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NUMERICAL MODELLING OF TERMINAL BALLISTIC FOR 40 X 46 MM LESS-LETHAL KINETIC GRENADE

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Abstract: *This paper presents the terminal ballistics of a 40x46mm less lethal grenade. The aim of the research was to determine the kinetic energy applied to the surface in the moment of impact and also the non-lethal characteristic of this ammunition. 40 x 46 mm less-lethal kinetic grenade is made of resilient material that increases its surface in the moment of impact in order to dissipate the kinetic energy developed.*

Keywords: 40x46 mm, less lethal, terminal ballistics

1. Introduction

Usually, in a definition of a weapon it is explained what a weapon should do, while the definitions of less-lethal weapons explain what a weapon should not do. Less-lethal weapons are specifically designed to incapacitate people, with minimal collateral damage and not cause unnecessary suffering. NATO defines "non-lethal" weapons as follows: *Non-lethal weapons are weapons which are explicitly designed and developed to incapacitate or repel personnel, with a low probability of fatality or permanent injury, or to disable equipment, with minimal undesired damage or impact on the environment [NATO mission statement, October 13, 1999].* According to the United Nations Institute for Disarmament Research (UNIDIR) non-lethal weapons (or less-lethal) can be defined as: *Non-lethal weapons are specifically designed to incapacitate people or disable equipment, with minimal collateral damage to buildings and the environment; they should be discriminate and not cause unnecessary suffering; their effect should be temporary and reversible; and they should provide alternatives to, or raise the threshold for, use of lethal force.*[1] As is apparent from these descriptions, the predicate less-lethal does not imply that these weapons cannot cause death, most important is the intent that they are non-lethal in case they are used and that death caused by the weapon employed is as unlikely as possible [4]. Non-lethality is dependent on the inherent nature of the weapon, the way a weapon is used and the vulnerability of the opponent or equipment. For a weapon to be less-lethal, it must hurt the enemy and not kill it [5]. So according to this, terminal ballistics (projectile-target interaction) of a less-lethal kinetic ammunition is very important. Of course, a less-lethal weapon should use a non-penetrating kinetic projectile in different shapes and weights, for example: baton rounds, beanbags, fin stabilised rubber projectiles, multi-ball rounds, rubber ball rounds, and sponge grenades, etc.

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Figure 1: Multi-ball rounds KO47/32

Figure 2: ALS3705 Interlocking Rubber Batons

2. 40x46 mm ammunition

In the middle of the seventh decade of the last century, in USA, a weapon system was developed, which by its low size, light weight, great mobility, constructive simplicity, and others, meets the characteristics of a system designed to equip infantry forces, but through the calibre, the organization of the shot, the precision and the effect on the target, belongs to the artillery.

A grenade launcher is a weapon that launches a grenade at a far greater distance than a soldier can throw it with hand, aimed to destroy or neutralize personnel and combat vehicles.

The 40x46 mm ammunition is unique in its operation because it features two distinct combustion chambers, one of low pressure and one of high pressure. The components of a cartridge tube for 40x46 mm ammunition are shown in the Figure 3: 1- the body of the cartridge tube (low pressure chamber), 2- high pressure chamber, 3- liner, 4- screw port primer, 5- primer, 6- propellant.

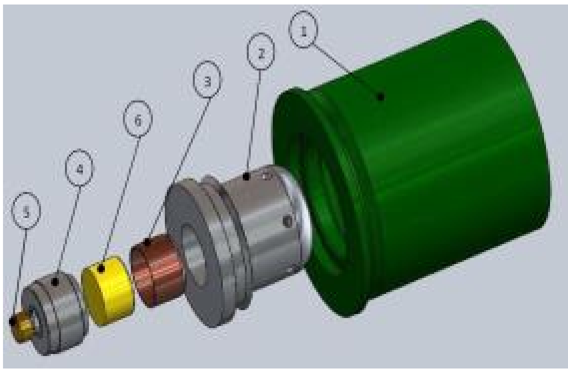

Figure 3: Components of a cartridge tube

3. Terminal ballistic

First of all, in order to be a non-lethal / less-lethal ammunition the projectile must not injure, perforate, or cause the death of the target. Until recently, the criterion of non-lethality was given by the kinetic energy the grenade provided to the target at the time of the impact, namely it was not allowed to be greater than 11-12 J, at which time the permanent damage to the target could occur [2]. Recently, this limit has been replaced by a condition of kinetic energy dissipated over a certain space. All this because it has been shown that with a kinetic energy of 10 J can penetrate the human body if it is distributed on a relatively small surface. For example, if you use 10J kinetic energy distributed by a rubber projectile on a 40 mm impact surface, it will not be enough to penetrate the human body, but if you use 10J kinetic energy through a needle, it will certainly penetrate the human body. That is why the limit of 11-12 J has been replaced by the limit of 6-7 J / cm^2 (at this limit the target is assumed to be physically traumatized). Up to 10J / cm^2 is considered that the skin will be penetrated.

