

# Influence of the collision speed and angle of a bullet: experimental reconstruction of bullet configuration and FE-analysis

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## Abstract

In this research, the bullet-firing test was carried out at different velocities and collision angles of the bullet. The influence of its velocity and angle on the deformation shape after firing was discussed by comparison with experiment and simulation. The velocity of the bullet was chosen in several kinds of speed ranges at 80m/s–250m/s. As for the angle of incidence with the collision object, four kinds of angles 90° (head-on collision), 45°, 30° and 60° were set. The deformation shape was measured by a 3D coordinate measurement machine and reconstructed with 3D-CAD based on the 3D digital data. The bullet hole and deformation of the polycarbonate board caused by the bullet's collision with the object was also examined. In addition, the collision simulation of the bullet was carried out using LS-DYNA, and these analytical results were compared with the 3D digital data of the bullet. The comparison of the FE-simulation analysis results of the experiment enabled the quantitative evaluation of the collision deformation.

*Keywords: collision, bullet, deformation analysis, LS-DYNA, 3D-CAD.*

## 1 Introduction

Gun crime has been increasing year on year. Collecting the bullet after firing is needed to solve these affairs [1]. It is often that a bullet is the only evidence in the affair. Therefore, studies about a bullet deformed by a collision are very



important. For example, rifling marks on a bullet after firing give information about the type of gun used; in the same way, deformation of the target will indicate the firing position and firing angle. The purpose of this research is to clarify the influence of collision velocity and collision angle on deformed shapes of bullets and targets. In addition, we simulated the collision of the bullet by FEM (Finite Element Method) and attempted a comparison between experimental and simulated results.

## 2 Experiment

### 2.1 Materials

Three types of bullet with full metal were used. The external appearances are shown in Figure 1. These are called “round nose bullet” and the lead core is coated with copper film. Bullets were shot with 38Auto and Wheel (S&W) gun (Figure 2) at a polycarbonate plate (PC), which was used as a shield. PC board of 10mm in thickness was used.

### 2.2 Experimental procedure

The distance from gun to target was about 6.4m shown in Figure 3. The velocity of the bullet was measured by a laser ballistic chronograph. The bullet velocity was controlled by adjusting the amount of explosive powder in the cartridge case. The 25AUTO and 380AUTO shown in Figure 1 (b)(c) were used in head-on collision tests. The 38SPL shown in Figure 1(a) was used in oblique collision tests. The collision angles are  $\theta=30^\circ$ ,  $45^\circ$  and  $60^\circ$  to the target shown in Figure 4.

## 3 Results and discussion

### 3.1 Test firing

The upper part in Figure 5 shows the bullet's original shape and deformed shapes in the case of head-on collision after firing. The corresponding bullet holes of the target plate were shown in the lower part. These configurations were precisely measured by a 3D coordinate measurement machine and were reconstructed by using a 3D-CAD system as digital data as shown in Figure 6. The reconstructed models of the deformed bullet were done to compare experimental and analytical results quantitatively. Moreover, by using the digital data, the deformed bullet's dimensions, for example, cross sectional areas and volumes, can be evaluated precisely.

Figure 7 shows the relationship between the bullet velocity and deformation rate. This indicates that the deformation rate's peak occurs at 150 m/s (corresponding to a kinetic energy of 100J). The reason comes from the fact that the compressive strength of the bullet overtakes the compressive strength of polycarbonate in the case of the low collision velocity (less than 150 m/s). The relationship between velocity and bullet hole are given in Table 1. The depth of

the bullet hole becomes bigger with increasing collision velocity. The diameter of the bullet also shows a similar trend. The depth of the bullet hole is comparatively small due to energy absorption by bending deformation of the polycarbonate. However, in the case of high velocity (more over 150 m/s), the plastic deformation region was limited to the contact region only. Therefore, both bullet hole diameter and compressive plastic deformation of the bullet have been decreased at 251 m/s [2,3].

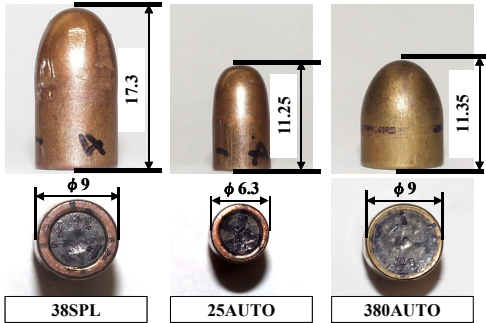


Figure 1: Geometry and dimension of bullets. Figure 2: 38Auto and Wheel (S&W) gun.

