International Journal of Natural Sciences Research
2018 Vol. 6, No. 1, pp. 15-22
ISSN(e): 2311-4746
ISSN(p): 2311-7435
DOI: 10.18488/journal.63.2018.61.15.22

A BEHAVIORAL STUDY OF CYLINDRICAL OBJECT IMPACTED BY BULLET USING FEA

Tanadon Saisueb[1+]
Pattaraweerin Woraratsoontorn[2]

[1,2]*Department of Industrial Physics and Medical Instrumentation, Faculty of Applied Science, King Mongkut's University of Technology North Bangkok, Bangkok, Thailand*
[1]*Email: mate_tanadon@hotmail.com Tel: +66839777077*
[2]*Email: pattaraweerin.w@sci.kmutnb.ac.th Tel: +66906472455*

(+ Corresponding author)

Article History
Received: 20 March 2018
Revised: 25 April 2018
Accepted: 8 May 2018
Published: 17 May 2018

Keywords
Bullet
Firearm
Cylindrical object
Stainless steel pen
Finite element method
Forensic science.

ABSTRACT

Crime news has now become a popular mass media topic with offenders often using pocketknives and firearms. Pocketknives are inexpensive and easily obtained while in Thailand firearms have also become readily available. Some people are lucky and survive gunshot wounds; articles carried in their shirt pockets, especially a metal pen, may increase survival chances. Deformation behavior of a cylindrical object and a stainless steel pen impacted by a 9 mm FMJ (full metal jacket) bullet were investigated under various conditions. Finite element analysis (FEA) was applied to simulate different shooting conditions. Comparison of FEA shooting test simulation results revealed that a cylindrical object and stainless steel pen behaved in a similar manner. Simulation results can be useful to support forensic science examinations. Analysis of the findings indicated that having a stainless steel pen in your shirt pocket may improve the chances of surviving a bullet wound.

Contribution/Originality: This study is one of very few studies which have investigated the chances of survival after being shot by a bullet. A simplified cylindrical object was used to replicate a stainless steel pen with a simulation using 3D finite element analysis.

1. INTRODUCTION

Firearms are often used by criminals. They are powerful weapons that cause damage to life and property. Illegal use of firearms is a serious offence. Forensic investigate of bullets and gunshot wounds is very important. This often results in a positive identification of the offender and acts as a deterrent to gun crime in society. Recent technological advancements in forensic examinations regarding bullets have reduced the time and cost of simulating real life situations. Moreover, analysis results can be used to confirm forensic examination findings regarding bullets trajectories and velocity.

In a previous study, M.R. Ahmad et al. attempted to use natural rubber to improve the structure of armour and increase its efficiency against bullets. Nonwoven fiberglass coated with natural rubber latex (NRL) specially prepared by Revertex (Malaysia) has 12 overlying layers which increase absorption of bullet velocity by up to 17% [1]. Mario Štiavnicky et al. experimented with various composite materials to fabricate armour for the arm at 50 mm thickness with a lighter weight than other materials. They found that Kevlar fabric reduced the speed of a bullet better than ceramic plates [2]. For ammunition, Roger Alimi et al. conducted laboratory tests to determine compensation temperatures that affected the efficiency of a 40 mm propulsion projectile. Generation of more than 1 MJ of power from a 1 GW power source increased the propulsion of a 300-gr projectile by 20% [3]. Finite element analysis (FEA) is often used for behavioral studies of variously-shaped bullets. FEA can economically and accurately reproduce real experimental conditions. Chuan Xua et al. used FEA to compare the head wounds of 17 pigs shot by an M43 bullet [4]. Human models have also been used in FEA. Jianyi Kang et al. studied the behaviour of the organs in the chest while wearing light armour after being hit with a 9 mm bullet. Their simulation results using FEA highlighted the forces acting on the internal organs and suggested that injury to the lungs may cause epicardial hemorrhages Jianyi, et al. [5]; Jack, et al. [6]; Hai, et al. [7]. Kui, et al. [8] investigated the behaviour of various organs after bullet impact, while one researcher used FEA to quantify brain injury caused by iron and wood sticks Kui, et al. [8]. Jean-Sébastien, et al. [9] analysed the behaviour of various shapes using FEA. This type of research has become popular in the forensic science field because the results are both accurate and reliable [9, 10].

