Experimental Study on the Penetration Effect of Shotgun Pellet on Soap

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Abstract. In order to make the shotgun play an effective role in maintaining stability, it is necessary to study the shotgun penetration effect systematically and scientifically. Based on the analysis of the mechanism of action of kinetic energy projectiles on human targets, the end effect experiments of different shot distances were carried out by establishing the shooting platform of shotgun and selecting soap to simulate the body tissues. The results show that within the effective range of 10m, the non-lethal strike effect of BB ammunition is the most ideal, which is helpful for the scientific use and optimization of this kind of anti-riot kinetic energy weapons and ammunition.

Introduction

In recent years, as a non-lethal anti-riot weapon, shotgun has played an important role in urban anti-terrorism and stabilization. At present, most of the armed police force is using military grapeshot, non-lethal effect is poor, can not achieve good dispersal effect without causing lethal damage to the population. Therefore, it is necessary to study the types and power of shrapnel. In this paper, through the establishment of a shooting platform for shotgun, soap is selected to simulate the body tissues, and the end effect experiments of different shotgun at different shooting distances are carried out, which provides a scientific basis for the scientific use and optimization of such anti-riot kinetic energy weapons and ammunition in the future.

Penetration Theory of Pellet to Target

The penetration power test of grapeshot is mainly used to test the penetration power of grapeshot at different distances. The velocity attenuation law is deduced by measuring the velocity of grapeshot at different distances[1]. The energy attenuation and specific kinetic energy attenuation laws of the graupel are deduced according to the penetration depth of the graupel into the target. The traumatic ability of the graupel is evaluated according to the depth and cavity volume of the simulated material.

According to the resistance law of poncelet, there is a corresponding relationship between the penetration depth and the velocity of the projectile, which can be calculated by Sabsky formula [2]

$$L = \frac{2m}{\pi d^2 Ajb} \ln\left(\frac{1 + bv_0^2}{1 + bv^2}\right) \tag{1}$$

We assume in the formula.

(1)medium resistance is composed of static resistance and dynamic resistance.

(2) the medium is homogeneous.

(3) do not consider the rotation of projectiles.

(4) the trajectory of the medium is straight.

When v=0, the maximum penetration stroke is obtained.

$$L_{\max} = \frac{2m}{\pi d^2 Ajb} \ln(1 + bv_0^2) \tag{2}$$

Medium :

M - -projectile mass (kg)

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D -- bullet diameter (m)
J -- coefficient related to projectile shape
L -- penetration stroke (m)
A, b - the coefficient determined by the medium, which can be taken for soap medium. $b = 80 \times 10^{-6}(s^2 / m^2)$
Suppose:

$$k = \frac{2m_i}{\pi d^2 A j b} \tag{3}$$

K is a coefficient related to media and marble, and the original expression can be expressed as

$$L = k \ln(1 + bv^2) \tag{4}$$

We have made some assumptions in the derivation, these assumptions are different from the actual situation, even very different (such as projectile rotation, medium ballistic non-linear, medium inhomogeneous, etc.), in order to make up for the shortcomings, through the test to get the correction coefficient (Sabsky formula A and b) to calibrate[3]. In this way, the accuracy of the formula depends to a large extent on the accuracy of the correction coefficient.

In practice, according to the relationship between the maximum penetration depth and the penetration velocity of the graupel, we calculate the coefficients of each medium and the graupel by using the experimental data of different groups, get the average value, and get the corresponding k value of the graupel with different materials, that is, from Eq.4, we can get the value of k.

$$k = \frac{L}{\ln(1 + bv^2)} \tag{5}$$

The formula is replaced by the average k value.

$$v_x = \sqrt{\frac{e^{\frac{L}{K}} - 1}{b}} \tag{6}$$

The theoretical speed Vx can be obtained.

Experimental Research

Design of canister for trial use In order to better test the penetration power of different shotguns and to test the lethal effect of different shotguns on human body, we have designed a shotgun structure conforming to the test. Its shape is shown in Fig. 1.

The diameter of short-tube shotgun[4] was 12 mm and high density polyethylene was selected as shell material. Cartridge cases are mainly cartridges, including sabot, marble, gaskets, propellants, and fire caps. The shrapnel is a cylindrical cartridge with 45 mm shell length, 12 mm inner diameter, 14 mm outer diameter. The firing chamber is used for loading nail projectiles. A low pressure chamber is closely connected with the shrapnel. The shell wall thickness is 1 mm and the bottom edge thickness is 1 mm.

