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Analysis of glass fracture pattern made by .177″ (4.5 mm) Caliber air rifle

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Abstract

Background: Glass is the hard, amorphous solid. Glass fragments may be an evidence of great value encountered in the investigation of various types of offences. At the scene of occurrence, the glass may be fractured either as an intentional act or due to accident. Glass fractures are of paramount importance in shooting cases where firearm is used as it can provide significant information related to the occurrence and facilitates a variety of evaluations. In fact, fractography i.e. analysis of fracture pattern, is the means and methods for characterization of fractured units or fragments in order to study or identify the mechanism of such fractures. The study of fracture pattern of glass has been of long interest to the forensic community. The glass fracture pattern analysis is very useful to establish the sequence of events and to link together items of evidence and it is of paramount importance in such cases where firearm is used. Now, the use of air guns in criminal activities is an alarm to the law enforcement agencies. The main objective of this work is to analyze the pattern of the fractures on windowpane of various thicknesses with regular .177″/ 4.5 mm lead pellet fired through the .177″/ 4.5 mm caliber Air Rifle manufactured in India. The window panes were kept at front, perpendicularly and away at a fixed distance from the muzzle end of Air Rifle. Samples were measured and analyzed on some fixed parameters. To analyze the consistency, measurements were analyzed graphically and statically checked for the goodness of fit (Chi-Square Test).

Result: The graphical representation of the measurements of different samples shows regularity in the features and Chi Square test gives very significant information regarding the consistency.

Conclusion: The hole diameter is ranging from 4.77 to 7.5 mm in case of air rifle. It can lead to distinguish the weapon by which fracture was made, whether it is standard or air weapon. The outcomes of this work on the windowpane by .177″/4.5 mm air rifles may be efficacious to forensic community.

Keywords: Scene of occurrence, Physical evidence, Fracture pattern, Fractography, Air rifle

Introduction

At the scene of the occurrence, investigating officer or forensic expert often encounters the shooting at inanimate target such as glass, door, window panes, windows of an automobile, etc. In fact, analysis of fracture pattern is the means and methods for characterization of fractured units or fragments in order to study or identify the mechanism of such fractures. The study of fracture pattern of glass has been of long interest to the forensic community. In literature, the importance of the glass evidence is described by Saferstein, Nabar and O'Hara in their books (Saferstein 2006; Nabar 2008; O'Hara and Osterburg, 1949). Fracture analysis of glass often provides much significant information like cause of fracture, direction of force applied, etc.

Glass can be defined as a semitransparent, transparent, non-crystalline and super cold mixture of metallic silicates. Glass is, therefore, by definition, amorphous or non-crystalline. Glasses are essentially super cooled liquids and they possess a unique combination of properties: transparency with or without colour, durability, electrical and thermal resistance, a range of thermal expansions, with hardness, rigidity and stability density, refractive index (Copley 2001).

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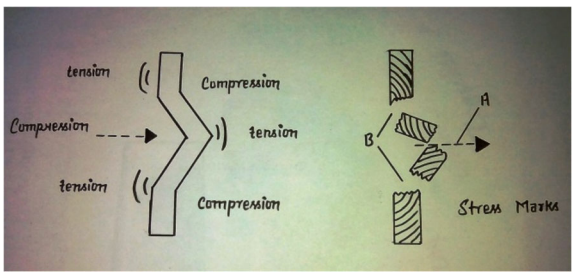

Fig. 1 Hitting of Projectile

These properties have been the subject matter of the various investigations (Jauhari et al. 1974). Specially, density and refractive index of a glass that impart the characterization and forensic individualization of the glass evidence (Gogotsi and Mudrik 2010). Silicate glasses are so much part of our everyday life having a forensic importance (Stoney and Thornton 1985).