Many people have tried to develop a lightweight material that can effectively reduce bullet impact. However, scant research has been conducted on the effects of the shape of the material with regard to ammunition impact. In everyday life, most people keep pens and belongings in their pockets. These may increase their chance of survival after being shot by a bullet. In this research, a cylindrical object was used as a substitute for a stainless steel pen. A 9 mm FMJ (full metal jacket) bullet with copper gilding was fired from varying distances at the object. The behaviour of the object was investigated using FEA.

2. METHODOLOGY

2.1. 3D Modeling

The 3D Model of the metal pen and the 9mm FMJ bullet have created in this research.Actually, the structure of these objects are complex. In 3D modeling, only some of the parts of object that affect the simulation were selected to create. In the case of the stainless steel pen, assume that the pen and gel refill are very close together without the volume of ink inside the pen. Since cylindrical objects are symmetrical throughout, a specific length has been used for modeling. This model is similar to a commercial stainless steel rod with a diameter of 7.525 mm, an external diameter of 9.525 mm and a length of 40 mm as shown in Figure 1. In this study, the 9 mm FMJ bullets made from copper has been used. In order to reduce time in processing using FEA, bullet without shell case after fired has been created. It has a diameter of 4.515 mm, a length of 10.54 mm and a length from the tip of bullet to the base of bullet 8.54 mm, this section is symmetrically curved as shown in Figure 2. Then, the type of element to fit has been identified properly for reality of simulation result.

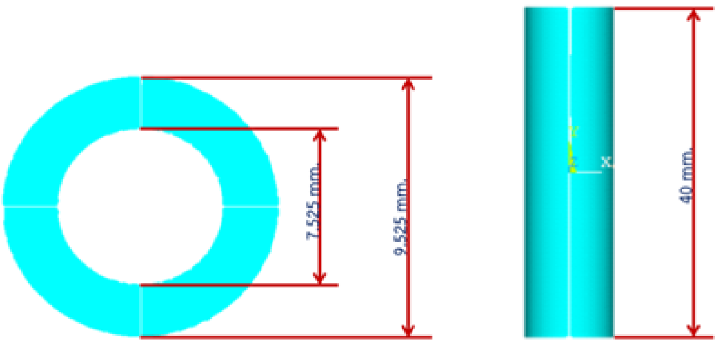

Figure-1. Dimensions of the 3D cylindrical object.

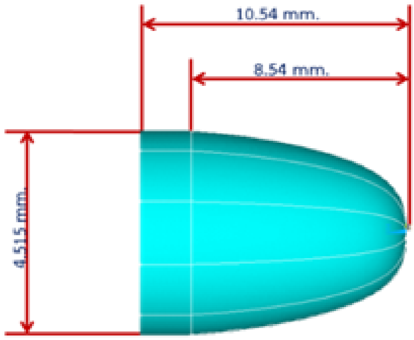

Figure-2. Dimensions of the 9 mm FMJ bullet.

2.2. Material Properties

Table-1. Material properties of 304 Stainless steel [11]

Mechanical Properties	Metric
Young's modulus	$193.00\times10^{9}\,N/m^{2}$
Poisson's ratio	0.290
Mass density	$8.00\times10^{3}\,kg/m^{3}$
Yield stress	$215.00\times10^{6}\,N/m^{2}$
Tangent modulus	$150.50\times10^{6}\,N/m^{2}$

Source:http://www.matweb.com/search/DataSheet.aspx?MatGUID=abc4415b0f8b490387e3c922237098da&ckck=1.

