



## INVESTIGATION OF THE IMPACT BEHAVIOR OF WINDOWPANE GLASS PLATES BY LOW VELOCITY 9MM SPHERICAL PROJECTILE.

### Forensic Science

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### ABSTRACT

In cases involving Firearms, it is very multifaceted work to investigate and authenticate cause behind the crime. In real life cases which involve glass as a target or mid target, it is very difficult to determine the distance of shooting. For near distance firing, GSR evaluation is effective, but the need of the day is to stronger the investigation for all firing ranges. For material like Glass panels or Glass windows, glass fractures when found in ballistic cases can help in evaluation of distance of firing and even velocity of fire. In this study, glass plates of equivalent dimensions were coated with thin film lamination and subjected to impact by projectiles at varying distance. The assessment firing was carried out at Ballistic Testing Range existing in our campus, during the assessment 9mm Projectile were impacted on the glass plates with velocity around  $400 \pm 20$  m/s. Experiments were carried out to obtain basic data for estimating the impact distances of projectiles from the morphology of the fracture. Projectiles of 9mm caliber were shot onto laminated windowpane glass plates firmly held around a frame. It was assumed that impact distance would create differences in surface tension on the glass plates, which in turn affects the fractography of glass under observation. A strong experimental correlation was found between fractures and the impact distances. A unique relationship was obtained between crack area and impact distance from the numerical analysis of the fracture of the glass plates.

### KEYWORDS

Fractures, Velocity, Glass, Tendency, Range.

#### 1. Introduction

Glass, a most commonly found evidence in cases like shooting, accident etc. It primarily constitutes silica ( $\text{SiO}_2$ ) and various amounts of element oxides hard, amorphous material, brittle and exhibits a predictable fracture pattern when hit usually transparent, composed primarily of. It is commonly found evidence at the scene of crime like, motor vehicle accident, theft, burglary, non target shooting, ricochet of bullet etc. When a projectile such as a bullet or stone hits a glass surface the impact causes changes, in the form of fractures, to occur within the glass. When a released projectile hits into the surface of a glass pane with great force, the glass surface firstly bends slightly; before it breaks. When the glass is hit with the projectile having velocity greater than the elasticity limit of the subjected material; then the projectile passes through the glass. In harmony with the laws of physics; the energy by the glass sample when the projectile hits the surface of glass will be dissipate along the path of least resistance surfaces, creating structural failure known as cracks or fractures. Along with that, a specific energy is transmitted in the form of shock waves, radiate from the point of impact causing specific types of damage to the glass. This is what makes it possible to determine the order of fractures. Fractography, is the study of the fracture on the surfaces of materials. The science of fracture diagnosis or fractography is that body of knowledge which enables one skilled in certain basic principles to determine the nature and cause of a particular fracture event. In material science research, fractographic techniques are used to determine the cause of failure in any structures, especially in product failure and the practice of forensic engineering or failure analysis. In present study, Fractographic techniques were used to determine the impact velocity and to relate distance of firing with fracture pattern.

In past many experiments have been conducted (see ref. 1 to 8), to study the behavior of glass or its laminates subjected to low or high impacts. In studies, scientist Knight et al. (1977) could conclude that diameter of cone and impact velocities are inversely proportional measures. Fracture mapping technology was introduced by Ball and Mckenezie (1994), he performed series of test on float glass with varying impact speed. They could identify conclusive results through mechanical failures of glasses and their construal mapping. Cavendish laboratory, University of Cambridge (2005) have remain important contributors to the study of glass and brittle material failures with solid impacts. Similarly Field (1971, 1988), Field and Sun (1989) conducted research on brittle materials viz. ceramics and glasses. In their work they provided practical threshold value of failure which could be related to impact speeds. It is conferred that thickness of material to be tested in relation with impact velocity and striking angle are also important factors affecting fractography of materials.

