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Effect of Three Types of Projectile Materials Considering Extent of Damage on the Laminated Glass: A Study

Nitin Thakur[1*], Pramod Kumar[2], and Rabinder Singh Bharj[3]
[1]Research Scholar, [2&3]Associate Professor
[1,2&3]Department of Mechanical Engineering, NIT Jalandhar, Punjab, India
[*]Corresponding Author
E-Mail: intnitin@gmail.com

Abstract - **Ballistic performance of laminated glass is highly influenced by its configuration. Ballistic impact results in typical glass failure pattern, featuring a central Hertzian cone comprising of splintered glass and a spider web like cracking pattern around the cone with circumferential and radial cracks. The extent of damage varies, depending on the projectile materials. The aim of this research was to numerically compare three projectile materials, Armor steel, OFHC copper and Armco iron in reference to damage of the laminated glass (LG), considering crack pattern and the depth of penetration, for the constant velocity of AK-47 projectile. The numerical analysis concludes that, copper projectiles inflicted more damage in comparison to other two materials.**
Keywords: **Ballistic Impact, Laminated Glass, Crack Pattern, Transparent Armors**

I. INTRODUCTION

Transparent armors play the most crucial role, of shield in armored vehicles and at the same time aiding in visual acuity. There have been major advancements in transparent armor fabrication technologies as safeguarding human lives are the major concerns, among the world super powers. Therefore comprehensive understanding of ballistic impact and ballistic damage behaviors of the armor specimens is must to systematically improve the transparent armor performance [1-4].

Typical transparent armors comprise of glass laminates with polymer inter-layers. As the projectile makes contact with striking face of armor, it fractures the layers of glass, resulting in the absorption of the energy from the bullet. The bullet loses its kinetic energy and finally is captured within the laminates [5,6].Extensive research is available to demonstrate that increasing the ratio and thickness of glass and the number of inter-layers, improves the ballistic performance of the laminates [5]. Ladner *et al.*, studied the crack patterns in laminates with and without polyurethane backing and concluded that design with a rear sheet of 1.2 mm polyurethane had higher impact resistance [6].

Several researchers have studied Ballistic impact on transparent armor, Bless *et al.*, notified different damage morphologies, starting from the impact crater, bundled radial cracks, the outward fan cracks, the coarse radial cracks and the bow-tie cracks, were shown on the striking plate. And on the rear plate, the florets, continuous radial cracks and inward fan cracks were observed [7]. Wells study results, matched bless reports. Limited studies are available on effect of different projectile materials on ballistic impact related to bullet proof glass [8]. Since experimental studies are costly because of incurring materials and infrastructure requirement. So the present study relates to the numerical simulation of the ballistic impact on the bullet proof glass employing three different projectile materials and studying its effect on the extent of damage.

II. MATERIALS AND METHODS

In the present research the numerical simulations of the ballistic impact event is being carried out using Ansys Autodyn 3D employing Finite element approach. The modeling of the physics was carried out in Ansys Design modeler itself. The mesh used to model the laminated glass was denser at the centre and coarser at the end edges which mean it was biased at the centre in order to replicate the conservative nature of the ballistic phenomenon. The approximate element size for the laminated glass was 0.5 mm, which was determined after convergence study; further decreasing the size of the mesh didn't enhance the results but significantly raised the computational time.

The dimensions of the laminated glass were 300mm x 300mm x 49 mm. In order to compensate for the mesh related errors, geometric strain erosion was considered in modeling. All the rotational as well as displacement degrees of freedom was considered fixed at the end faces of the laminated glass in order to provide clamping to the laminated glass at its end edges. The thickness of the each layer of glass, polycarbonate (backing material) as well as Polyurethane interfacial layer was according to the Table I given below.

TABLE I CONFIGURATION OF THE LAMINATED GLASS

S. No.	Materials	Thickness (mm)	No. of Layers
1	Soda lime glass	13	3
2	Poly-urethane (inter-bonding layer)	1.50	3
3	Polycarbonate (backing layer)	5	1

Soda-lime glass was numerically modeled using JH-2 material model and the properties for the same are given in Table II [9]. Elasto- Plastic material models were used for polyurethane and polycarbonate as mentioned in [9].

TABLE II JOHNSON-HOLMQUIST 2 MATERIAL PROPERTIES FOR SODA-LIME GLASS [9]

JH-2 Parameters for soda-lime glass	Value
Density (kg/m^3)	2530
Shear modulus (GPa)	30.4
A	0.93
B	0.088
C	0.003
M	0.35
N	0.77
Ref strain rate	1.0
Tensile Strength (GPa)	0.15
Normalized Fracture Strength	0.5
HEL (GPa)	5.95
HEL Pressure (GPa)	2.92
HEL Strength (GPa)	4.5
D1	0.053
D2	0.85
K1(GPa)	45.4
K2(GPa)	-138
K3(GPa)	290
Beta	1.0

In order to accomplish our objective three different materials (OFHC copper, Armco iron and Armor steel) had been used to model the AK-47 Projectile, with a constant velocity of 720 m/s. Johnson-Cook material model was employed to model the physics of the projectile and the properties for the same were taken from [10].

