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Detection of Gunshot Residue on Glass Fired using Airguns and Insas LMG 5.56mm

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ABSTRACT

Locating and retrieving gunshot residue from the scene of the crimeis important for the investigation of shooting-related crime incidents. The presence of gunshot residue on the glass that can be hit as anintermediate target is occasional but not collected commonly because of its nature and the amount found on the glass. They may be found in crimes such as shooting where the target involves windowpanes or windshields among many other shooting related incidents. It is indicative that gunshot residues provide an exemplary source of partially burnt, completely burnt, and unburnt residues of primers and propellants that can help establish the manufacturer's details. Gunshot residues are deposited on the hands, face, and clothing of the shooter and are commonly found on the entry hole of the targets. These residues can be recovered from the surface of intermediate targets through which the bullet travels. Detection of gunshot residue from these intermediate targets can be useful for forensic investigation. They can be promising in absence of other pieces of evidence such as cartridge cases, bullets, or firearms. The current study was performed to explore the detection of gunshot residue on glasses fired at 25 metres range. Lead, barium, and antimony were successfully detected on all samples fired at 25 metres range. The analysis provided consistent evidence that gunshot residue detected can be helpful to obtain reliable data for forensic investigation. The statistical analysis of the data revealed a significant difference in the diameter of entry, number of radial fractures, diameter and thickness of mist zone with types of glass.

Keywords: Scene of crime; Intermediate target; Glass; Gunshot residue; Glass fracture.

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INTRODUCTION

The position, recognition, and retrieval of glass containing gunshot residue help in the reconstruction of shooting-related crimes involving firearms. Trace evidence can be collected from the crime scenes even if found in minimum amount. Trace evidence of forensic interest commonly includes glass, soil, paint, fibres, and hair. Analysis

of glass fractures can aid in forensic investigation to establish a link and determine the sequence of events at the scene of crime.[1] However, the use of country made firearms in the commission of crimes has become a matter of concern for law enforcement agencies. The analysis of glass fractures is useful in forensic science in determining the direction of impact and the position or location of the shooter. The fracture analysis can provide a useful tool for differentiating the range of firing. The energy of absorption and distribution depends on various factors that result in variations of impact patterns.[2] Projectile impacts can be classified into low velocity, medium velocity, high velocity, and hypervelocity based on the velocities of the projectile.[3] Glass fracture analysis hence becomes an important tool in investigation depending upon the type of crime. Glass fracture analysis also becomes important in arson investigation to investigate whether the thermal stresses result in the formation of fractures on the glass surface.[4]

The impact of air rifles on windowpanes of different thicknesses to study multiple fractures has exhibited a difference in hole diameter. It is found that the diameter made by the first impact is larger as compared to the second in the transparent glass with the thickness of glass panes 4mm and 5mm. In the case of tinted pane glass having 4mm thickness, the hole diameter of the second impact is found to be more than that of the first impact. It is also found that the increase in distance for a few meters does not change the impact pattern to a greater extent.[5] Recent studies have shown the impact of projectiles on window glasses. The impact made by air guns has a hole diameter almost double the calibre of the gun. There exists a huge variation in fracture patterns and hole diameter formed due to the impact of improvised weapons. However, they exhibit a key-hole appearance on glass.[2,6]

While analyzing the fracture patterns, it is observed that there are various regions around the bullet hole. The smooth region is known as the mirror zone. Surrounding the mirror zone is the mist zone which is rough and does not have well defined boundaries. After the mist zone, the hackle region exists which has radiating lines away from the fracture origin.[7]

Analysis of bullet holes and features such as the number of radial and concentric fractures, and analysis of mist zone can provide crucial information to the investigators.[8] The impact of a projectile on the surface of the glass may result in radial, concentric, and cone fractures. Cone fractures are formed from the impact of high-velocity projectiles.[9,10] The fracture always initiates from pre-existing flaws which are termed commonly Griffith's flaws.[11]