(see Refs. 1-7)

The purpose of this research is to provide objective scientific backgrounds, that will illustrate the impact fractures, under controlled conditions (9mm bullet with target velocity around 400 m/s) on target materials such as glass window panes, are in unique in all prospects. In this phase of our study, we fractured glass window panes with 9mm bullet maintaining all standards as per standard firing protocols. Each and every fracture and impact hole was documented in detail for subsequent inter-comparison and to illustrate the uniqueness of the fracture pattern in relation with distance of firing. Similar mechanism of fractures can be observed not only on glass or glass panes, but also on diverse materials structured from brittle materials. This study outlines those principles of fracture diagnosis dealing specifically with glass panels, caused to break under the action of a variety of loads. This study leads to more clear and concise knowledge to determine the nature of load and related structural failures on brittle surfaces.

#### 2. Materials and Methods

For the present study, a specially designed metal frame was used to fix the window pane glasses of the size  $40 \times 40$  cm with thickness of 4 mm, setup in the way that it was perpendicular to the muzzle end. It was taken care of that all the glasses are of the same nomenclature. The plate was fired at with a 9mm pistol (Glock); MP (heckler and Koch) with full metal jacketed spherical projectiles and simultaneously initial velocity and remaining velocity were recorded using Radar gates to achieve constant kinetic energy.

The projectiles fired were allowed to penetrate into glass samples with predefined distances i.e. 5 meters, 10 meters and 15 meters. After each firing, the glass samples were removed and numerical analyses of cracks were carried out.

The pilot study was carried out for 30 glass samples, which were taken and labeled as S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, .... to S30. For distance of 5 meters, distance firing purpose samples marked as S1 to S10 were undertaken for fracture examination Likewise for distance of 10 meters: samples marked as S11 to S20 were taken up and for 15 meters : samples marked as S21 to S30 were taken for the examination.

#### 3. Results and Discussion

Experimental results reveal that the target hole and dimensions of cracks formed give a clue which can be related to the distance between the muzzle end and the target. When the projectiles of a firearm pass through an ordinary windowpane glass, the fractures distribute up to a

long distance in all the directions from the penetration hole. The fractures produced by projectiles vary in fractographical aspects from those by blunt impact, irrespective of energy.

Present experimental study of 9 mm caliber shooting on prefixed glass frames over pre-cised distances, gives the types of Fractures and centric holes which proves to be more effective measure to relate distance of firing with structural failure of glasses. Hence, if the applied distance is near, fracture occurs with clear cut keyhole pattern, almost equivalent to the diameter of the bullet, crater and crack branching leading to the fracture of glass surface appears very smooth.

**3.1. Results for Impact distance of 5 meters**

Glass plate was subjected to a 9mm projectile impact from a distance of 5 meters. The projectile velocity was recorded over radar gates, the velocity of fire for S1 to S10 was reported to be between 398 to 410 m/s. It was found that 9mm projectile impact for the selected glass specimen lead to destruction of the glass specimen leaving evidences to investigate its structural failure. A sample of glass plate specimen is shown in Fig. 1 after the projectile impact where the central crater with comminuted material and circumferential and radial cracks were visible. The number of radial cracks varied between 17 and 20 in total. Some cracks linking two radial cracks were occasionally visible at a larger distance from the center. These cracks were responsible for shattering away of the glass plate corners for higher projectile velocities. The keyhole, crater and fractures generated in a glass specimen upon projectile impact from the distance of 5 meters is shown in Fig. 1.



Fig.1: Glass plate after 9mm projectile impact from the distance of 5 meters showing keyhole at the center followed by crater and circumferential cracks around the crater and large radial cracks.

From Fig. 1, we observed that radial cracks extend from the central crater region along the quadrant directions and then diagonally towards the frame corners. The region around the crater, radial cracks appeared to be straight, and the radial cracks continue to be straight whereas the corners cracks had more turns. These features were found to be distinguishing in the experimental result as in Table 1. Radial cracks pattern in the computational model S1 to S10 appeared as elongated from 17 to 20 in number extending from 20 to 23 mm in the distance from the center of key hole to the outer sides of the plate. The crater or cone formed around the hole is much prominent and the experimental set up revealed that the entry hole to be 10 to 11 mm in diameter and crater to be 3 to 4 mm in diameter. A similar pattern was displayed by other experimental setups, in which the dimensions of cracks and fractographical data varied from each other.