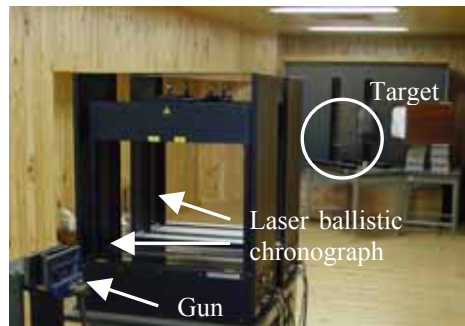


Figure 3: Firing experimental layout.

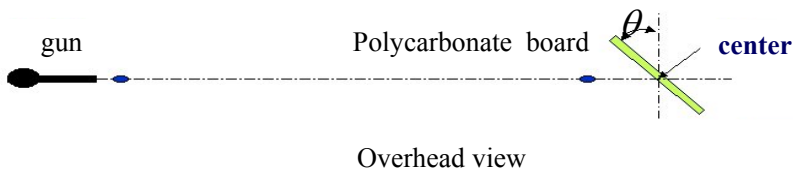


Figure 4: Overhead view of firing experiment system.

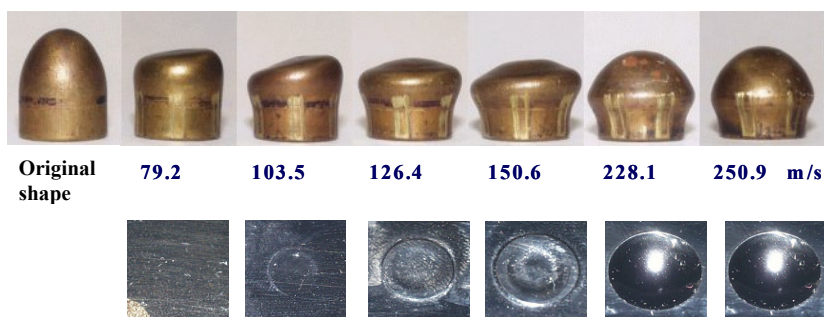


Figure 5: Bullet's shapes and bullet's holes (head-on collision, 380AUTO,  $V=79.2\sim 250.9\text{m/s}$ ).



Figure 6: Reconstruction bullet shape by using 3D measurement and 3D-CAD.

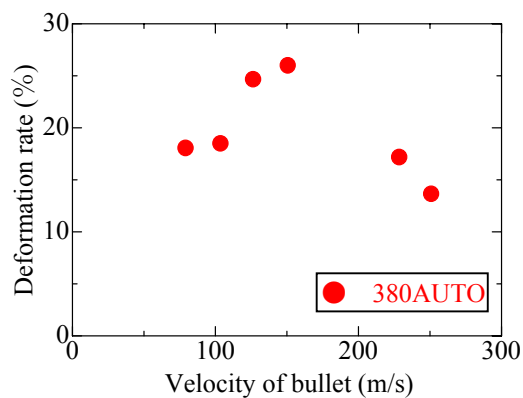


Figure 7: Relationship between bullet velocity and deformation rate (head-on collision).

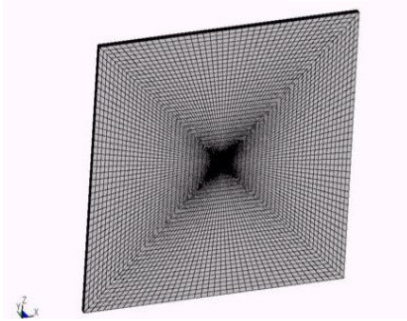
### 3.2 Numerical simulation

Finite Element models for the bullet and polycarbonate plate are shown in Figure 8. As analysis conditions, the collision velocities and the angles in experimental conditions were used. In addition, the spinning of the bullet, material's strain rate

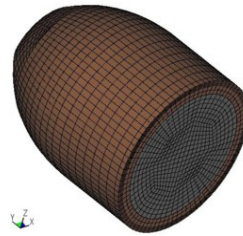
dependence, Mach number and friction were considered [3–6]. The main analytical constants of the material properties used in the simulation experiment are shown in table 2.

Table 1: The dimensions of bullet holes.

Type of bullet	Collision velocity (m/s)	Diameter of bullet hole (mm)	Depth of bullet hole (mm)
380AUTO (head-on collision)	79	7.2	0
	104	8.3	0.1
	126	10.3	0.3
	151	11.4	0.4
	228	12.2	3.9
	251	11.7	4.0



(a) Target model (polycarbonate board)



(b) Bullet model (380AUTO)

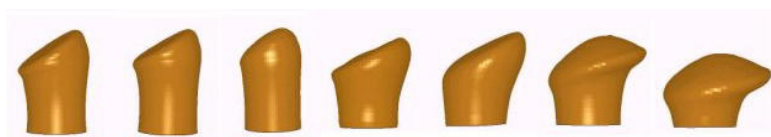
Figure 8: An example of the analysis model using an FEM simulation.

Table 2: Analytical constants of material properties.