Gunshot residue (GSR) recovered from intermediate targets such as glass is not routinely considered in a crime scene concerning firearm-related crime.[12] Gunshot residue which is termed nowadays as firearm discharge residue may not be present in weapons that utilise compressed air.[13]

When a firearm is discharged a series of events occur in the firearm from the time when the trigger of the firearm is pulled, the firing pin of the weapon strikes the primer cup which holds the primary explosives.[14] These explosives are susceptible to pressure or friction. The oxidants present in the primer provide oxygen for the flame creating a sudden rise in the temperature. The temperature leads to the ignition of the fuel in the presence of oxygen which later ignites the propellants.[15] The burning of the propellant produces a large volume of gases which in turn provides an adequate amount of kinetic energy to the projectile.[16] The heat developed inside the barrel causes the vaporisation of components and the pressure generated pushes the vapours and particles out of the muzzle end of the firearm.[17] The particles released from the firearm are referred to as gunshot residue and can be found on the target, shooter, and the surrounding exhibits as far as 10m from the position of discharge.[18] The gunshot residue contains burned or unburned particles of primer, propellant, and any other component present inside the firearm.[19] The GSR can be classified as organic gunshot residue (OGSR) and inorganic gunshot residue (IGSR). Inorganic components such as Lead (Pb), Barium (Ba), and Antimony (Sb) are considered major components of GSR and are used to establish the presence of GSR.[20] Along with the inorganic components, the GSR also contains organic components such as Nitrocellulose, Nitro-glycerine, Diphenyl Amine (DPA), and Nitroguanidine which are present in the propellants as well as stabilizers used. Over the decades, different chemical and instrumental techniques were employed for the detection and identification of GSR.[4] With the latest advancement in technologies, various instrumental techniques such as Neutron Activation Analysis (NAA), Flameless Atomic Absorption Spectroscopy (FAAS), Scanning Electron Microscope (SEM) with Energy Dispersive X-rays (EDX), Inductive Coupled Plasma Mass Spectroscopy (ICP-MS), Laser Ablation Inductive Coupled Plasma Mass Spectroscopy (LA-ICP-MS), Laser Induced Breakdown Spectroscopy (LIBS).[21-23]

While the quantity of gunshot residue may vary at the crime scene, it is possible to encounter gunshot residues on intermediate targets through which the bullet has travelled.[24] They are always present when fired through standard firearms containing primers and propellants.[25] The composition of gunshot residue might differ when improvised or country made firearms are used.[26] The improvised or country made firearms utilise readily available materials and hence do not follow any specific standard for manufacturing.[27,28]

The factors that can contribute to variation inthe deposition of gunshot residue include the angle of firing, the distance of firing, the type of ammunition used, the condition of the barrel, and the condition of the firearm.[29] The manufacturing process and materials used in making country made weapons make it difficult to standardize the amount of gunshot residue which can be obtained at a specific range to determine the range of firing.[30] The gunshot residues deposited on glass are retained longer as compared to the skin making it more probable for detection and study.[31,32]

MATERIAL AND METHODS

Sample Collection

The current study focused on the analysis of glass fracture pattern to analyse the trends in feature of radial and concentric fractures, mist zone and entry hole. Windowpanes of 4mm thickness of 1ft x 1ft dimension were obtained from a local glass manufacturer. The test firing was carried out at an enclosed shooting range in Bengaluru, Karnataka, India by random sampling using 30 samples. Inclusion criteria were the glass of 4mm thickness and exclusion criteria were glasses with pre-existing fractures. Soda lime glass, patterned glass, and tinted panes are more commonly used in doors and windows. Soda lime glass is relatively economical and chemically stable and extremely feasible. It is composed of about 70 percent silica (silicon dioxide), 15 percent soda (sodium oxide), and 9 percent lime (calcium oxide), with much smaller amounts of various other compounds. Tinted windows have a film applied to the glass. This film blocks out some of the light, making it more difficult to see through the window. Patterned glasses have a pattern that gets embossed on to the glass which provides privacy that many homeowners desire. In addition to privacy, there is no loss of artificial or natural light, as light can still easily pass through the glass.

