armor steel plates
The 6mm Ø5T10 multi-hole plate was used as the facing bullet plane, which was crossly bounded with the 5mm Ø5T10 multi-hole plate. Then the general thickness of two-layer multi-hole armor steel plates is 11mm. At the shot condition of 0° normal angle, the ballistic performance of the two-layer multi-hole plates was further tested. The ballistic test results are shown in Figure 4. The results show that the two-layer multi-hole armor steel plates can effectively protect the 7.62mm armor piercing projectile. As shown in Fig. 5, whether the 7.62mm armor piercing projectile hit the hole gap area or the hit hole edge region, the ballistic trajectory directions are all deflected, which is equivalent to raise the normal angle of the target plates. That is helpful to improve the ballistic performance[1,4]. The ballistic test results also show that the 15mm thickness non-hole armor steel plates can protect the 7.62mm armor piercing projectile.

4. Conclusion
Under conditions of 100m shot distance, 76° normal angle, the multi-hole and non-hole armor steel plates both appeared typical ricochet phenomenon for the 7.62mm armor piercing projectile. The main reason for the ricochet phenomenon is the obliquity effect of the target plate. At the same time, the weight of multi-hole plates compared to the weight of non-hole plates can be reduced by 26.24%.

Under conditions of 100m shot distance, 0° normal angle, the multi-hole armor steel plate with thickness of 11mm and the non-hole armor steel plate with thickness of 15mm could both effectively protect the 7.62mm armor piercing projectile. The deflection of ballistic trajectory directions from the holes is the main reason for improvement of ballistic performance. While, the weight of multi-hole plates compared to the weight of non-hole plates can be reduced by 40.85%.

The designed multi-hole armor steel plates can effectively protect the 7.62mm armor piercing projectile, and have great advantages of weight loss. The multi-hole armor steel plates have extremely broad application prospect for battlefield protection of light armored vehicles.
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