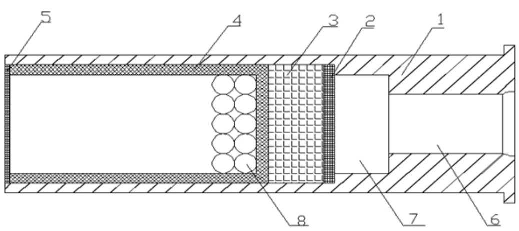

Figure. 1 shotgun section view
1 cartridge case; 2 gaskets; 3 felt; 4 cartridge; 5 sealing cover; 6 nail shooting chamber; 7 low pressure chamber; 8 shotgun;

In the test, we use interference fit gasket seal, the sabot is designed to be cylindrical, no valve, the sabot behind the pad and cotton pad, to play a buffer role. No rust rusting agent is chosen as the base charge for the canister, and 3 small grains are chosen as the propellant for the canister[5]. From the non-lethal effect of the attack, the choice of graupel bullets are steel balls, rubber bullets, BB bullets, the specific characteristics of each graupel as shown in Table 1.

Table 1 Types and characteristics of pellets

Types of pellets	Diameter (mm)	quality (g)	density (g/cm^3)
Steel ball shotgun	4	0.25	7.8
Rubber pellet	5	0.11	1.63
BB shot	6	0.2	1.77

In this paper, the traditional test method is used to evaluate the traumatic ability of the graupel and directly measure the penetration effect of the graupel on the target[6]. The density of soap is very close to the body tissue, which can directly reflect the relationship between marbles and the energy transfer of the body tissue. In the experiment, we use soap as an abiotic analog material. The trauma ability of canister with different kinds of pellets is measured at different distances. Three layers of ordinary soap are accumulated before the test target plate. The muzzle height and firing distance[7] were set according to the test plan. The aiming point is located in the center of the soap target, and the aiming point coincides with the center of the barrel, on the same horizontal line. The velocity measuring target is placed in front of the target plate. The center of the velocity measuring target is the same height as the barrel center. The aim point is fired at 0.1m, 3m, 6m and 9m respectively with the shotgun. Each shot was replaced with a new soap, taking pictures and recording the test data.

The following is a test picture of the pellet penetrating the soap (due to the limitation of space, not all posted).

Figure. 2 Penetration test site

We cut the soap after the test (without affecting the test data measurement) and then measure it. The test data are tabulated as shown in Table 2.

The test was carried out under the same test conditions, using the same charge quantity, the same charge method, the total mass of all kinds of shotguns was set at 1.6g. Therefore, under the condition of neglecting the secondary factors, the pellet has the same initial speed[8].

Therefore, according to the relationship between the maximum penetration depth and the penetration velocity, the coefficient k of the medium and the projectile can be obtained from Eq.5. The corresponding average k of each projectile is shown in table 3.

Table 2 Test results

type	Ejection distance（m）	Average penetration depth（mm）	Penetration rate (m/s)	kinetic energy（J）	Specific kinetic energy(J/cm^2)
Steel ball	0.1	79.33	232	6.67	53.1
	3	72.10	207	5.39	42.9
	6	65.5	191	4.57	36.4
	9	57.75	170	3.62	28.8
rubber	0.1	21.00	232	2.96	15.1
	3	14.77	169	1.58	8.1
	6	13.82	150	1.54	6.3
	9	7.68	105	0.61	3.1
BB Bomb	0.1	30.25	231	5.29	18.7
	3	26.75	207	4.29	15.2
	6	25.60	193	3.71	13.7
	9	24.75	186	3.45	12.2

Table 3 Coefficient K of all kinds of pellets

Type of bullet	K value of marble penetrating soap（s^2-/m^2）
Steel ball shotgun	48.044
BB shot	18.343
Small rubber pellet	12.812

The theoretical penetration velocity of the graupel can be obtained from Eq.6. Comparing the calculated results of the external ballistic of the graupel, the difference between the experimental data and the theoretical data fluctuates within the range of (+) 5% as shown in table 4. The experimental data are reliable[9].

Table 4 The pellet on different firing distance

type	Ejection distance（m）	Theoretical penetration speed (m/s)	Penetration rate (m/s)	Deviation rate
Steel ball	0.1	229.49	232	1.09%
	3	208.71	207	-0.82%
	6	190.70	191	0.16%
	9	170.54	170	-0.32%
rubber	0.1	227.78	232	1.85%
	3	164.59	169	2.68%
	6	155.76	150	-3.7%
	9	101.31	105	3.64%
BB Bomb	0.1	229.20	231	0.79%
	3	203.06	207	1.95%
	6	194.86	193	-0.95%
	9	188.90	186	-1.53%

Theoretical penetration velocity, penetration velocity and deviation rate From the above data, we can get the relationship between penetration depth and penetration speed, as shown in Fig. 3.