In contrast to most other materials, the molecular structure of glass does not consist of a regular geometry of crystals, but of an irregular network of silicon and oxygen atoms with alkaline parts in between. In soda lime silica glass, which is generally referred to as glass, the alkaline parts consist of oxides of sodium and calcium. The forces of the inter-atomic bonds describe the theoretical strength of a material. In practice the tensile strength of annealed glass is much lower. Furthermore, the tensile strength is not a material constant, but depends upon many aspects such as the condition of the surface, the size of the glass pane, duration of load and environmental conditions (Overend et al. 2007). The experiment of Griffith on the glass forms the basis for modern fracture mechanics. Griffith stated that fracture always starts from the preexisting flaws that are termed as Griffith's Flaw (Griffith 1920). Sir Nevill Mott explained the dynamic fracture mechanism that was an extension to the Griffith's law (Mott 1946).

When a projectile such as a bullet or stone hits a glass surface the impact causes changes, in the form

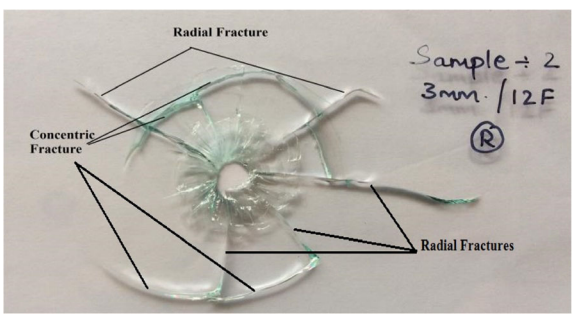

Fig. 2 Radial and Concentric Fractures

Table 1 Specifications of the weapon and the pellet used

Name of Manufacturer: Precihole Sports Pvt. Ltd., Thane, Maharshtra, India Model: SX100 Pegasus	
Specifications of Air Rifle	
Power source	Spring piston
Mechanism	Break barrel
Caliber	.177″/ 4.5 mm
Velocity	240 mps
Power	16 J
Weight	3.1 K.G.
Total length	1065 mm
Barrel length	450 mm
Action	Single Shot
Specifications of the Pellet	
Metal	Lead
Brand	Magnum
Shape	Spherical Head
Caliber	.177″(4.5 mm)
Average weight of pellets used	.41 g
BIS standards for weight of pellet	.40 ± .03 g

Source: SX100 Owner Manual Published by Precihole Sports, Pvt. Ltd., Thane, Maharashtra, India

of fractures, to occur within the glass. The glass bends slightly when a projectile hits a glass as shown in Fig. 1. The glass breaks when it reaches limit of tensile stress and the projectile passes through the glass (Saferstein 2006; Nabar 2008).

In accordance to the laws of physics a certain amount of energy from the projectile that is absorbed by the glass will dissipate along the path of least resistance thereby creating cracks. Shock waves of energy originate from the point of impact causing specific types of damage to the glass (Grady 2010).

When a projectile i.e. a bullet or rock hits the glass, it will form two distinct types of fractures: Radial and Concentric. There is another terminology that is

