ORIGINAL ARTICLE

Analysis of Glass Fracture Pattern on Soda Lime and Tempered Glass Caused by Shotgun Bullet Impact

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ABSTRACT

Introduction: Broken glass exhibits unique fracture patterns depend upon the nature of the impact. The fracture patterns provide information like point and angle of impact, direction of force and sequence of firing. Recent studies have shown that the use of shotgun in Malaysia is increasing, yet, the relationship existing among the fracture pattern and the projectile impact factors are not well documented. The objective was to analyse the fracture characteristics on different glass types of variable thickness and distance made by shotgun ammunition. **Methods:** Soda lime and tempered glass panel with dimension of 12'x 12' with 3 or 4 mm thickness were shot from various distances of 4, 6 and 8 m from the muzzle end of the shotgun. Samples were analysed under fixed parameters and observations were recorded. **Results:** It is found that the bullet hole diameter of 4 mm tempered glass were larger compared to 4 mm soda lime glass ranged from 14.33 to 24.17 cm as distance increased. Tempered glass surface also exhibited dicing fragments unlike soda lime glass where only radial fracture patterns are evident. This can be attributed to high inherent strength and ductility that makes the tempered glass remarkably resistant to external force. **Conclusion:** The findings from this study can lead to distinguish the type of glass through examination of fracture patterns, whether it is soda lime silica or tempered glass. The type of glass and the source of impact can be determined using the fragments, no reconstruction necessary.

Keywords: Physical evidence, Fracture pattern, Shotgun, Soda-lime silica, Tempered glass

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INTRODUCTION

Glass and polymer are commonly encountered as it can be found everywhere from building windows, beverages bottles and also in the automobile windows (1). Generally, glass is super cooled liquid that possesses features such as electrical and thermal resistance, and has a range of thermal expansion and refractive index (2). There are various types of glass such as borosilicate, tempered, soda lime silica and float glass (3). Fracture pattern analysis has been confirmed to be beneficial as it provides much useful information like cause of fracture, and direction of force applied. The glass fracture analysis is very beneficial to establish the sequence of events and to link collectively items of evidence and it is of paramount importance in such instances in which firearm is used (2).

When a projectile hitting a glass surface, the glass does not only break but it creates fracture patterns (4). The glass bends slightly and breaks when it reaches limit of tensile stress and the projectile passes through the glass. It often leaves a spherical, crater shaped hole that is surrounded by a almost symmetrical pattern of radial and concentric cracks (2). Waghmare further reported that the hole is wider at the exit side and hence its examination is a crucial factor in determining the direction of impact (5). Mirrors, mist regions, hackles, and wallner lines also were defined as part of fracture patterns (6). McJunkins & Thornton in their study have emphasized the examination of glass fracture from forensic point of view and a more detailed clarification on nature of glass fracture as a useful resource in the solution of forensic issues (6).

In a study conducted by Bradt, it was observed and concluded that projectile with high velocity develops a number of radial cracks that is proportional to the kinetic energy of the projectile (7). Gamble et al. also found that the effect of shots of moderately high speed bullet on window panels cause fractures having characteristics dependent to the velocity and angle of impact (8). In a separate study, Waghmare concluded that the variation in size of glass sheet have a significant influence on the resultant fracture of glass (5). This absolutely proved that numerous parameters of bullet and target materials did affected the fracture pattern that is formed on the surface

of a glass (5). Each glass fracture pattern produced is varied as it is prompted by type and thickness of glass and the intensity of the impact itself (5).

Recent studies have shown that gun violence in Malaysia is increasing, yet limited number of studies being done related to firearm in Malaysia especially shotgun as the requirement for the data is needless (9). Shotgun is a gun that has comparative outer appearance to a rifle, but range as it absences in rifling in the barrel (10). Although there have been considerable effort to study the fracture pattern of glass under such impact, the relationship existing among the fracture pattern and the projectile impact factors are not well documented (11). Hence, this study focus on the fracture patterns shot by shotgun ammunition on soda lime and tempered glass at various distance in order to facilitate a forensic examiners to ascertain the nature of glass fracture. This study is embarked to assist the police or forensic investigators to analyse fracture pattern of glass panes in order for them to reconstruct the sequence of events that occurred when the crime was committed.