Glass sample firing

A designed wooden frame was used to affix the glasses of fixed dimension. The firing was carried out in the firing range of the Corps of Military Police, Bengaluru under the supervision of experts. An INSAS LMG 5.56mm rifle having a capacity of 30 rounds was used in the study. It has a rimless cartridge case made of brass with bottle neck shape. Bullet used was made of gilding metal envelope FMJ, steel insert and lead core. A ball powder of with mass 1.64gm is utilised as propellant. The frame was fixed at a suitable height of 3 feet from the ground to ensure consistency in height for firing. Each glass sample was kept perpendicular to the muzzle end of the barrel. The glass sample was then fired at a 25-metre range. Each test firing was repeated five times for 25 metres distance. Each glass type was utilised and replaced after every round of test firing. The fired samples were packed in zip lock bags and labelled. To avoid possible contamination while the sample collection, gloves were utilised. The glass samples were further transported to the laboratory for examination. The fragments from the area near the bullet hole was collected using rubber tipped forceps and packaged with a label separately. To replicate the probability of discovering glass fragments at the crime scene, a random selection of the glass piece near the bullet hole was made.

Sample Measurements

The bullet holes were identified due to characteristic entry and exit hole specifications of the margins of the hole. The diameter of the impact hole was measured using a Mitutoyo Vernier Caliper of 0.01 to 150mm dimension with a measuring range of 6 inch. The measurements were calculated thrice, and an average of the readings was noted. Similarly, the diameter and thickness of the mist zone were measured. The number of radial and concentric fractures were also counted.

Detection of Gunshot Residue

The fragments of glass near the bullet holecollected using rubber tipped forceps were subjected to SEM-EDX analysis. The analysis was carried out using the CARL ZEISS Field Emission Scanning Electron Microscope (FESEM) instrument. The microscope is equipped with a Schottky thermal field emission gun with an accelerating voltage variation between 0.2 to 30kV with a resolution of image 2.8nm at 1kV and 1.5nm at 15kV. The instrument operates on high vacuum

mode with a variable pressure range of 2 to 133pa.

RESULTS

Gunshot residue was successfully detected on the glass samples fired at a 25-metre range. The gunshot residue on the glass indicates the deposition and presence with a sufficient detectable limit enough to identify the bullet hole on the glass samples. The glass samples utilised were soda-lime glass, patterned glass, and tinted pane fired at 25 metres in firing range. All the glass samples exhibited bullet hole, radial, and concentric fractures along with the formation of a mist zone (Fig. 1). The glasses were deposited with gunshot residue particles and successfully detected (Fig. 2). The presence of lead, barium, and antimony suggests that gunshot residue was deposited on the glass samples. A sufficient amount of gunshot residue was detected on all three types of glass samples for analysis at a 25-metre range (Fig. 3). The overall validity of the method adopted, and results obtained were checked by analyzing gunshot residue found on the same glass at the same distance for comparison.

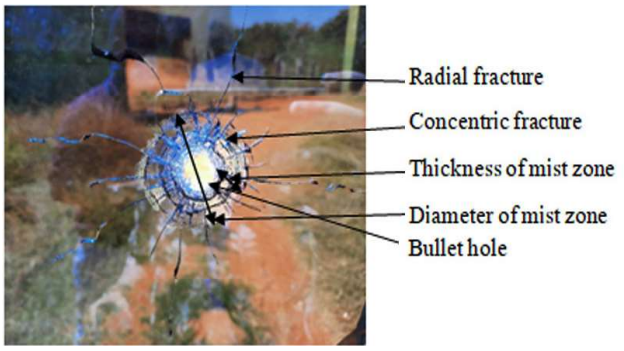

Fig. 1: Tinted pane 4mm thick depicting bullet hole, radial fractures, concentric fractures, and mist zone