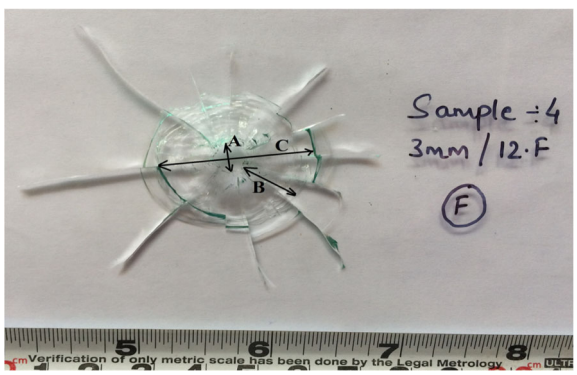

Fig. 3 Representation of Measurements

Table 2 Measurements for the Glass panes without coating of the Sun Control Film

Sr No.	Sample No.	No. of radial fractures	No. of concentric Fractures	Hole diameter	Thickness of mist zone	Diameter of Mist zone
3 mm						
1	1	11	9	6.35 mm	11.21 mm	28.76 mm
2	2	8	8	5.96 mm	10 mm	25.96 mm
3	3	11	8	5.86 mm	12.33 mm	30.52 mm
4	4	11	7	5.6 mm	12.8 mm	25.6 mm
4 mm Privacy Glass						
5	1	8	5	6.10 mm	13.52 mm	33.14 mm
6	2	10	6	6.46 mm	13.35 mm	33.16 mm
7	3	9	8	5.63 mm	12.62 mm	30.86 mm
8	4	5	2	5.52 mm	13.17 mm	31.86 mm
4 mm Transparent Glass						
9	1	6	1	7.5 mm	15.45 mm	38.4 mm
10	2	7	3	6.2 mm	13.37 mm	32.94 mm
11	3	8	0	6.4 mm	13.7 mm	33.8 mm
12	4	12	13	5.1 mm	11.27 mm	27.64 mm
13	5	10	3	5.57 mm	13.22 mm	32.00 mm
5 mm						
14	1	11	6	5.37 mm	12.37 mm	30.10 mm
15	2	10	7	6.07 mm	12.9 mm	31.87 mm
16	3	11	0	6.70 mm	16.0 mm	38.70 mm
17	4	7	4	5.45 mm	15.44 mm	36.30 mm

known as cone fracture, observed to be caused by a penetration of the high velocity projectile such as a bullet. Projectile leaves a round crater shaped hole which is surrounded by radial and concentric cracks. There is the appearance of the cone as the hole is wider on the exit side and gives the appearance of the cone. This is caused by the high strain and appears at the impact point on the glass. The point of impact and the direction of the impact on the glass can be determined by the cone fractures (Saferstein 2006; Nabar 2008; Mcjijnkins and Thornton 1973).

When a projectile first hits the glass, the glass will be stretched, causing tension on the back side directly behind the projectile. This causes compression around the point of tension. The radial cracks begin on the opposite side of the force at the point where the projectile hits the glass and radiate out from the origin of the impact. They will always end if they encounter an existing fracture line. The concentric cracks begin on the same side as the force, where the tension occurs and formed early in the fracture process. Afterwards the radial fractures are created (Saferstein 2006; Nabar 2008). Figure 2 shows radial and concentric fractures.

The shape of the Mist Zone (chipping) may help to determine the angle of impact. If the bullet strikes at