Table-2. Material properties of Copper [12]

Mechanical Properties	Metric
Young's modulus	$110.00\times10^{9}\,N/m^{2}$
Poisson's ratio	0.343
Mass density	$8.93\times10^{3}\,kg/m^{3}$
Yield stress	$33.30\times10^{6}\,N/m^{2}$
Tangent modulus	$23.31\times10^{6}\,N/m^{2}$

Source:http://www.matweb.com/search/DataSheet.aspx?MatGUID=9aebe83845c04c1db5126fada6f76f7e.

Material properties of the 304 stainless steel used to fabricate the cylindrical object and copper for the bullet are shown in Table 1 and Table 2 respectively.

The bullet velocity was defined according to data from Marshall and Sanow's experiments. They used 9 mm FMJ Winchester bullets weighing 7.5 g fired at a velocity of 352 m/s to study the permanent cavity volume and temporary stretch cavity volume in ballistic gelatin. Their results gave expansion 9.1 mm, penetration 620 mm, permanent cavity volume 41 mL and temporary stretch cavity volume 174 mL [13].

2.3. Boundary Conditions and Simulation

Firing a bullet into a cylindrical object was simulated. Characteristics of the bullet which impacted the cylindrical object were divided into four cases at various impact positions of the object to investigate its behaviour as follows:

2.3.1 The bullet impacted at the centre of the cylindrical object as shown in Figure 3.

. 2.3.2 The bullet impacted at 3/4 diameter of the cylindrical object as shown in Figure 4.

2.3.3 The bullet impacted at the edge of the circumference of the cylindrical object as shown in Figure 5.

2.3.4 The bullet impacted at the edge of the circumference of the cylindrical object with the additional speed of the pen moving towards the bullet at 0.5 m/s as shown in Figure 6.

In cases 1-3, the cylindrical object was fixed in the same plane as the bullet's direction of travel. The assumption was made that the pen was attached to the chest. In case 4, the cylindrical object was moving at 0.5 m/s towards the bullet, assume that the human body remove rapidly to avoid the bullet while shock.

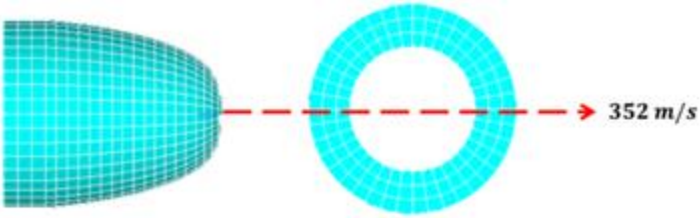

Figure-3. Case 1: The bullet impacted at the centre of the cylindrical object.

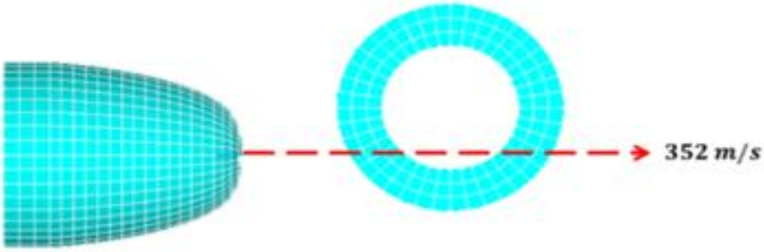

Figure-4. Case 2: The bullet impacted at 3/4 diameter of the cylindrical object.

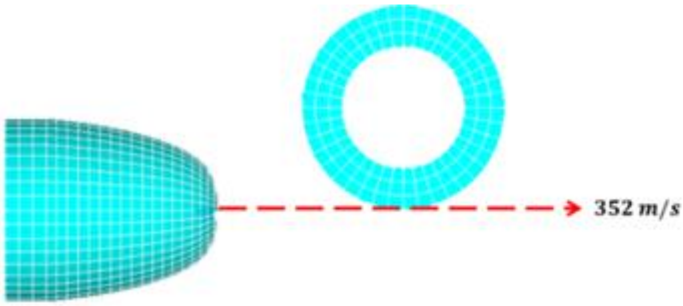

Figure-5. Case 3: The bullet impacted at the edge of the circumference of the cylindrical object.