Table 1 shows the numerical analysis of fracture characteristics on the windowpane glass targeted with 9mm spherical bullet from 5 meter distance

Sample Number	Diameter of entry hole (in mm)	Number of radial cracks	Diameter of the crater or cone around the keyhole (in mm)	Distance of farthest travelled Radial cracks from centric hole (in mm)	Distance of shortest travelled Radial cracks from centric hole (in mm)
S1	10.3	20	4.5	23.2	4.2
S2	10.8	17	4.1	20.8	3.5
S3	10.4	18	4.3	21.6	4.1
S4	11	20	4.6	23.1	3.9
S5	10.4	19	4.2	21.9	4.6

S6	11.2	18	4.1	4.8	20.6
S7	10.5	16	4.6	3.7	21.2
S8	10.6	15	4.8	4.0	20.9
S9	10.9	16	4.4	3.6	20.3
S10	10.5	18	4.6	4.1	22.6

**3.2. Results for impact distance of 10 meters**

At the impact distance of 10 meters, the mark of the projectile entry was wider, with cracks showing on both the strike and the back face of the glass plate (see Fig. 2). Radial cracks appeared in similar pattern as indicative in previous experimental results, but the frequency of cracks reduced to 10 to 13 cracks (as seen in table 2). The radial cracks elongation distance was found to be 15 to 16 mm farther away from the center of the plate, they were continuous fractures. The distinctive pattern of the damage on the face of the glass plate sample near the center of the plate could be better understood from the cross-sectional view (as in Fig. 2). It is interesting to remark that the crater region, between the center of the plate and the first major radial crack observed in the experimental results, extended from 3 to 4mm in diameter. The damage pattern was found to be extensive and diffused key hole at the centre as strike of hole of about 12 to 13 mm in diameter was found.

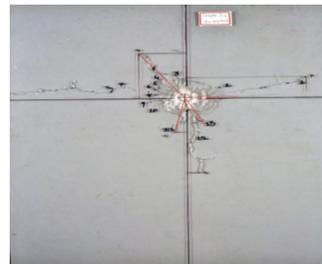


Fig.2: Glass plate after 9mm projectile impact from the distance of 10 meters showing keyhole at the center followed by crater and circumferential cracks around the crater and large radial cracks.

Table 2: shows the numerical analysis of fracture characteristics on the windowpane glass targeted with 9mm spherical bullet from 10 meters distance

Sample Number	Diameter of entry hole (in mm)	Number of radial cracks	Diameter of the crater or cone around the keyhole (in mm)	Distance of farthest travelled Radial cracks from centric hole (in mm)	Distance of shortest travelled Radial cracks from centric hole (in mm)
S11	12.1	13	4.2	16.5	3.2
S12	12.0	11	4.5	15.8	3.5
S13	12.8	12	4.0	16.2	3.1
S14	12.3	12	4.9	16.1	3.7
S16	12.0	14	4.2	16.0	3.6
S17	13.2	13	4.2	16.0	3.8
S18	12.9	11	4.7	15.2	3.5
S19	12.6	10	4.3	15.7	3.0
S20	12.3	13	4.6	15.9	3.6

**1.2. Results for impact distance of 15 meters**

When the glass plate was subjected at impact distance of 15 meters, the damage obtained by the experimental setup was concentrated with the wider centric entry hole of 13 to 14 mm in diameter and glass layer was fragmented. Three different regions could be identified from (Fig. 3) a central region with key hole other than crater area from 2 to 3 mm in diameter and few radial cracks i.e. 9 to 10 in number, the farthest radial crack was about 13 to 14 mm in the length from the centre of hole (table 3). These regions seen from the experiments were well captured in all the samples that had been taken for experimental work.