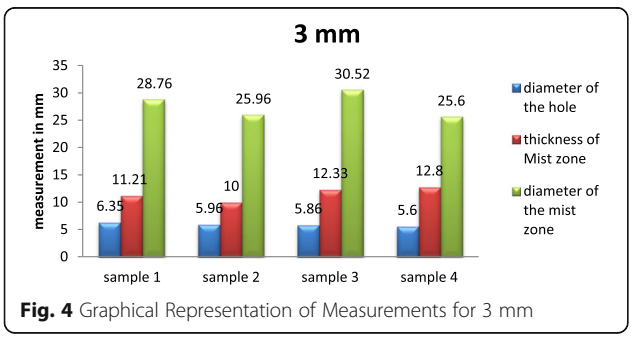

Fig. 4 Graphical Representation of Measurements for 3 mm

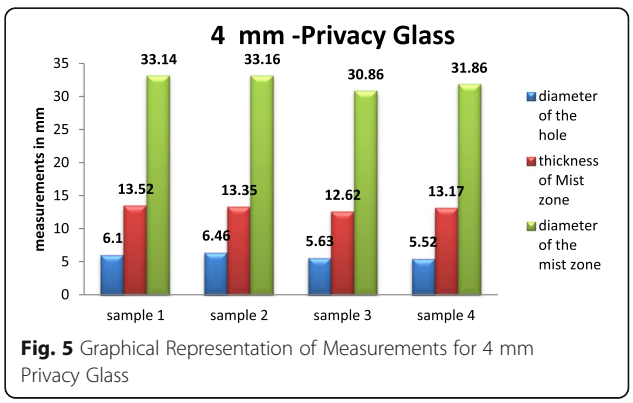

Fig. 5 Graphical Representation of Measurements for 4 mm Privacy Glass

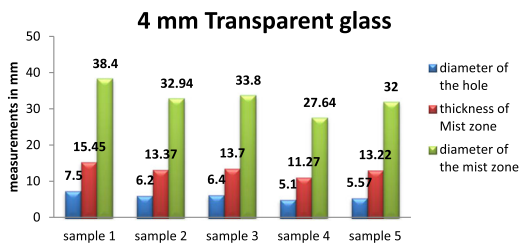

Fig. 6 Graphical Representation of Measurements for 4 mm Transparent glass

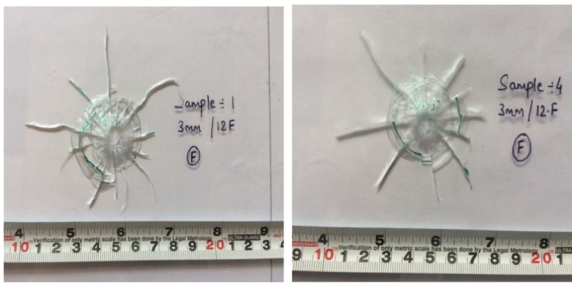

Fig. 8 Fractured glass panes of 3 mm thickness

right angle, the chip pattern around the hole is eventually distributed making a symmetrical hole. But if it strikes from the right side, it will make considerable chipping around the glass making an elliptical hole also. As well as when it hit the glass from the left side, these indicators are found to be reversed (Saferstein 2006; Nabar 2008; O'Hara and Osterburg, 1949).

An air gun is special kind of small arm that hurls projectiles by means of mechanically pressurized air or other means which involves no any chemical reaction. All air weapons e.g. rifle and pistol generally propel metallic projectiles. Generally air gun involves three types of action mechanisms that are Spring Piston Mechanism, Pneumatic Air Mechanism and Compressed Gas (CO_2) Mechanism (Vanzi 2005).

It is found to be lethal and may cause grievous injury and even death (Lal and Subrahmanyam 1972) as well as bone micro fracture from the direct impact of the projectile (Kieser et al., 2013).

Material and methodology

The present study has been conducted for the analysis of glass fracture made by .177″ (4.5 mm) caliber Air Rifle. Window panes of 3 mm, 4 mm and 5 mm thickness of 1 ft × 1 ft dimension were used. Category of 4 mm thickness was taken in two varieties of which one was transparent pane and other was privacy glass. Test firing was conducted by .177″ (4.5 mm) Air Rifle. A special frame was designed to fix the glass with help of clay that is used to put the glass pane in windows. The frame was kept perpendicularly at the fixed distance of 12 ft away from the muzzle of the weapon. Table 1 describes the specifications of the Air Rifle and pellet used.

After test firing, samples were directly analyzed. Following measurements have taken with a Vernier Caliper to analyze the trends in the features:

1. Radial Fracture Count
2. Concentric Fracture count
3. Diameter of Bullet Hole (Represented by "A" in Fig. 3)
4. Thickness of Mist Zone (Represented by "B" in Fig. 3)
5. Diameter of Mist Zone (Represented by "C" in Fig. 3)

Measurements were taken and to analyze the consistency in the feature, graphs were drawn. As the radial and concentric fractures are the results of stress travelling and it is not material constant, therefore radial and concentric crack counts have not been taken for graphical representation.

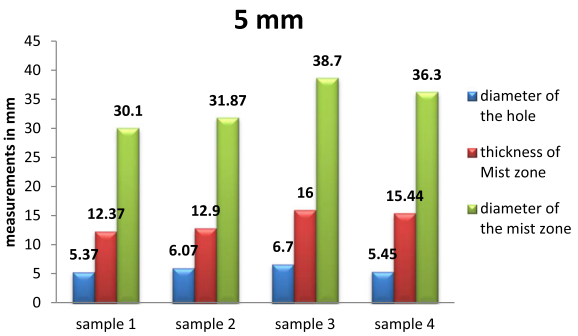

Fig. 7 Graphical Representation of Measurements for 5 mm Glass Pane

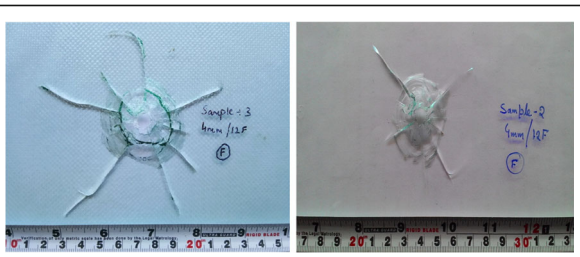

Fig. 9 Fractured glass panes of 4 mm thickness Privacy Glass (left), 4 mm thickness Transparent glass (right)