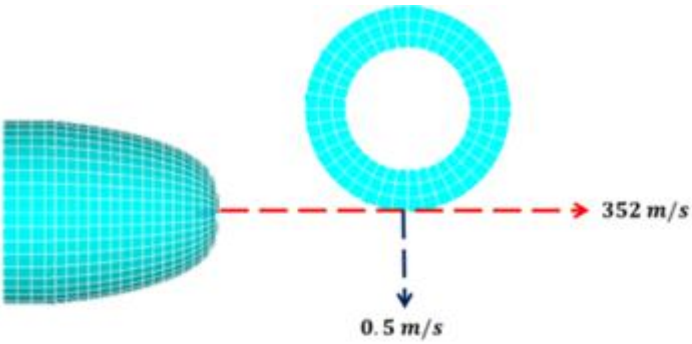

Figure-6. Case 4: The bullet impacted at the edge of the circumference of the cylindrical object that was moving at 0.5 m/s towards the bullet.

2.4. Validation

Experimental simulation results were compared with a shooting test of a bullet at a shooting range to confirm accuracy. A cylindrical object and bullet of the same size as used in the 3D model were tested. Figures 7 and 8 show the length of the 9 mm FMJ bullet with a lead soft core and copper gilding and the diameter of the cylindrical object respectively.

Figure-7. 9 mm FMJ bullet with copper gilding.

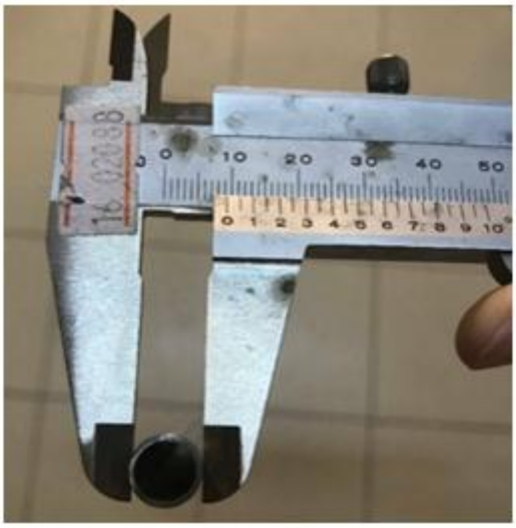

Figure-8. Diameter of the cylindrical object.

The shooting test to validate the simulation was designed carefully. When firing a bullet into a cylindrical object there is a limitation on the testing equipment. Furthermore, a gun is a dangerous weapon. Safety of the shooter and the observer was paramount. Therefore, only the first three cases were tested through actual shooting. In case 4, the cylindrical object was replaced with a stainless steel pen under the same conditions as in case 3. Shooting distances were set at 5, 10, 15 and 20 metres. Shooting test results can be summarised as follows:

2.4.1 The bullet impacted at the centre of the cylindrical object.

2.4.2 The bullet impacted at 3/4 diameter of the cylindrical object.

2.4.3 The bullet impacted at the edge of the circumference of the cylindrical object.

2.4.4 The bullet impacted at the edge of the circumference of the stainless steel pen.

3. RESULTS

Test results of the actual shooting into the cylindrical object were split into four cases to validate the behaviour of the cylindrical object achieved from the FEA simulation results. Findings of both the simulation and the actual test recorded a change in bullet trajectory and deformation, and cylindrical object deformation and fracture (Table 3). Cases 1-3 had the same test conditions and recorded the same results between the simulation and actual shooting. In case 1, the bullet impacted at the centre for both tests and the cylindrical object was bent at an angle of about 100 degrees; the bullet was deformed and the cylindrical object was fractured. Figure 9 shows the FEA result compared with the actual shooting test for a bullet impacting at the centre of the cylindrical object (case1).