	Cu	Pb	PC
Mass density ( $\text{kg/m}^3$ )	$8.93 \times 10^3$	$11.337 \times 10^3$	$1.2 \times 10^3$
Young's modulus (GPa)	132	17.2	2.06
Yield stress (MPa)	196	60	100
Poisson's ratio	0.34	0.44	0.3

Comparison between analysis results and experimental ones in oblique collision (collision angle  $30^\circ$ ) are shown in Figure 9. In the case of not considering the strain rate dependence, as the bullet deformation for high velocity is overestimated, the simulation was performed by using the strain-strain relation obtained under different velocity compression tests.

The deformation shapes obtained from simulation were in good agreement with experimental results for the collision angle of  $30^\circ$ . However, for the angle of 60-degrees, the calculated model and the experimental results were a little different. Although the contact between the bullet bottom part and PC-plate in the experiments was recognized, this contact mark on the PC plate was not observed in the simulation. The same tendency is observed for the collision angle of 45-degrees. This is probably caused by the definition of friction between the bullet and polycarbonate and the bonding condition between lead and copper of the bullet used in the simulation. Results of head-on collisions are not presented here, however experimental results and simulation results show very good correlation.



(a) Analysis results in collision angle  $30^\circ$  ( $V = 79 \sim 218 \text{ m/s}$ )



(b) Experiment results in angle  $30^\circ$  ( $V = 79 \sim 218 \text{ m/s}$ )

Figure 9: Comparison of analysis results with experiment ones (38SPL, collision angle:  $30^\circ$ ).

Cracks on copper coated bullets were recognized in oblique collision experiments. These cracks caused by the rifling mark in spirals have little influence on the deformed shape of the bullets shown in Figure 9. However, the non-coated lead bullet breaks with cracks caused along rifling marks in the head-on collision experiment (Figure 10). Figure 11 shows an example of the simulation result for the non-coated lead bullet [7,8]. From comparison with both figures, it is found that the deformation and fracture behaviour can be evaluated by simulation quantitatively.

## 4 Conclusion

The effect of collision velocity and collision angle on bullet deformation was discussed and performance of a protection board made of polycarbonate was estimated by experiment and FE Analysis. The results obtained are summarized as follows.





Figure 10: Fracture under head-on collision for non-coated bullet.

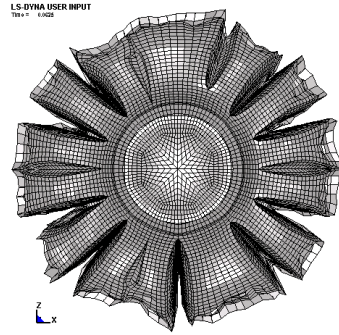


Figure 11: Fracture analysis under head-on collision for non-coated bullet.

- (1) For the low collision velocity region, polycarbonate plate undergoes bending deformation. In the case of high collision velocity, the plastic deformation region of polycarbonate plate was limited to the bullet's contact region only.
- (2) For a collision angle smaller than  $30^\circ$ , the simulation results show good agreement with experimental ones under consideration of the strain rate dependence.
- (3) When the collision angle is bigger than  $45^\circ$ , the simulation results and the experimental ones are a little different because of the friction between the bullet and polycarbonate, and the bonding condition between lead and copper.
- (4) In collision simulations, the rifling marks on full metal shield bullets of firing have little influence on the deformed shape of bullets. However, the crash and fracture phenomenon occur along the cracks ignited by the rifling marks.

## References

- [1] K. Kashiwatani, Forensic science for Investigation, 1983.
- [2] N. Cristescu: Dynamic Plasticity, North-Holland Publishing Company, 1967.
- [3] T. Borvik, O.S. Hopperstad, T. Berstad, M. Langseth, A computational model of viscoplasticity and ductile damage for impact and penetration, Eur. J. Mech. A/Solids 20, pp.685-712, 2001
- [4] T. Negishi, T. Ogura, T. Masumoto, T. Goto, K. Fukuoka, and J. Syono: Mat. Sci. 20, 1985.
- [5] R. Barauskas & A. Abraitiene, Computational analysis of impact of impact of a bullet against the multiplayer fabrics in LS-DYNA, International Journal of Impact Engineering, 2005
- [6] K. Sakino, Strain Rate Dependence of Dynamic Flow Stress of Aluminum Alloy 6061 at Very High Strain Rates, Original Paper, vol.54 No.12 pp.1301-1306



- [7] H. Kurtaran, M. Buyuk & A. Eskandarian, Ballistic impact simulation of GT model vehicle door using finite element method, Theoretical and Applied Fracture Mechanics 40,pp.113-121, 2003
- [8] P.A. Vityaz, V. Roman: Proc.13th Int. J. Mach. Tool Des. & Res., 1972.