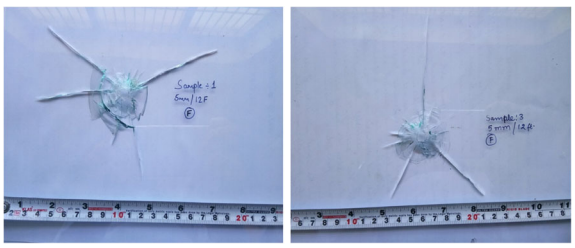

Fig. 10 Fractured glass panes of 5 mm thickness

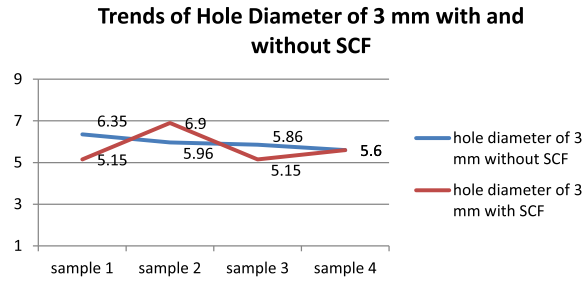

Fig. 11 Graphical Representation of Hole diameter of 3 mm Glass Pane with and without SCF

Results

To analyze the fracture pattern, the samples were test fired. Some measurements were taken to analyze the glass fracture pattern and afterwards the graphs were drawn to find the regularity in features and the trends of the characteristics. First of all, the glass panes of 3 mm thickness without Sun Control Film (SCF) were test fired at fixed distance. Similarly 4 mm and 5 mm window panes were test fired. Measurements are tabulated and graphically represented. Table 2 summaries the measurements for the glass panes without SCF and Figs. 4, 5, 6 and 7 shows graphical representation of 3 mm, 4 mm Privacy, 4 mm Transparent and 5 mm thickness glass respectively.

These all glass panes show somewhat similarities in the features that it reveals on the general visual examination. Figures 8, 9 and 10 show that fractured glass pane of 3 mm, 4 mm Privacy 4 mm Transparent, 5 mm thickness glass respectively.

Now a days glass pane are coated with a SCF to maintain privacy in house, office and automobile as well as for fancy purpose. To analyze the fracture pattern on the glass coated with SCF, the sample were test fired as same as that of previous. The test firing was conducted on the glass panes of 3 mm, 4 mm privacy panes and 5 mm coated with a thin SCF. Samples were measured and analyzed as that of previous. These measurements have been tabulated in Table 3.

To analyze the trends of the hole diameter, linear graphs have been drawn. It also provides a comparison between the glass panes coated with sun control film and those without sun control film of same thickness. Figures 11, 12, 13 and 14 shows the linear trends for the 3 mm, 4 mm Privacy, 4 mm Transparent and 5 mm thickness glass panes respectively. Further, to establish the consistency in hole diameter i.e. whether all the values are consistent (equals or near to the mean value), test of goodness of fit has applied. The findings of chi-square test have been summarized in Table 4.

On the basis of observations of all the glass panes, it is observed that diameter of hole shows a consistency that can be observed in the above graphs and has been proved in the Chi Square Observations.