MATERIALS AND METHODS

Research materials

Soda lime panel with dimension 12 x 12 x 3 mm and 12 x 12 x 4 mm and tempered glass with 4 mm thickness were used in this research. A 12- gauge Rattueil 650 break action shotgun was used to produce fracture pattern on the glass panels. Soda- lime glass is made up of 70 -75 % silica, 12-18 % soda and 5 -12 % lime. The glass panel will be held by using a wooden frame and sponge padding was added in the wood frame to reduce vibration and avoid additional damage during the impact.

Experimental design

The glass target was kept perpendicularly at 4, 6 and 8 m to the muzzle end of the firearm. For this study, soda lime silica and tempered glass of variable thickness were taken namely 3 mm and 4 mm. Each type of glass with their respective distance and thickness was repeated three times to establish the consistency in hole diameter. The firing arrangement is shown in Fig. 1. After test firing, samples were numbered and photographed. The fracture patterns were examined from the point of impact, and extending outwards following the crack pattern. Following measurements have taken with a Vernier Caliper to analyse the trends in the features:

1. Diameter of Bullet Hole
2. Radial Fracture count
3. Concentric Fracture Count

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. Graphs were drawn to find the regularity in diameter of bullet hole. All data were analysed using the Statistical Package for Social Sciences (SPSS). One-way ANOVA and Multiple Means Comparison (Post Hoc) test were performed to determine the significance of difference among the type of glass, thickness and distance.

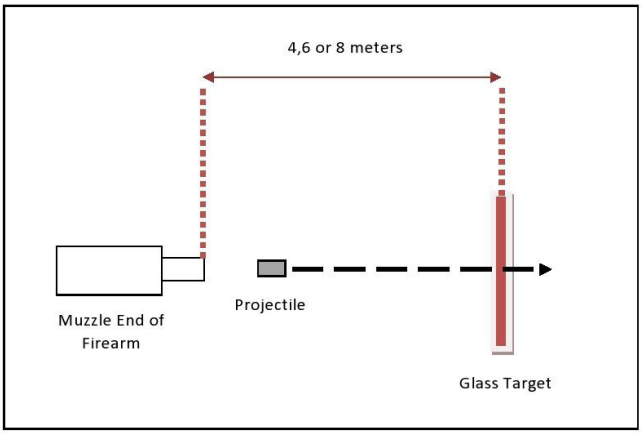


Figure 1: Schematic diagram of firing arrangement. The glass target was kept perpendicularly at 4, 6 and 8 m to the muzzle end of the firearm.

RESULTS

Diameter of bullet bole

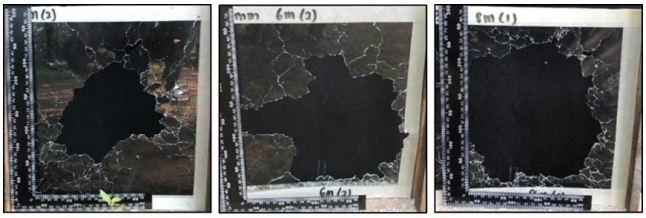
Impact of shotgun bullet on glass sheet causes glass fracture having characteristics features depends on the distance and type of glass. Table I shows the measurement of bullet hole diameter produced by each glass at various distances. It is observed that there is a consistency in hole diameter for a particular thickness and type of glass as distance increased. All the measurements show linearity for soda lime glass irrespective of glass thickness and same trend follow for tempered glass as distance increased. Using one-way ANOVA and Multiple Means Comparison (Post Hoc)

Table I: Diameter of bullet hole formation on surface of 3mm soda lime glass, 4mm soda lime glass and 4mm tempered glass at 4 meter, 6 meter and 8 meter distance