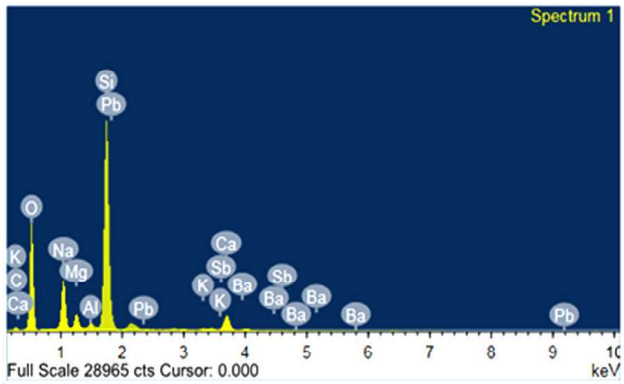

Fig. 2: EDX spectrum of residues detected on glass

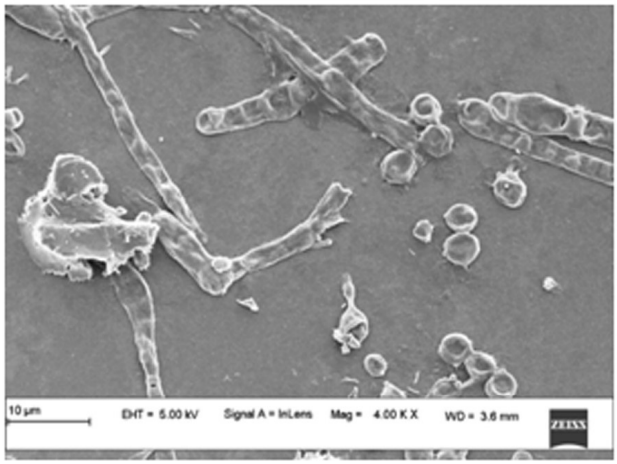

Fig. 3: Glass fragment with traces of gunshot residue

The glass fractures were analysed for the number of radial and concentric fractures, the diameter of the mist zone, and the thickness of the mist zone. Descriptive statistics were used to summarise the data. Table 1 shows the results of descriptive statistics utilising measures of central tendency (mean) and dispersion measure (standard deviation).

Table 1: Descriptive Statistics

Variables		N	Mean	Std. Deviation
Diameter of entry (mm)	4mm Tinted Glass	5	11.940	0.2510
	4mm Textured Glass	5	9.740	0.2302
	4mm Soda-lime Glass	5	16.080	0.4550
	Total	15	12.587	2.7375
Diameter of mist zone (mm)	4mm Tinted Glass	5	24.480	0.9284
	4mm Textured Glass	5	23.960	1.8876
	4mm Soda-lime Glass	5	26.380	1.2235
	Total	15	24.940	1.6885

Table Contt...

Number of concentric fractures	4mm Tinted Glass	5	4.600	0.5477
	4mm Textured Glass	5	4.800	0.8367
	4mm Soda-lime Glass	5	5.800	0.8367
	Total	15	5.067	0.8837
Number of radial fractures	4mm Tinted Glass	5	37.200	1.9235
	4mm Textured Glass	5	35.400	1.1402
	4mm Soda-lime Glass	5	50.400	3.0496
	Total	15	41.000	7.2111
Thickness of mist zone (mm)	4mm Tinted Glass	5	7.180	0.5450
	4mm Textured Glass	5	6.660	0.3362
	4mm Soda-lime Glass	5	8.720	0.6017
	Total	15	7.520	1.0199

Source: SPSS output

A parametric independent sample Analysis of Variance (ANOVA) was used to measure the statistically significant difference among the population mean. Table 2 depicts the homogeneity assumption using the Levene test which signifies the equal variance assumed. All the dependent variables have a significance value higher than 0.05 which states the homogeneity assumption has been met to execute ANOVA. (Refer to Table 2)

Table 2: Test of Homogeneity of Variances

Dependent Variables	Levene Statistic	Sig.
Diameter of entry (mm)	0.620	0.554
Diameter of mist zone (mm)	0.533	0.600
Number of concentric fractures	0.330	0.725
Number of radial fractures	3.240	0.075
The thickness of the mist zone (mm)	1.683	0.227

Source: SPSS output

The normality assumption using the Kolmogorov-Smirnoff test signifies the cumulative distribution among the datasets (Refer to Table 3).