Table 3 Measurements for the Glass panes coated with the Sun Control Film (SCF)

Sr. No.	Sample No	No of Radial fractures	No of concentric Fractures	Diameter of Hole	Thickness of the Mist Zone	Diameter of the Mist Zone
3 mm with SCF						
1	1[a]	10	7	5.15 mm	15.45 mm	33.475 mm
2	2[b]	12	9	6.9 mm	10.77 mm	28.44 mm
3	3[b]	10	8	5.15 mm	12.1 mm	29.35 mm
4	4[a]	11	8	5.60 mm	13.25 mm	32.10 mm
4 mm Privacy Glass with SCF						
5	1[a]	9	6	5.97 mm	12.35 mm	30.67 mm
6	2[b]	8	5	6.4 mm	13.25 mm	32.9 mm
7	3[a]	9	–	6.67 mm	13.22 mm	33.11 mm
8	4[b]	7	2	6.30 mm	11.07 mm	28.44 mm
5 mm with SCF						
9	1[a]	10	5	5.40 mm	14.35 mm	34.10 mm
10	2[b]	8	0	5.63 mm	11.16 mm	27.94 mm
11	3[a]	8	2	4.77 mm	17.3 mm	39.37 mm
12	4[b]	4	2	5.92 mm	17.17 mm	40.26 mm

[a]Sun control Film was facing to muzzle end
[b]Sun Control Film was opposite to the striking site

Discussion

The glass panes were test fired and analyzed. Consistency was observed in linear plots which was

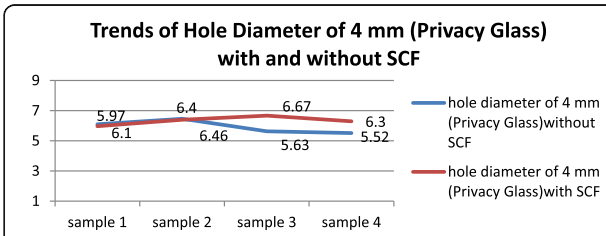

Fig. 12 Graphical Representation of Hole diameter of 4 mm Privacy Glass Pane with and without SCF

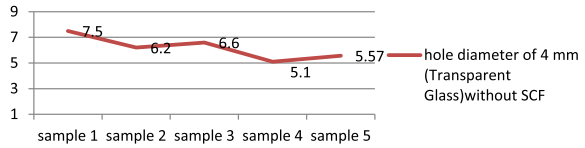

Fig. 13 Graphical Representation of Hole diameter of 4 mm Transparent Glass Pane without SCF

proved by Chi-Square Test. It was also found that all hole diameter are ranging in between 4.77 mm to 7.5 mm. Waghmare et al. (2016) analyzed the glass fracture pattern that was made by regular .315 Rifle, .303 Rifle, 9 mm Pistol, A.K. 47 Rifle manufactured in Indian ordinance Factory in India and Improvised Pistol, and produced data of hole diameter made by different ammunition (Waghmare et al., 2016). Table 5 summarizes the findings of Waghmare et al.'s work.

They found that the diameter of bullet hole is somewhat double to the caliber of the weapon in case of .315″, .303, A.K. 47 rifle. While 9 mm pistol produces hole of diameter ranging from 11.04 to 14.63 mm. As well as a large variation was observed in the hole diameter, made by Improvised Pistol, ranging from 11.35 mm to 19.43 mm.

Thus the findings of this work may help to opine whether the fracture is made by standard/ regular arm or by air gun by examining the hole diameter. As well as shape of mist zone also have some indication like in 3 mm glass without SCF, mist zone is somewhat spherical in shape, in 4 mm privacy glass panes mist zone is slightly triangular with rounded edges and 5 mm glass panes have irregular shape of mist zone. 5 mm glass pane shows some markings in the mist zone that are easily visible.

Table 4 Observations of the Chi Square Test

Chai Square Observations	
Null Hypothesis: All the values are consistent i.e. equals to the mean value.	
For 3 mm thickness	
Total no of observations	8
Calculated value of chi square	0.470328
Tabulated value For 7 degree of freedom at 1% and 5% level of significance respectively	1.239, 2.167
Conclusion	Calculated value of χ^2 < tabulated value; null hypothesis accepted
4 mm Privacy	
Total no of observations	8
Calculated value of chi square	.13867
Tabulated value For 7 degree of freedom at 1% and 5% level of significance respectively	1.239, 2.167
Conclusion	Calculated value of χ^2 < tabulated value; null hypothesis accepted
4 mm Transparent	
Total no of observations	5
Calculated value of chi square	0.540878
Tabulated value For 4 degree of freedom at 1% and 5% level of significance respectively	.297, .711
Conclusion	Calculated value of χ^2 < tabulated value; null hypothesis accepted
5 mm	
Total no of observations	8
Calculated value of chi square	0.406755
Tabulated value For 7 degree of freedom at 1% and 5% level of significance respectively	1.239, 2.167
Conclusion	Calculated value of χ^2 < tabulated value; null hypothesis accepted