3.1. Numerical simulation

The purpose of impact simulation between projectile and target was to compare the numerical results with the experimental ones in terms of the evolution mode and the value of the maximum pressure induced in the target at the moment of impact. This aspect is of particular relevance because the criteria for defining non-lethality are based precisely on the value of the pressure induced in the target.

The numerical impact simulation was done in LsDyna v971, the type of analysis being explicit.

Following the meshing of the structures involved in the impact phenomenon, 34718 knots, 5928 solids (hexahedrons) and 24556 SPH particles were obtained. Once the continuous meshing phase has been completed, the material patterns have been chosen and defined. The starting point was the physical structure defined in the design of non-lethal ammunition. Thus, a projectile with an elastic layer and a core of wheat flour was chosen, the impact target being made of steel.

The types of solid elements used were: Type 1 for target and Type 5 (ALE type element) for the coating of the projectile.

To describe the behavior of the materials involved in the simulation, we chose the following material models:

- A plastic-kinematic model (MAT_PLASTIC_KINEMATIC) was used for the steel target;
- For the projectile core, a granular model (MAT_SOIL_AND_FOAM) was chosen;
- For the coating of the projectile, a hypelastic material (MAT_MOONEY-RIVLIN_RUBBER) was chosen.

3.1.1 The Mooney-Rivlin model

As with other types of material, efforts to mathematically define the behaviour of hyperelastic materials can be dated from the early 1900s. For the Mooney-Rivlin model, the earliest dates are found in 1940 when Mooney proposed a two-parameters being introduced the hypothesis of a linear relationship between tension and deformation in the case of shear tests. Later, in 1950, Mooney's relationship was changed to introduce a relationship of deformation energy based on deformation invariants.

The mathematical expression of the model is:

$$W = A(I - 3) + B(II - 3) + C(III^{-2} - 1) + D(III - 1)^2$$

$$C = 0{,}5A + B$$

$$D = \frac{A(5\nu - 2) + B(11\nu - 5)}{2(1 - 2\nu)}$$

Where: W is the energy density function, ν is the Poisson coefficient, I, II, III represents the invariants of the deformation tensor and A and B are material constants.

Determination of material constants is based on a simple stretch test that allows the recording of force and displacement values. Subsequently, based on the numerical processing of the results, the correspondence between the conventional voltage and the deformation will be obtained. Then, one of the basic numerical methods (such as the least squares) can determine the values of the constants so that the linear relation approximates exactly the well-known form S of the hydraulic material.

3.1.2. Soil and Foam model

This type of model is recommended to be used when trying to model the behavior of granular or foam material. It is specific to this type of material that the material law is defined by points expressing the pressure dependence on the volume deformation.

The definition of the ratio between the two sizes is made on the basis of a compression test in which the flour (whose percentage of moisture was previously determined) is introduced into a cylinder (to confine) and then on the test bench of an universal test machine is pressed by means of a piston on the flour, recording the values of force and displacement. Subsequently, knowing the cross-sectional area of the piston, pressure and volume variation are determined.

This type of material model also has a condition where the particles that have been attributed to this model are coated.

3.1.3. Plastic Kinematic model

The plastic-kinematic model with viscosity has the mathematical expression provided by the relationship.

$$\sigma_{ef} = \sigma(\varepsilon)\left[1 + \left(\frac{\dot{\varepsilon}}{c}\right)^{\frac{1}{\rho}}\right] \qquad (4,70)$$

Where: c, p - coefficients of material and $\sigma(\varepsilon)$ *is the diagram characteristic of the static regime.*

To complete the models, it is necessary to define the boundary conditions and initial conditions. The initial conditions refer to the velocity of the projectile at the moment of impact, in the accepted simulation the assumption of a normal impact and the null value of the velocity rotation vector of the projectile.

In terms of boundary conditions, these refer to restrictions on degrees of freedom, restrictions due to the modeling of only ¼ of the 3D structure and the movement restrictions imposed on the plate as a result of its attachment during the tests.

Another key element in defining the simulation parameters was to define the contacts between the three parts of the model (projectile core, projectile coat and target). At this stage, furthermore, in order to avoid the possibility of occurrence of negative volumes during impact, an internal contact for the shell of the projectile was also defined.

The simulation captures the terminal ballistics phenomenon that occurs as a result of the interaction of a 75g projectile (15% moisture wheat flour core and the latex tire) impacting a 3mm thick steel plate.

The deformation of the projectile during impact with the steel target is shown in *Figure 4*, *Figure 5 and Figure 6*. The velocity variation of the projectile during impact is shown in *Figure 7*.

