Aspects Related to the Analysis of the Terminal Effect of Non-Lethal Kinetic Projectiles

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***Abstract*—The paper studies the issue of interaction and energy transfer between non-lethal kinetic projectiles and the human body. It aims to present a method for determining the risk and level of injury to the body by assessing and analyzing the maximum force applied to a rigid wall by a non-lethal projectile. The experimental shootings with the Mossberg 500 were carried out for a distance of 2.8 m from the target. The ammunition used for the tests was an improvised ammunition.**

***Index Terms*—Photron, sensor, procedure, impacts, projectile.**

I. Introduction

Regarding the study of lesional ballistics associated with non-lethal kinetic weapon systems, the observation and working environment is represented by ballistic simulators. With those simulators, the ability to penetrate human skin can be assessed, but also the ability to dissipate a sufficient amount of energy, whose amplitude must correspond to reversible trauma.

To evaluate and quantify the risk of injury to the human body with non-lethal projectiles we used as a reference the following method based on the maximum force applied to a rigid wall by a non-lethal projectile. The maximum contact force correlates with the severity of the injury.

The purpose of the experimental shootings carried out in this paper is to evaluate the terminal effect of rubber components fired with a 12 gauge shotgun. The speed of the projectiles and the scattering of rubber balls fired by the Mossberg 500 series semi-automatic weapon will be measured.

The goal of this paper is to give us a clear idea of the ability of a non-lethal kinetic ammunition to generate trauma of a certain severity for different target engagement distances.

II. Equipment

The tests on a simulant consisting of a rigid environment were carried out in order to highlight the energy transfer between a non-lethal kinetic projectile and the target, the impact speed but also the deformation of the projectile after the moment of contact on the rigid target. The weapon system used in the tests is the Mossberg 500 pump action shotgun presented in Fig. 1.

Figure 1. Mossberg 500 shotgun

The experimental shooting sessions involved the use of 12-gauge non-lethal kinetic improvised ammunition, compatible with the available firearm. In order to ensure a low lethality, it was necessary to use ammunition in experimental configurations that involved inserting into the cartridge different rubber spheres, keeping the same amount of propellants originally provided in the cartridge. One type of the configurations is presented in Fig. 2.

Figure 2. 12 gauge rubber round

Thereby, four configurations of non-kinetic improvised ammunition with rubber balls were obtained, as follows:

The experimental tests carried out in the shooting range involved the use of electronic equipment (ballistic chronograph, two high-speed cameras, two laptops with the PicoScope 6 data acquisition software platform), the rigid target together with a power transducer.

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TABLE I. IMPROVISED AMMUNITION PROPERTIES OF THE CONFIGURATIONS USED

Type	Diameter (mm)	Mass (g)	Density (g/mm^3)	Speed (m/s)	Number of cartridges available
A	17	3.57	0.0013	197.08	10
B	10.5	1.38	0.0022	195.7	3
C	10.5	0.726	0.0012	269.9	4
D	12.7	1.33	0.0012	241.21	3

III. PROCEDURE

The main objective is to study and evaluate the risk of non-lethal kinetic projectiles penetrating human skin. This objective can be achieved by analyzing the value of the maximum force applied to a rigid wall by non-lethal kinetic projectiles. The maximum amplitude of the contact force will be correlated with the level of severity of the potential traumas generated. It was found that the average critical value of the normal stress that is induced during blunt impact is 10 MPa, for the penetration of human skin.

For the experiments, the Mossberg 500 shotgun was positioned at a distance of 2.8 m from the target and fixed on a support to ensure the immobility of the weapon during firing. The piezoelectric force transducer was mounted in the impact area to determine the instantaneous impact force between the projectile and the target.

Figure 3. Target-shotgun setup

A number of 6 shots were fired on the rigid wall. Footage recorded using ultra-fast cameras indicated that, as a result of some shootings, the rubber components bounced, and in other situations, they broke instantly after the contact with the surface of the rigid wall.

Related to the projectiles, one of the important parameters addressed is their impact kinetic energy given by the following relation:

$$E_c = \frac{1}{2} m_p v_p^2, \quad (1)$$

where: m_p - represents the mass of the projectile; v_p^2 - represents the square of the impact velocity at the target of the projectile.

In order to calculate the impact energy density, the kinetic impact energy as well as the contact surface between the projectile and the target needs to be known.

$$DE = \frac{E_c}{A_c}, \quad (2)$$

where: E_c - kinetic energy; A_c - represents the area of the contact section between the projectile and the target.

Normal stress is the ratio of the force generated to the instantaneous cross-sectional area of the projectile

$$\sigma = \frac{F(t)}{S(t)}, \quad (3)$$

where: σ represents the normal stress; $F(t)$ - the force measured in the time instance; $S(t)$ - the cross-sectional area of the projectile in the time instance.

One of the reference values in studies evaluating the terminal effect of non-lethal kinetic ammunition is energy density.

IV. RESULTS

During the experiments, after high-speed recording, it was noticed that the projectiles broke instantly, parts of it bouncing as presented in Fig. 4.

