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Comparison of less lethal 40 mm sponge projectile and the 37 mm projectile for injury assessment on human thorax

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Abstract. Since there is an increasing interest in avoiding human body injury in diverse situations like crowd control or peacekeeping missions, less lethal ammunition are more and more used. In this study we focus only on kinetic energy non-lethal (KENLW) projectiles. Their desired effects on human body are the temporary incapacitation through blunt trauma. There are different types of KENLW projectiles ranging from rigid to deformable projectiles. Unfortunately, the effects of such projectiles are not really well known as it is difficult to measure the force transmitted to the human body or the related deformation. Because the potential of injury excludes human living tests, tests are performed on cadavers, animals or human tissue surrogates. Besides these tests, numerical simulations are more and more used to gain more understanding, to assess or to predict the effects of this kind of projectile on human body. In this paper a comparison based on the viscous criterion between the 37 mm rigid projectile and the 40 mm sponge projectile was made.

1 Introduction

Since few years, KENLW (Non Lethal Kinetic weapons) ammunition has been used by law enforcement or military communities in diverse situations like controls of individuals and crowds, access denial to installations or peace keeping operations …The desired effects of these ammunitions are the temporary incapacitation through blunt trauma, avoiding serious or fatal injuries.

There exists a large spectrum of KENLW projectiles ranging from rigid to deformable. In the earliest days of KENLW use, most of the projectiles were rigid. One of the widely used rigid projectiles is the 37 mm baton round [1]. The validation of the lethality of this projectile has been made and data is available in the open literature [1,2].

Nowadays modern projectiles are generally large deformable projectiles. The reasons are twofold: A larger diameter will likely avoid the penetration of the human body as it increases the impact surface; The deformable nose will absorb a part of impact energy and reduce force as it deforms during the impact.

The most widely deformable projectile being in use is the 40 mm grenade. There are different types of 40 mm grenade as many ammunition manufacturers have developed their own approaches. In this paper we will consider the 40 mm NS projectile developed by Nobel Sport [3].

To evaluate these KENLW ammunitions, different injury criteria exist. The most used criterion for thoracic impacts is the viscous criterion $(VC)_{max}$ [1,4]. But one major issue still exists as it must be measured on a biofidelic material. At the one hand, the potential of injury excludes human living tests. At the other hand, for deformable projectiles, the human body (or the surrogate) as well as the projectile deform during the impact and measurements of such events are not easy. Therefore numerical simulations can be used as an ideal tool in the assessment of the injury risk.

A numerical thorax model has been developed [5]. In this study, the viscous criterion $(VC)_{max}$ has been used to assess thoracic injuries of the 37 mm rigid projectile and the 40 mm NS one. Validation of the $(VC)_{max}$ as an injury criterion has been made for the 37 mm projectile [1], but to our knowledge, no validation on human targets for the 40 mm NS or any deformable projectiles is publicly available.

2 Injury criterion

An injury criterion is a physical parameter whose quantity correlates with the level of injury. An injury tolerance is a value of the criterion at which an injury appears. It has been shown that the viscous criterion correlates well with the injury assessment for tests done on PMHS (Post Mortem Human Subject) [1]. This criterion is only based on the impacted zone characteristics, more precisely on the thorax deflection and the deflection rate [6–8]. Reference [1] shows that a $(VC)_{max} = 0.8$ m/s corresponds experimentally to a 50% chance of sustaining thoracic injury (rib facture) of AIS ≥ 2. The comparison of $(VC)_{max}$ of both projectiles will be made at the same initial kinetic energy.

3 Numerical modeling

The numerical thorax model developed in [5] was validated thanks to the results of the firings of the 37 mm hard plastic projectile against PMHS [1,2,9]. Indeed, this study [1] aimed at collecting physical measures of the impact phenomenon, observing the induced injuries and finding injury criteria that correlate well with them. It is essential of course that the target represents at best a human body, hence the choice of the PMHS.

The 37 mm-projectile is a rigid projectile made of non-compressible polyvinyl chloride (PVC) cylinder of diameter 37 mm and 100 mm long with a mass of 140 g.

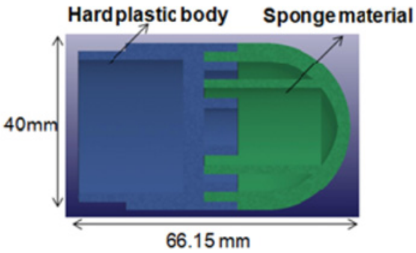

Fig. 1. Cross-section of the 40 mm NS.