Fig.3: Glass plate after 9mm projectile impact from the distance of 15 meters showing keyhole at the center followed by crater and circumferential cracks around the crater and large radial cracks.

Table 3: shows the numerical analysis of fracture characteristics on the windowpane glass targeted with 9mm spherical bullet from 15 meters distance

Sample Number	Diameter of entry hole (in mm)	Number of radial cracks	Diameter of the crater or cone around the keyhole (in mm)	Distance of farthest travelled Radial cracks from centric hole (in mm)	Distance of shortest travelled Radial cracks from centric hole (in mm)
S21	13.5	09	2.7	13.3	3.1
S22	14.0	10	2.5	13.4	2.9
S23	14.1	09	3.0	14.0	2.6
S24	13.9	11	2.2	13.1	2.7
S25	14.0	09	2.6	13.4	3.7
S26	13.8	10	2.4	13.1	3.3
S27	14.4	08	2.3	13.9	3.1
S28	13.6	10	2.4	13.7	3.3
S29	13.5	09	2.3	13.8	3.4
S30	13.9	10	2.5	13.7	3.2

#### 4. Trends with increasing impact distance

The distance profiles as mentioned earlier, leads to positive sign of observation towards determination of distance of firing from the glass failures and damages. The results obtained coincide with the observation. Damage maps for impact distances a) keyhole diameter (b) the crater or cone diameter, (c) the number or frequency of radial fractures, and (d) the longest or farthest radial fracture from the centre. While the trend observed in the experiments, of increased impact distances with a constant speed, is matched by the key hole which tends to increase in diameter as the distance increases; two possible reasons are believed to contribute to the differences between the measured values i.e. jump of the projectile and the yaw of the bullet. The magnitude of the structural failures taken over glass samples, are found to differ for all the three experimental test conditions: at 5 meter impact distance the model gives a keyhole of diameter 10 -11 mm, almost equivalent to the diameter of the bullet, while in the experimental condition at 10 meters and 15 meters impact distance the computing failures show larger keyhole diameter 12-13mm and 13-14 mm respectively. The second trend observed from the numerical is that the number of radial cracks decreases as the impact distance increases; and the travelling of the radial crack or the length of the farthest fracture also demonstrates distinctive results; Differences may counter the factor of the impact velocity. Nevertheless, the fact that for the trend of crater or cone, the computed values are in a similar range at 5 meters and 10 meters impact distances but for 15 meters the intensity and diameter of crater or cone decreased from 3-4mm to around 2mm experimentally, thus the results are very encouraging.

#### 5. Conclusion

This paper presents experimental and numerical simulation results for the impact damage in a windowpane glasses with a thin film lamination subjected to impact from a 9mm spherical projectile at varied distances. Significant changes in the damage patterns that develop in the glass plate at three different impact distances takes place in the experimental tests. These changes are predicted by the numerical analysis and fractographical analysis of the tested plates.

Some very specific damage and crack features observed in experiments are, remarkably, reproduced by the experimental models at specific impact distances, at about the same location as in the experiments. The numerical results are obtained here using the simplest coordinate plane method. We can conclude that at these levels of loading, modeling the glass plate as a linear fractures material is sufficient to explain the damage structure from impact in the thin glass plate. The simplified numerical values and its frequency of fractures are the conditions used in the computing important factor for the differences between the experiments and the computations in this problem. In the experiments, the trend of increasing distance of ejection of projectile from the target is observed and is reproduced by the multiple samples firing. The numerical results allow for an

understanding of the composite progression of damage in the glass layer induced by stress waves propagation and reflections. The results presented here lead us to conclude that, for determining the distance of fire, following factors can be used for the purpose of evolution: frequency of fractures, keyhole diameter and the fractures formation due to the elastic properties of the material. A plan for the future also includes more accurate and more profound experimental condition: set up monitoring the time evolution of damage and comparison with varied distance models.

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