Conclusion

The aim of this work is to study the fracture pattern of the glass made by air rifle of .177″/4.5 mm caliber. The graphical trends shows the consistency in hole diameter, thickness of mist zone and the diameter of the mist zone. The hole diameter is ranging from 4.77 to 7.5 mm in case of air rifle. It can lead to distinguish the weapon by which fracture was made, whether it is standard or air weapon. No significant difference has been observed in pattern on the pane coated with sun control film and the pane without sun control film as well as no any

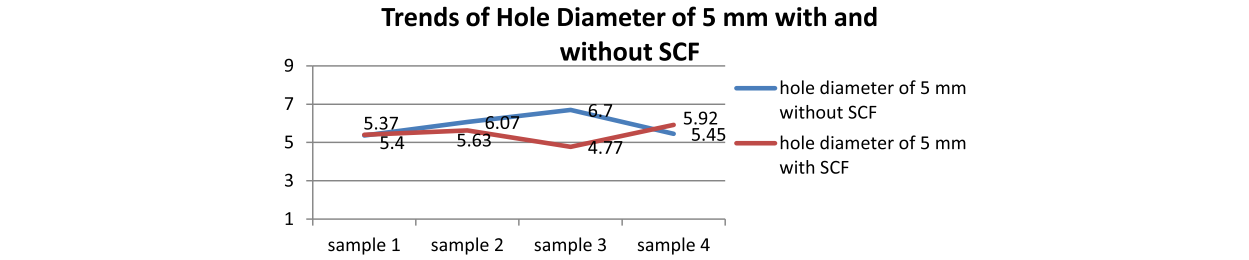

Fig. 14 Graphical Representation of Hole diameter of 5 mm Glass Pane with and without SCF

Table 5 Data of Hole Diameter Made by Different Ammunition

Shot No.	Firearm Used	Ammunition Used in the Weapon	Diameter of the Hole Obtained After Firing
1.	.315 Rifle	8 mm, soft nose, K.F.,01	15.748 mm
		Bullet weight: 15.34 g	
2.		Diameter of the Bullet: 8.102 mm	17.221 mm
3.			16.256 mm
4.			16.662 mm
5.	.303 Rifle	.303, Ball, MK-7,K.F.	13.817 mm
		Bullet weight: 11.3 g	
6.		Diameter of the Bullet: 7.899 mm	13.843 mm
7.			11.404 mm
8.			14.224 mm
9.	A.K. 47 Rifle	7.62 × 39 mm,322,74	17.094 mm
		Bullet weight: 9.5 g	
10.		Diameter of the Bullet: 7.721 mm	16.459 mm
11.			16.002 mm
12.			14.097 mm
13.	9 mm Pistol	9 mm, ball, auto, K.F.,	13.538 mm
		Bullet weight: 7.4 g	
14.		Diameter of the Bullet: 9.220 mm	14.147 mm
15.			14.630 mm
16.			11.049 mm
17.	Improvised Pistol	8 mm, soft nose, K.F.,01	13.970 mm
		Bullet weight: 15.34 g	
18.		Diameter of the Bullet: 8.12 mm	19.431 mm
19.			12.192 mm
20.			11.353 mm

Source: Waghmare et al. (2016)

significant differences observed in the fracture pattern of the glass panes when force is applied to the same side of coating of sun control film and when direction of the impact is opposite to the coating. The finding of this work may lead provide extreme help to a forensic expert in criminal investigation.

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All data generated or analysed during this study are included in this published article (and its supplementary information files).

Authors' contributions
All the authors made significant contribution to all aspects of this research. All authors read and approved the final manuscript.

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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