Table-3. The simulation results comparing with the Shooting test results.

Test condition	**Changed bullet trajectory**	**Deformation of bullet**	**Deformation of cylindrical object**	**Fracture of cylindrical object**
- **FEM simulation** The bullet impacted at the centre of the cylindrical object.	✗	✓	✓	✓
The bullet impacted at 3/4 diameter of the cylindrical object.	✓	✓	✓	✓
The bullet impacted at the edge of the circumference of the cylindrical object.	✓	✓	✓	✓
The bullet impacted at the edge of the circumference of the cylindrical object that was moving at 0.5 m/s towards the bullet.	✓	✓	✓	✓
- **Shooting test (cylindrical object)** The bullet impacted at the centre of the cylindrical object.	✗	✓	✓	✓
The bullet impacted at 3/4 diameter of the cylindrical object.	✗	✓	✓	✓
The bullet impacted at the edge of the circumference of the cylindrical object.	✓	✓	✓	✗
- **Shooting test (stainless steel pen)** The bullet impacted at the edge of the circumference of the stainless steel pen.	✓	✓	✓	✗

Note : ✓ = Yes, ✗ = No

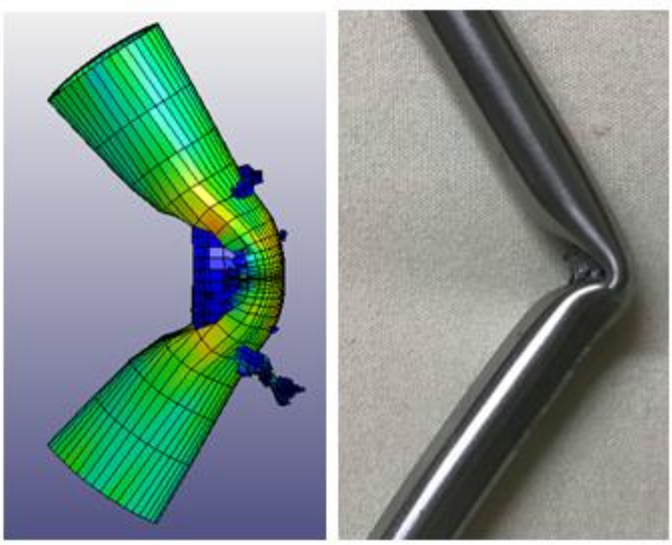

Figure-9. FEA (left) and actual shooting (right) for the bullet impacting at the centre of the cylindrical object.

Figure-10. Deformation of the cylindrical object impacted by the bullet at the edge of the circumference (left) and the stainless steel pen impacted by the bullet at the edge of the circumference (right).

4. CONCLUSION

Simulation results of the bullet impacting into the cylindrical object yielded a close approximation to the shooting test. Thus, FEA played a very important role in analysing the behaviour of the object. FEA can yield valuable information to support forensic evidence. Moreover, FEA reduced the time and costs incurred in staging an actual shooting. In everyday life, many people frequently carry a metal pen in their shirt pocket. This may increase their chances of survival if they are shot by a bullet. FEA simulation results and actual shooting test results indicated that a pocket pen may increase survival chances after being shot by a bullet. The stainless steel pen partially reduced the energy from the bullet through deflection. Thus, the bullet may not directly penetrate the heart following the path of the original shot.

Funding: This study received no specific financial support.
Competing Interests: The authors declare that they have no competing interests.
Contributors/Acknowledgement: Both authors contributed equally to the conception and design of the study.

REFERENCES

[1] M. R. Ahmad, N. Hassim, W. Y. W. Ahmad, A. Samsuri, and M. H. M. Yahya, "Utilising natural rubber latex in improving ballistic impact performance of unidirectional fabric systems," presented at the IEEE International Conference on Business Engineering and Industria Applications (ISBEIA), 2012.

[2] Š. Mario and A. Norbert, "Improved ballistic protection of vehicles using composites," presented at the IEEE International Conference on Military Technologies (ICMT), 2015.