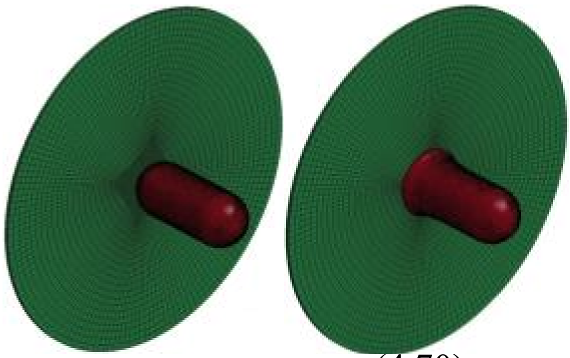

Figure 4: t = 0 ms; t = 0,4 ms

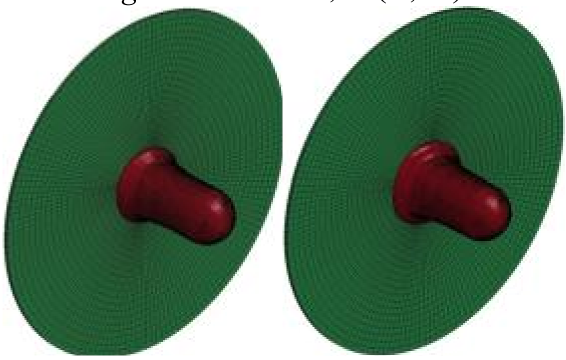

Figure 5: t = 0,5 ms; t = 0,6 ms;

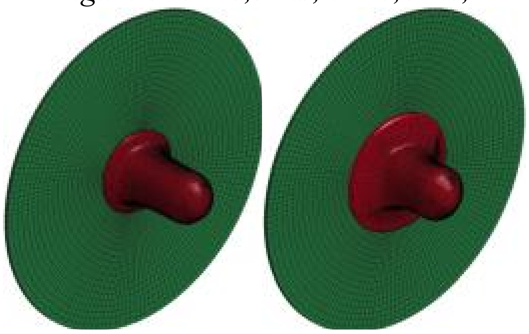

Figure 6: t = 0,7 ms; t = 1,4 ms;

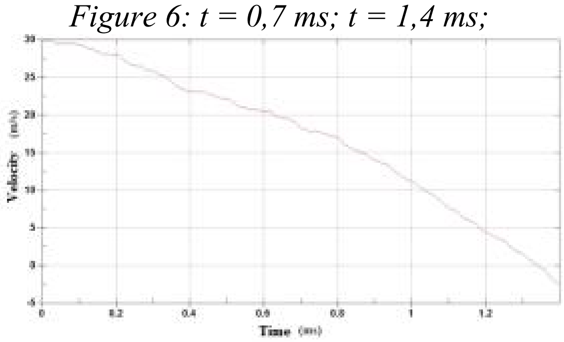

Figure 7: Velocity variation

3.2. Experimental tests

In order for ammunition to be non-lethal, it must not cause a penetration of the skin's target. According to AEP-94 [3] there are two methods to check whether non-lethal ammunition is capable of perforating the skin of a human subject.

3.2.1 The method using a surrogate

The first method is represented by the use of a human body simulator (a surrogate) in which the fire will be executed at certain distances. The inner layer of the surrogate is represented by a block (cube) of 20% ballistic gelatin (ballistic gelatin, 20% 80%water). The outer cover is a goatskin. A 6mm thick bumper screen is provided between the outer layer and the gelatin block. The conclusions of this test are easy to interpret because it should only be studied the effect of the non-lethal projectile on the surrogate. The projectile is considered to have non-lethal effect if there is no visible damage to the outer layer or to the ballistic gelatin block. If the skin layer is penetrated or cracks appear in the gelatin block then the projectile is considered to have caused the injury.

The human body simulator consists of three components: goatskin, sponge screen, and gelatin block.

• The gelatin block will have a 20% concentration and will be stored at 10 degrees Celsius. Each side of the cube will have a length of 25 cm and will be able to try on any face of it.

• The sponge screen has a thickness of 6mm and the properties it needs to meet are listed in ISO 4593: 1993.

• Goat skin is recommended to have a thickness as close as 1.39 mm and this must be recorded in advance.

3.2.2. Method using force sensors

This method involves the use of force sensors placed under a rigid wall on which the fire is executed, thus checking the force exerted by the projectile and the impact surface, both depending on time.

4. Conclusions

Less-lethal weapons are specifically designed to incapacitate people, with minimal collateral damage and not cause unnecessary suffering.

In order to be a non-lethal / less-lethal ammunition the projectile must not injure, perforate, or cause the death of the target and his kinetic energy distributed on the impact surface is not allowed to be greater than 6-7 J / cm^2.

After interpreting simulation results, the remaining speed of 40x46 mm less-lethal projectile at the time of impact is 30 m / s, the impact time is 1,4 ms and the initial diameter of 40 mm, it appears to deform a lot at the moment of impact, increasing the contact surface with the target and thus reducing the amount of energy dissipated at the moment of impact.

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