Type of glass	Sample number	Distance		
		4 meter	**6 meter**	**8 meter**
3mm soda lime glass	1	19.5 cm	16.0 cm	18.0 cm
	2	13.5 cm	13.0 cm	19.5 cm
	3	6.5 cm	18.0 cm	20.5 cm
	Average	13.16 cm	15.67 cm	19.33 cm
4 mm soda lime glass	1	11.5 cm	15.5 cm	19.0 cm
	2	8.0 cm	11.5 cm	21.0 cm
	3	8.0 cm	13.5 cm	19.5 cm
	Average	9.16 cm	13.5 cm	19.83 cm
4 mm tempered glass	1	8.5 cm	24.5 cm	23.5 cm
	2	18.0 cm	18.0 cm	24.0 cm
	3	16.5 cm	22.0 cm	25.0 cm
	Average	14.33 cm	21.5 cm	24.17 cm

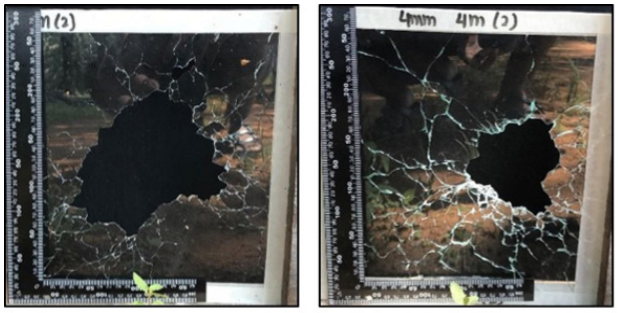
test, there is significant different (p=0.03) for 6 m and 8 m distance (p=0). However, there is no significance difference (p>0.05) for 4 m distance.

As shown in Fig. 2, bullet hole diameter for 3 mm soda lime glass was increased and largest at 8 m distance. It was also observed that, the bullet hole which was formed on the glass was irregular in shape. As seen in Fig. 3, soda lime glass with 4 mm thickness has smaller diameter compared to 3 mm soda lime glass due to the ability of thicker glass, which can withstand more stress from the ammunition compared to thinner glass. While, 4 mm tempered glass produced larger diameter compared to 4 mm soda lime glass at 4 m distance as shown in Fig. 4 due to the shattering of glass into smaller fragment. Hence, the chances of the fragment falling out from the frame are much easier.



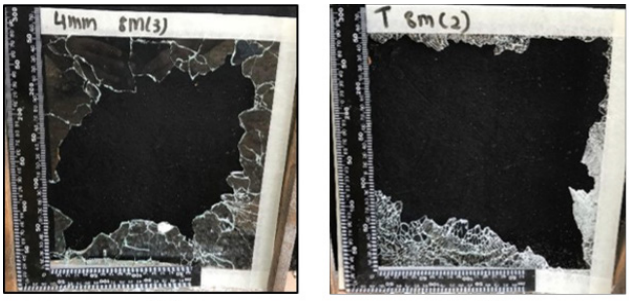
(A) (B) (C)

Figure 2: (A), (B) and (C) showing, 3 mm soda lime glass sample shot at 4 meter, 6 meter and 8 meter distances. After shooting, the observation shows that the diameter of the bullet hole increases as the distance increase. The observation shows that 4 meter has much smaller bullet diameter compared to 8 meter distance diameter which is much large in size.



(A) (B)

Figure 3: (A) is 3 mm soda lime glass and (B) 4 mm soda lime glass that is shot at 4 meter distances. The diameter of thinner glass is much larger than thicker glass.



(A) (B)

Figure 4: (A) is 4 mm soda lime glass and (B) 4 mm tempered glass that is shot at 4 meter distances. It can be observed that the both radial and concentric fracture is present on the surface of the soda lime glass. On the contrary, the tempered glass produced dicing effect that are cubiodal in shape.

Fracture patterns

Table III summarises the fracture pattern that was formed on both soda lime and tempered glass. It can be observed that there are different number of radial and concentric cracks, fragmentation and glass fragment size formed on each type of glass at different distances. As distance increased, more fragmentation was observed as shown in Fig. 2. Even though, soda lime and tempered glass was most fragmented at 8 m distance, yet radial, concentric and dicing effect was still observable respectively as seen in Fig. 4. This shown that the fracture pattern formed on the glass was visible and unique to each type of glass.