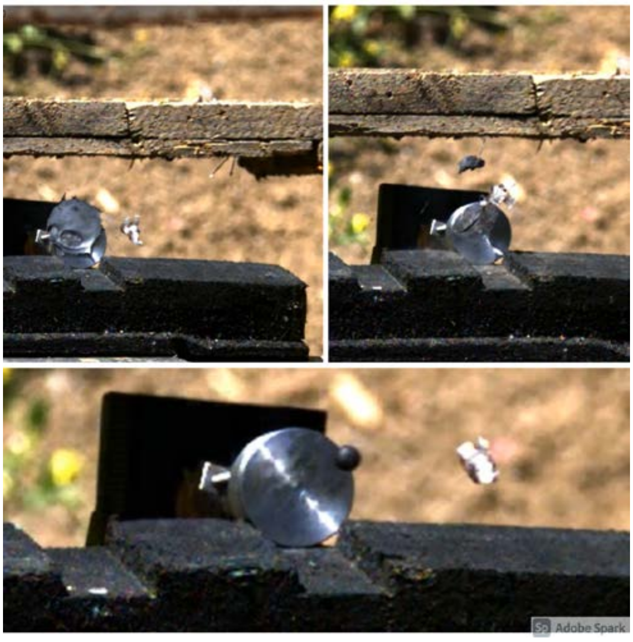

Figure 4. Impact of ammunition with the impact surface of the rigid wall during firing

For each non-lethal kinetic projectile used, the procedure detailed in the “Skin Penetration Assessment of Non-Lethal Projectiles” standard involves the evaluation of the normal stress generated by the impact with the rigid wall.

Fig. 5 shows the diameter of the impact surface measured.

Figure 5. The diameter of the impact surface of the rigid wall

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Table II shows the dimensional evolution of the cavity formed by the non-lethal kinetic improvised projectile on the contact surface. Therefore, the energy transfer between a non-lethal kinetic improvised projectile and a target consisting of a rigid wall can be quantified from the perspective of how the target absorbs. a certain amount of energy that the projectile stores at the time of impact.

TABLE II. THE EVOLUTION OF THE CONTACT SURFACE OF THE COMBAT COMPONENTS AS A FUNCTION OF TIME

Frame	Time (μs)	Diameter (mm)	Surface (m^2)
-316	010533	17	0.0002
-315	010500	28	0.0018
-314	010466	66.5	0.0034
-313	010433	77	0.0047
-312	010400	77	0.0047
-311	010366	70	0.0038
-310	010333	70	0.0038
-309	010300	63	0.0031
-308	010266	63	0.0031
-307	010233	49	0.0018
-306	010200	49	0.0018

The piezoelectric force transducer was capable to record the signal corresponding to the impact caused by each shot. The transmitted signal represents the impact force as a function of time, and the data recorded was analyzed using the Picoscope 6 acquisition platform.

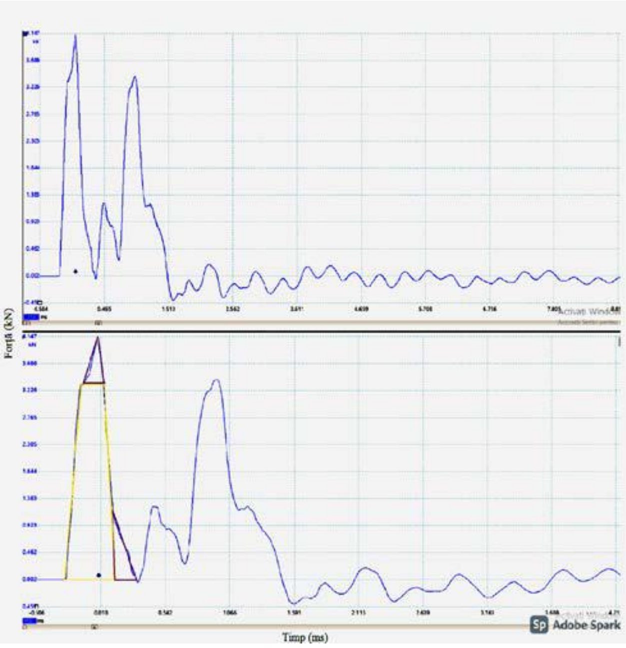

Figure 6. Signal recorded at shot number 1

At the top of Fig. 6 is the signal recorded by the PicoScope 6 data acquisition platform, and at the bottom are the geometric figures used to calculate the momentum absorbed by the target during the impact.

As can be seen, the total momentum is represented by the area below the graph as the sum of the areas consists of 2 triangles and a trapezoid. The value of the maximum impulse and force recorded using the data acquisition platform are as follows:

- the total impulse has the value of $p = 0.1214\ \mathrm{N \cdot s}$

- the maximum force recorded was $F_{\max} = 4123\ \mathrm{kN}$.