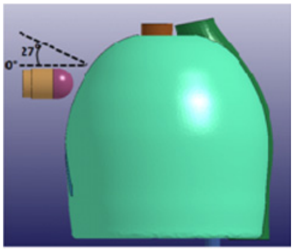

Fig. 2. Set-up of the impact of 40 mm NS on thorax.

Table 1. Material model.

	37 mm Projectile	40 mm NS hard body	40 mm NS sponge nose
Model	Elastic		Mooney-Rivlin
ρ(kg/m3)	1380		1000
E (Pa)	2.3 E+9		–
ν	0.33		0.49875
A (Pa)	–		5.60E+05
B (Pa)			−3.00E+04

Material model of the 37 mm projectile can be found in [5,10]. It is similar to the plastic baton round used in real crowd control situations [1]. Two projectile velocities were used: 20 m/s and 40 m/s.

The 40 mm NS is a projectile made of deformable rubber-like nose and a hard plastic body (figure 1). Its mass is 41.9 g. Nevertheless, material characterization and validation of the 40 mm NS against rigid wall was made in a previous study [11]. A set-up for the impact of 40 mm NS on thorax is given at figure 2. A second configuration was used with an impact direction of a = 27° as to have a normal impact to the thorax (figure 2). The thorax thickness is 0.236 m. Ls-Dyna was used for simulations.

Table 1 gives a summary of the different projectile material models.

Different impact velocities were used and Table 2 gives the corresponding projectile velocity for a given initial energy.

The nominal velocity for the 40 mm NS being around 90 m/s, the velocity of 73 m/s corresponds approximately to the velocity at a range of 60 m.

Table 2. Corresponding velocity for a given energy.

Corresponding velocity			
		37 mm Projectile	40 mm NS Projectile
@Equal kinetic energy	28J	20 m/s	37 m/s
	112J	40 m/s	73 m/s

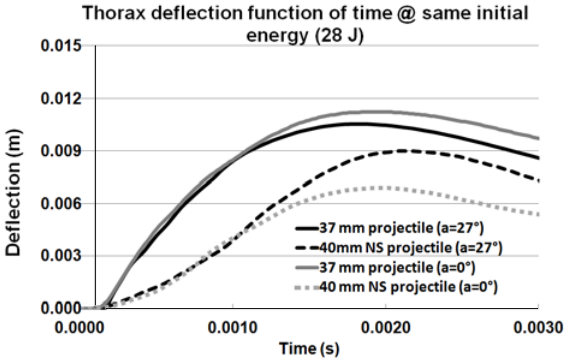

Fig. 3. Thorax deflection comparison between the two projectiles at initial energy of 112 J.

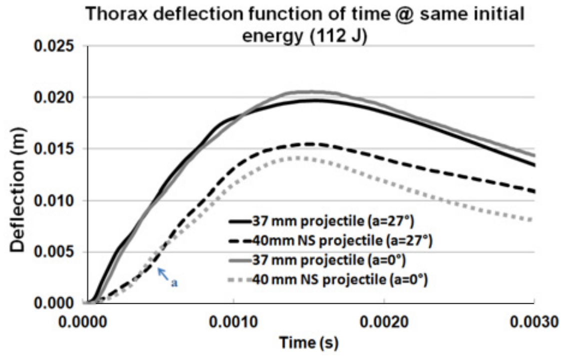

Fig. 4. Thorax deflection comparison between the two projectiles at initial energy of 112 J.

4 Numerical results

Numerical simulations show that at 0°, the projectile tumbles while at 27° (normal impact) there is no tumbling of the projectile.

Figures 3 and 4 give the thorax deflection histories for a given energy at the 2 different impact angles. We see that there is a big difference in the thorax induced behavior by the two projectiles at the same energy. All the curves related to the 40 mm NS are below those related to the 37 mm projectile, the thorax deflection induced by the 40 mm NS is always lower than for the 37 mm at the same energy.

For a given projectile, the deflection curves show the same profile at the different impact angles with some differences. The impact angle influence looks limited for the 37 mm projectile, but seems more important for the 40 mm projectile. The maximum error on the maximal deflection is about 30%. Nevertheless, this influence is reduced at higher energies.