Table 3: Kolmogorov Smirn off Test of Normality

-	Kolmogorov-Smirnov		
	Statistic	df	Sig.
Diameter of entry (mm)	0.208	15	0.079
Diameter of mist zone (mm)	0.149	15	0.200
Number of concentric fractures	0.126	15	0.199
Number of radial fractures	0.201	15	0.061
Thickness of mist zone (mm)	0.128	15	0.200

Source: SPSS output

The output of the analysis of variance (ANOVA) signifies that the diameter of entry hole and the mist zone, number of radial fractures, and thickness of the mist zone have a significant difference among the types of glasses. This indicates the different types of glasses may have variation in fracture pattern which could be useful for forensic investigators. The factors that can affect the fracture pattern may include velocity of the weapon used, type of firearm and the angle of impact. The number of concentric fractures has an insignificant difference among the types of glasses. (Refer to Table 4).

Table 4: Analysis of Variance

ANOVA		F	Sig.
Diameter of entry (mm)	Between Groups	481.22	0.000
Diameter of mist zone (mm)	Between Groups	4.11	0.044
Number of concentric fractures	Between Groups	3.64	0.058
Number of radial fractures	Between Groups	70.36	0.000
Thickness of mist zone (mm)	Between Groups	22.29	0.000

Source: SPSS output

DISCUSSION

The primary focus of the present study was to Fig. out if glass present at a crime scene can be a good source for finding gunshot residue. Gunshot residues are deposited on target surfaces in trace amounts and are not readily visible. This methodology was created with the intention of stimulating a real world situation in which a bullet strikes glass as an intermediate target and then the fragments are found at the crime scene as a piece of evidence. Altogether, the findings of this

study firmly supports the consideration of glass fragments containing gunshot residue as trace evidence alongside commonly considered pieces of evidence such as bullets, cartridges, or firearms. The present study also demonstrates the effectiveness of analysis for gunshot residue to make use of a minimum quantity of gunshot residue obtained on the glass samples. In real-life crime scenarios, the quality and quantity of gunshot residue found as evidence critically determine the suitable method selected for detection and analysis.

Gunshot residue particles found on intermediate targets such as glass, clothing, furniture, etc can be considered an excellent source for detecting the residues. In the present study, the glass fractures were impacted due to bullets. The glass fracturedepicts the hole diameter, radial, and concentric fractures, and mist zone formed (Fig. 1). A minimal quantity of unburnt, partially burnt, or completely burnt gunshot residues can be recovered from intermediate target surfaces. Factors such as the angle of firing, the distance of firing, the type of ammunition used, the condition of the barrel, and the condition of the firearm can influence the fracture formed for scientific analysis.[29] Hence, it is recommended that the glass pieces found at the scene of the crime should be packed carefully and transported thus aiding the analysis of gunshot residue if impacted by bullets.[20]

The path of the bullet from the barrel till it hits the target resulted in the formation of radial and concentric fractures at different ranges. By the contact between the bullet and the glass surface, the possibility of the transfer of gunshot residuecannot be ruled out. During sample collection, the number of radial and concentric fractures differed. This could be due to the composition of the glass. In absence of evidence such as bullets, cartridge cases, or firearms, the gunshot residue composition can be equally powerful for identification and narrowing down the type of weapon used. SEM-EDX is recommended to analyse the trace amounts of gunshot residue that can be deposited on intermediate surfaces such as glass. The recommended sampling strategy for detecting gunshot residue would be in and around the bullet hole formed on the glass and the bullet hole. The area around the bullet hole helps in narrowing down the area for detection of gunshot residue to identify the traces of gunshot residue which is not visible. The variables that impact the gunshot residue deposition are based on the amount of transfer, persistence, and recovery that interests the investigators to identify and narrow down the type of weapon used. This can open ideas on the type of firearm and statistical estimates in real-life crime scenarios.