For comparison, other signals correponding to different configurations were obtained:

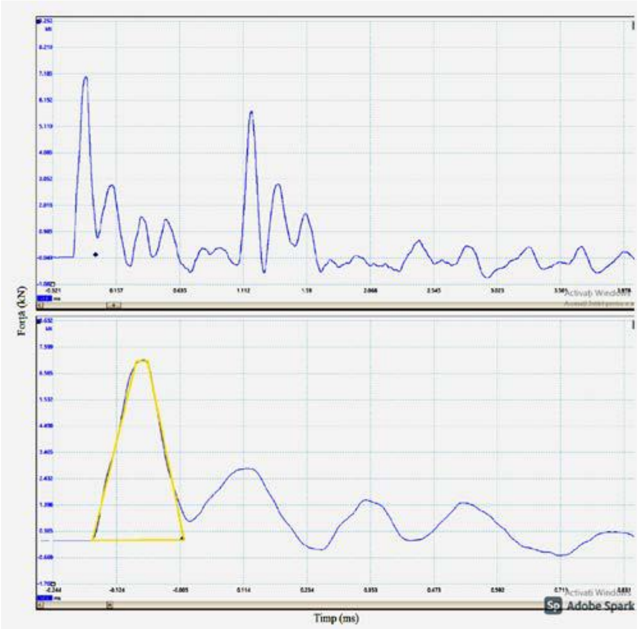

Figure7. Signal recorded at shot number 2

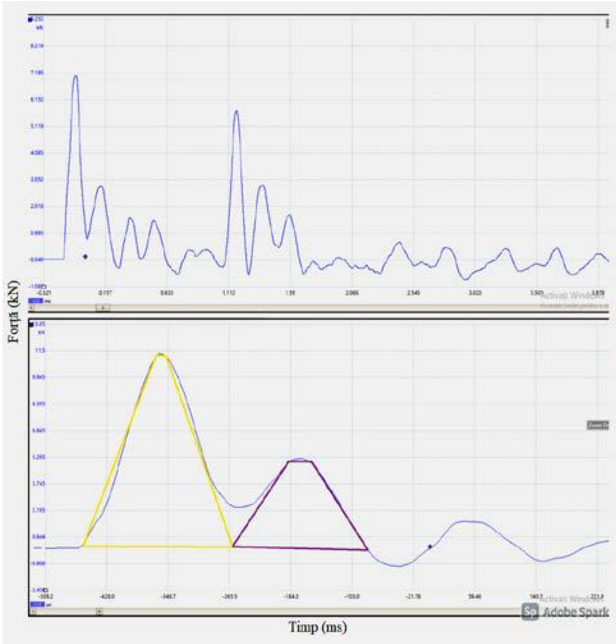

Figure 8. Signal recorded at shot number 3

V. DISCUSSIONS

Following the experiments, it was observed that the support ensures the stability of the weapon during several firing sessions and the impact points are able to fit in a circle having a diameter less than or equal to the surface of the contact flange corresponding to the rigid wall.

Therefore, the energy transfer between a non-lethal kinetic projectile and a target made of a rigid wall can be quantified from the perspective of how the target absorbs a certain amount of energy that the projectile stores at the time of impact. The experimental results obtained due to be used to establish the purpose and engagement of targets for different non-lethal kinetic weapon systems, in relation to the level of threats faced by users.

Also, the experimental data can be evaluated from the evolution of normal stress with time obtained during firing with prototype ammunition in configuration A (Fig. 8). The recorded stress increases relatively linearly until the maximum value is reached, after which it suddenly decreases. The maximum stress value was 1642 MPa, when the recorded force was 2957 N, at 322 µs from the moment of impact between the projectile and the rigid wall. At that time, the contact surface had a diameter of 49 mm. Following the impact with the rigid wall, the ammunition in configuration A underwent an elasto-plastic expansion, following to fragmentation.

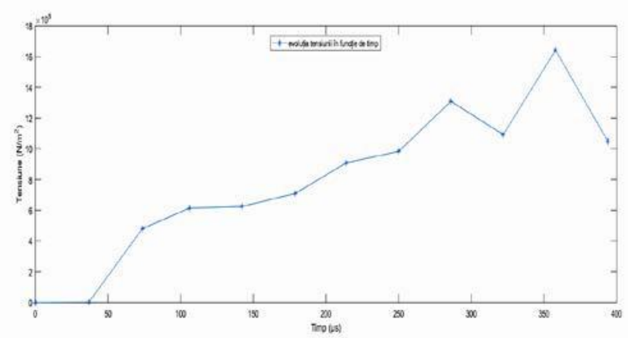

Figure 9. The evolution of the normal stress as a function of time during the firing with improvised ammunition in configuration A

VI. CONCLUSIONS

The values obtained and emphasized in Fig. 9 corroborated with the value thresholds determined for the risk of trauma, indicate that, following the impact with the rigid wall, the improvised non-lethal kinetic rounds can transfer a sufficient amount of energy to cause severe trauma.

It should be noted that the terminal effect of non-lethal kinetic ammunition, whose characteristics such as size, shape and constituent materials are very varied, can be assessed not only in terms of kinetic energy or energy density, but also in terms of projectile density, whose proportionality with the depth of penetration was observed.

The energy transfer between a non-lethal kinetic projectile and a target can also be quantified by the way in which the target absorbs a certain amount of energy that the projectile stores at the moment of impact.

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