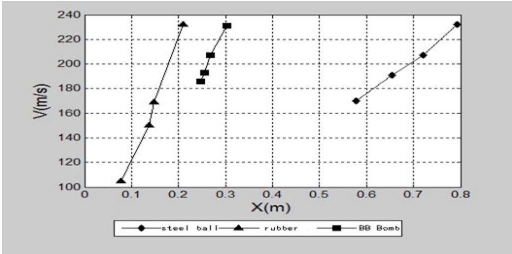

Figure. 3 Relationship between penetration depth and penetration velocity of shrapnel

$$E = \frac{1}{2} mv^2 \tag{7}$$

(E is the kinetic energy of the pellet, M is the quality of the pellet, and V is the penetration velocity.) [10].

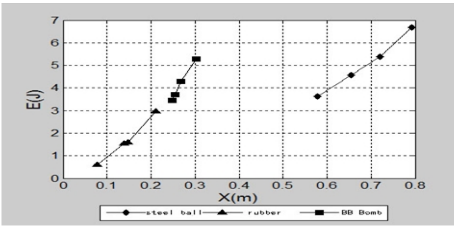

Figure. 4 Relationship between penetration depth and kinetic energy of shrapnel.

The relationship between penetration depth and specific kinetic energy of shrapnel is shown in Fig. 5.

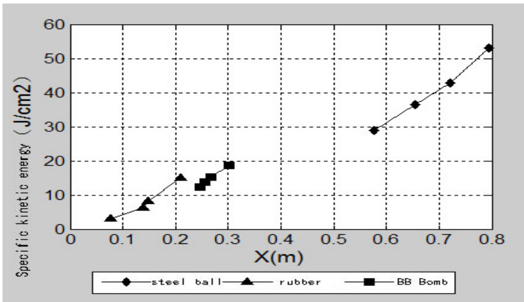

Figure. 5 Relationship between penetration depth and specific kinetic energy of shrapnel

According to the above data, the velocity and specific kinetic energy attenuation law of various kinds of pellets can be obtained, as shown in Fig. 6, Fig. 7.

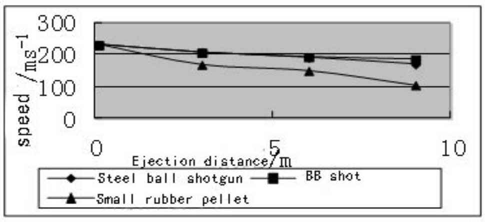

Figure. 6 Schematic diagram of velocity attenuation for each canister

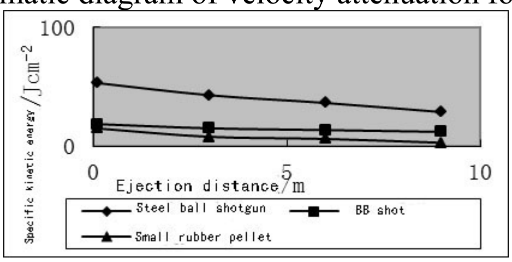

Figure. 7 Schematic diagram of kinetic energy attenuation for each shrapnel

Conclusion

On the basis of the experiments on the terminal damage effect of different shotguns, the coefficients in the formula are calibrated by the test data and the experimental results are analyzed. The following conclusions can be drawn by combining with the National Military Standard of China (GJBZG20262-95):

1. The penetration power of steel ball and shrapnel exceeds the prescribed kinetic energy standard when the firing distance is less than 10 m, but when the firing distance of steel ball and shrapnel is more than 10 m, the damage degree will be reduced, showing a slight damage. The penetration power of BB bomb and rubber bomb is within the set range, which can cause certain damage to the living target without causing permanent injury or death. At the same distance, the steel ball has the most penetrating power, followed by the BB bullet, and the rubber bullet has the weakest penetrating power. The velocity (within the range of 10m) of all kinds of graupel is greater than 100m/s, and the kinetic energy of all graupel is less than 10J; the specific kinetic energy is less than 60J/cm2.

2. From the velocity and specific kinetic energy decay diagram of each shrapnel, it can be seen that the best non-lethal impact effect is the BB shrapnel. The specific kinetic energy of BB shrapnel is within the prescribed range, and the attenuation is relatively mild. On the premise of meeting the injury standard, the quantity of the launching charge of BB shrapnel can be increased appropriately to improve the wound ability of the shrapnel.

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