The present study utilised glass samples used in windowpanes fired at a 25-metre range which led to the deposition of gunshot residue on glass and a significant amount of gunshot residue was recovered from the glass. The glass fragments formed after impact were preserved with sufficient support to prevent further fragmentation. Improper handling, collection and preservation may result in the fragmentation of small glass pieces. These glass pieces were found to be significantly useful in the forensic context as it retains the gunshot residue. Impact on three types of glass by INSAS LMG 5.56mm weapon was analysed for traces of gunshot residue which yielded excellent results. Fig. 2 depicts the detection of gunshot residue at a 25-metre range. SEM-EDX was preferred over other methods owing to its capability in identifying particles that contain all the critical elements and demonstrates the strong possibility for false-positive results when total elemental analysis techniques, such as AAS, are used.[15,21,25] It was observed that gunshot residues can be detected on intermediate glass fired over a 25-metre range. This is due to the nature of the target surface and velocity of the projectile and the constructional feature of the projectile for retention of gunshot residue.[3] Fig. 3 depicts the traces of gunshot residue on the fired glass samples. Any surface which comes in contact with the bullet is capable of instantaneous transfer/deposition with few traces of gunshot residue as a bullet wipe. Nevertheless, glass samples of different compositions were capable of yielding a useful composition of gunshot residue. Gunshot residue due to the impact of the bullet can transfer onto intermediate targets which can retain them, and this happens due to impact and friction. The detection of lead, barium, and antimony is suggestive that gunshot residue is retained. The morphological (visual) results showed a nodular specific morphology of metal particles lead, barium, and antimony resulting from the gunshot residue.[20,21] However, the quantity could vary due to environmental factors, while impact pattern was variable due to either composition of glass or surface defects.

Intermediate targets of different glass types were considered primarily to imitate the practical scenario of finding panes or fragments of glass in the investigation even after considerable time for analysis.

The comparison of the types of glass was performed with the diameter of entry, the diameter

of the mist zone, the number of concentric fractures, the number of radial fractures, and the thickness of the mist zone.[3] The statistical testing found a significant difference among the diameter of entry, the diameter of the mist zone, the number of radial fractures, and the thickness of the mist zone with types of glass. Sodalime glass shows significantly greater diameter of entry hole and mist zone, along with number of radial and concentric fractures and thickness of the mist zone. The quantifiable difference between the impacts found on glasses could be related to the energy of the impact, combination of firearm ammunition, range of firing and tensile stress. These observations may prove useful to the forensic investigators at the scene of crime.

CONCLUSION

Intermediate targets such as glass hit by the bullet can be considered as trace evidence in addition to routinely encountered evidence like firearms, fired bullets, and cartridge cases in shooting related crimes. The sample conditions may vary from intact glass to fractured, fragmented, trace, or mixed glass samples. While the amount of gunshot residue deposited and the ease of detection might vary, it is possible to retrieve gunshot residue from glass impacted as an intermediate target that is properly collected. It was demonstrated that the role of glass samples in retaining the gunshot residue particles is necessary to obtain information on primers and propellants that can be compared with profiles of primer and propellants for different firearms. A statistically significant difference among the diameter of entry, the diameter of the mist zone, the number of radial fractures, and the thickness of the mist zone with types of glass can provide important clues to forensic investigators to solve the crime. The detection and analysis of gunshot residue from intermediate targets such as glass are hence practically useful and area promising field to explore further.

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