[3] A. Roger, B. Lior, K. Eran, and S. Moris, "Temperature compensation and improved ballistic performance in a solid-propellant electrothermal-chemical (SPETC) 40-mm Gun," *IEEE Transactions on Magnetics*, vol. 43, pp. 289-293, 2007.
View at Google Scholar | *View at Publisher*

[4] X. Chuan, C. Yubin, L. Bingcang, Z. Liangchao, W. Jianmin, K. Jianyi, C. Zhiqiang, and L. Xiaoxia, "Finite element analysis vs experimental study of head firearm wound in pig," *Technology and Health Care*, vol. 23, pp. S61-S70, 2015.
View at Google Scholar | *View at Publisher*

[5] K. Jianyi, C. Jing, D. Ping, L. Hai, and Z. Qikuan, "Numerical simulation of human torso dynamics under non-penetrating ballistic impact on soft armor," *International Journal of Digital Content Technology and its Applications*, vol. 6, pp. 843-850, 2012. *View at Google Scholar* | *View at Publisher*

[6] R. C. Jack, B. J. Paul, O. C. V. James, W. E. Emily, C. P. Russell, C. G. Bliss, and M. C. Andrew, "Modeling nonpenetrating ballistic impact on a human Torso," *Johns Hopkins apl Technical Digest*, vol. 26, pp. 84-92, 2005. *View at Google Scholar*

[7] L. Hai, C. Jing, K. Jian-Yi, L. Xiao-Xia, and A. Ivan, "Finite element analysis of the dynamic response of the cardiovascular system to the blunt ballistic impact," *Computer Modelling & New Technologies*, vol. 18, pp. 44-49, 2014. *View at Google Scholar*

[8] L. Kui, W. Jiawen, L. Shengxiong, S. Sen, F. Chenjian, F. Xiaoxiang, and Y. Zhiyong, "Biomechanical behavior of brain injury caused by sticks using finite element model and Hybrid-III testing," *Chinese Journal of Traumatology*, vol. 18, pp. 65-73, 2015. *View at Google Scholar* | *View at Publisher*

[9] R. Jean-Sébastien, D. Caroline, W. Rémy, and L. Bertrand, "Finite-element models of the human head and their applications in forensic practice," *International Journal of Legal Medicine*, vol. 122, pp. 359-366, 2008. *View at Google Scholar* | *View at Publisher*

[10] A. Mota, W. S. Klug, M. Ortiz, and A. Pandolfi, "Finite element simulation of firearm injury to the human cranium," *Computational Mechanics*, vol. 31, pp. 115-121, 2003. *View at Google Scholar* | *View at Publisher*

[11] Matweb (Material Property Data), "304 stainless steel properties." Retrieved from http://www.matweb.com/search/DataSheet.aspx?MatGUID=abc4415b0f8b490387e3c922237098da&ckck=1. [Accessed 2017 Aug. 17], 1996.

[12] Matweb (Material Property Data), "Copper properties." Retrieved from http://www.matweb.com/search/DataSheet.aspx?MatGUID=9aebe83845c04c1db5126fada6f76f7e. [Accessed 2017 Aug. 17], 1996.

[13] Marshall and Sanow, "Handbook of handguns." Retrieved from https://books.google.co.th/books?id=njAeBQAAQBAJ&pg=PA162&lpg=PA162&dq=Marshall+and+Sanow,+Street+Stoppers,+Appendix+A,+Paladin+2006&source=bl&ots=QPPJOBWirA&sig=Nt5GYaRJm6kXfWdEY2gwhMEOXYw&hl=th&sa=X&ved=0ahUKEwig4p6665XZAhWLKo8KHVt6AswQ6AEIJTAA#v=onepage&q=Marshall%20and%20Sanow%2C%20Street%20Stoppers%2C%20Appendix%20A%2C%20Paladin%202006&f=false. [Accessed 2017 Oct. 1], 2006.