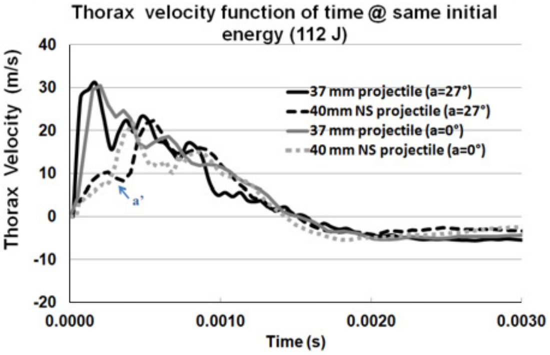

Fig. 5. Thorax velocity comparison between the two projectiles at initial energy of 112 J.

Table 3. (VC)max for a given energy and impact angle.

@Equal energy	**Impact angle**	**37 mm Projectile (m/s)**	**40 mm** NS **projectile (m/s)**
28 J	0°	0.27	0.11
	27°	0.29	0.18
112 J	0°	1.14	0.63
	27°	1.13	0.77

The thorax deflection rate (thorax velocity) during the loading phase is almost constant for the 37 mm up to the maximal deflection whereas that is not the case for the 40 mm NS. This can be clearly seen on the figure 5 (point a') which gives the velocity of the thorax deflection (we did not represent the curves at energy of 28 J as they presented the same trend). This difference may be attributed to the high deformability of the 40 mm NS nose. Therefore the 40 mm NS (nose) acts as a dashpot at the beginning of the impact process (up to the inflexion point (a) in figure 4) and afterwards the projectile behaves like a stiff projectile. Table 3 gives the (VC)max. The (VC)max for the 40 mm NS is lower than the (VC)max for the 37 mm baton round at the same energy. Therefore the 40 mm NS is supposed to be less harmful than the 37 mm baton round, at the same energy.

We also see that for a given velocity and at the same energy, there is almost no difference at different impact angles for the 37 mm baton round. But the difference is more important for the 40 mm NS. As a comparison, at nominal velocity (90 m/s), the value of $(VC)_{max}$ for the 40 mm NS is 0.90 m/s. It is lower than the value obtained for the 37 mm baton round at 40 m/s. This value of 0.90 m/s corresponds to a 64% chance of sustaining thoracic of AIS ≥ 2.

5 Conclusions

Numerical simulations have been used to assess and compare the lethality of two projectiles. Simulations were performed at two different impact angles. For both angles, the thorax deflections corresponding to the impact of 40 mm NS were lower than the ones corresponding to the 37 mm baton round and accordingly the (VC)max. Because if its high deformability, the 40 mm NS projectile nose acts like a dashpot which dissipates a part of the energy impact at the early stage of the impact process and reducing by the way the effect on the thorax. It has been shown that at the same energy, the 40 mm NS performs better in reducing the risk of injury than the 37 mm baton round.

References

1. C. Bir, *The evaluation of blunt ballistic impacts of t he thorax,* Doctor of Philosophy Dissertation. Wayne State University Detroit, Michigan, (2000)
2. C. Bir, D. Viano, A. King, *Development of biomechanical response corridors of the thorax to blunt ballistic impacts*, Journal of Biomechanics **37** 73–79 (2004)
3. C. Robbe, N. Nsiampa, A. Papy, *Impact Measurements of Different 40mm Non-Lethal Sponge Grenades.* 26th International Symposium on Ballistics (2011)
4. I. Lau, D. Viano, *"The Viscous Criterion - Bases and Applications of an Injury Severity Index for Soft Tissues,"* SAE Technical Paper 861882, (1986), doi:10.4271/861882
5. N. Nsiampa, C. Robbe and A. Papy, *Numerical Investigations of Impact of Non Lethal Kinetic Projectiles onto Human Thorax,* 16th International Symposium on Non Lethal weapons (2011)
6. DC Viano, A. King A, *Biomechanics of chest and abdomen impacts*, Biomechanics: principles and applications. CRC Press 7:119-130, CRC Press (2003)
7. Schmitt K-U, Niederer P, Muser M et al. *Trauma biomechanics: accidental injury in traffic and sports,* 2nd Ed. **5**:127-131, **6**:147-153(2007)
8. C. Robbe, E. Lemaire, A. Papy, V. Esthers, *Armes non létales*, 317 - 332. *Traité de médecine légale* (Beauthier), (2011)
9. C. Bir and D.C. Viano, *Biomechanical predictor of commotion cordis in high-speed chest impact.* J Trauma **47**(3):468-473, (1999)
10. A. Bouamal and Lévesque H., *Development and validation of a finite element human thorax model under blunt ballistic trauma,* (2007)
11. N. Nsiampa, C. Robbe, A. Papy, *Development of a thorax finite element model for thoracic injury assessment,* 8th European LS-DYNA Users Conference, (2011)