Table III: Fracture pattern formed on surface of 3 mm soda lime glass, 4 mm soda lime glass and 4 mm tempered glass at 4 meter, 6 meter and 8 meter distance

Fracture Characteristics/ Type of Glass	Soda lime glass	Tempered glass
Radial & Concentric	Both radial and concentric fracture is present	No visible radial & concentric as dicing or cubes were observed on glass surface
Fragmentation	Fracture spread apart and less fragmentation	Fracture is closer to each other and innumerable
Fragment Size	Fragment of glass broken into large and sharp shard	Small and blunt glass fragments

DISCUSSION

It was observed that the diameter of bullet hole increases regularly for each type of glass with increased in distances as a result of the dispersion of shotgun pellet which also increases as it travel further from the muzzle of the firearm. Little work has been discovered in this regard in the literature. Our findings agree with the principle from Rhodes & Thornton suggesting that the diameter of the hole varies with the bullet velocity (12). The results also in line with Nyoungue et al. stated that the window glass no longer merely exhibits a hole however it is shattered when the velocity of bullet is reduced through increased distance or decreased discharge energy (13). Further studies have been conducted by Waghmare et al. involving soft nose bullet fired on windowpane at varied distances. They discovered that the bullet hole diameter were increased as distance elevated at precise thickness. They concluded that energy loss by the soft nose bullet on the window glass pane increases with increased in distance and thickness of glass pane. Similarly, pressure on impact like bullet hole also increases (14). The further bullet travel from the muzzle, the bullet will lose their energy rapidly (15). One possible limitation with our results could have been that the used of chronograph to measure the bullet velocity. Future studies to include chronograph to relate bullet energy loss and glass fracture patterns.

Harshey et al. analysed the glass fracture pattern made by .177″ calibre air rifle and produced data of hole diameter on different thickness of glass. They observed that the bullet hole was irregular in shape unlike common bullet entry hole which was more defined in shape where circular or elliptical is more outstanding (2).

According to Bradt, radial fracture patterns are regularly resulting impact from blunt object. This justifies the radial fracture produced at the the glass surface is indeed originated from a blunt impact as shotgun pellets are spherical lead ball that are blunt and rounded contrary to the handgun bullet which can be much extra sharper on the tip (7). In addition, Vandenberghe et al. also stated that star- like cracks emerged from the point of impact and circular fractures are also developed. These fractures are similar to "spider web" appearance (16).

Meanwhile, tempered glass produced small fragment that is denoted as dicing or cubes. This is due to the residual stress that is stored in the glass during thermal tempering which also provides to reserved elastic strain energy that results in formation of small fragment called dicing on the tempered glass surface as external force is applied as reported by Lee et al. (17). The same finding also was reported by Warren where he has extensively studied the dicing fragmentation process in tempered glass panes. The extensive fragmentation that happens during the fracture process resulting in small equiaxed fragments unlike large "lance-like" shards in soda lime glass pane (18). The manner in, which that fragment are produced is the main reason, for choosing tempered glass over ordinary glass as it's much safer as claimed by Savic et al. (19). When tempered glass break, the small pieces produced cannot be categorized as radial or concentric, therefore we reported as no radial or concentric were present (refer Table III) (20).

The other evidence that strongly supported our findings was also reported by Overend et al. They found that the pre- compression of soda lime glass surface is relatively low thus; the soda lime glass fails or breaks at low stress level into much sharp shards. Meanwhile, tempered glass breaks only at excessive level of stress as it has higher surface pre-compression and produced small harmless dice. The size and shape of fragment produced by tempered glass correlated with the magnitude of external forced that is applied on glass surface (21). From the work of Bradt & Tressler and in Fig. 4, it is apparent that the fracture pattern on soda lime glass is much further apart and lesser in number while tempered glass is closer to each other and innumerable in amount (22).

CONCLUSION

In a nutshell, this study confirmed the key factors that contributed to the glass fracture characteristic such as distance from muzzle of firearm, thickness and type of glass. The findings of this work may help to opine whether the fracture is made by regular firearm or by shotgun by examining the hole diameter. This study could be used as a guidelines in future research but more controlled conditions and variations of glass samples are required to provide more statistical significant to characterise the fracture patterns.

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