III. RESULTS AND DISCUSSIONS

It was observed from previous studies that whenever there is a high velocity impact on ceramics there is conservative as well as extended damages caused by the projectile on the ceramics. The central region consists of comminuted cone which extends out to form a crater. Next to the crater there is formation of circumferential cracks; which extends to the long radial cracks. The crater and the comminuted cone region stand below the projectile and the radial cracks forms secondary zone which surrounds the circumferential cracks. Similar behavior has also been observed when there is ballistic impact on the laminated glass [7,8].

Fig.1 (a, b, c) shows the crack pattern observed during the ballistic impact on the laminated glass, which is a good attribute to check the damage as well as strength of the laminated glass since the larger number of cracks tends to weaken the bullet-resistant glass. Fig.1 shows that the copper projectile spits out 8 long radial cracks on the surface of laminated glass which is more than the cracks generated by steel and iron projectile (6 in number) on the laminated glass. Similar behavior has been observed by Shah *et al.*, which is contradictory as steel and iron are harder than the copper projectile [11].

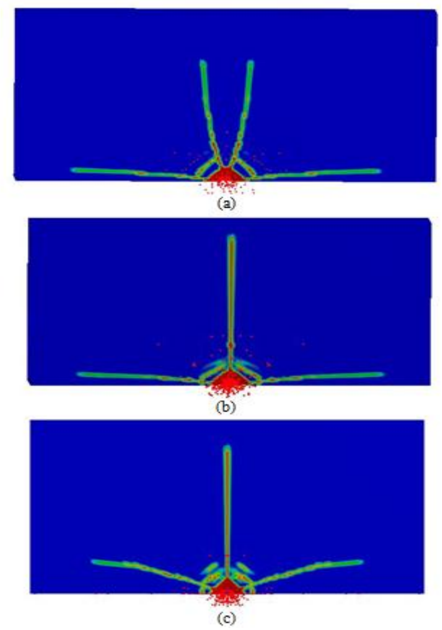

Fig.1 Observed crack pattern by (a) Copper projectile (b) Iron projectile and (c) Steel projectile on the laminated glass

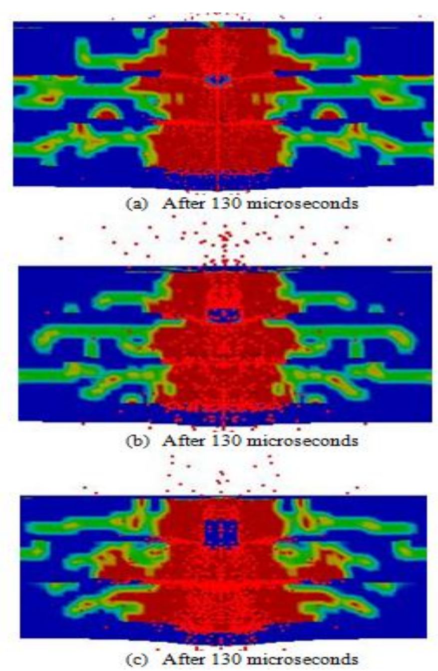

Fig.2 Depth of penetration contour plots for (a) copper projectile (b) iron projectile (c) steel projectile

To further investigate this behavior and to check the extent of damage, the depth of penetration generated by the three different projectile materials after 130 microseconds is shown below in Fig.2 (a) for copper projectile (b) for iron projectile (c) for steel projectile. From this figure it is clear that the copper projectile and iron projectiles generate nearly 30.6 % DOP as compared to steel projectile which is 26.5 %.

Further Fig.3 (a, b, c) shows the extent of damage to the steel, iron and copper projectile respectively during the ballistic impact event. It is clear as well as obvious from this figure that the copper projectile has undergone maximum damage during this phenomenon due to its low yield strength.

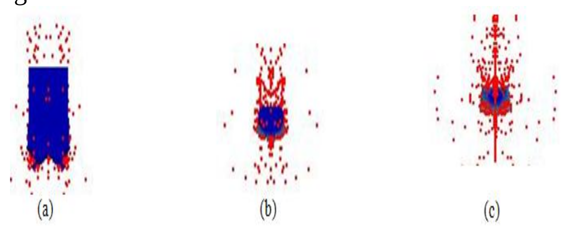

Fig.3 Extent of damage during ballistic impact to (a) steel projectile (b) iron projectile (c) copper projectile

From the above discussion it is clear that copper projectile produces more damage to the laminated glass as compared to the iron and steel projectiles, which is similar to the results by [11]. This behavior is attributed to the fact that copper projectile has more density as compared to the iron and steel, so for the same velocity and volume of the projectile, copper projectile exhibits more impact energy upon the laminated glass as compared to other projectiles. Also as, the copper projectile is less stiff as compared to the other projectiles, so there is longer contact time between copper material and laminated glass, hence generating more number of cracks on the surface of laminated glass in comparison to other.

IV. CONCLUSION

In the present study the effect of three types of materials of the projectiles on the extent of damage of the bulletproof glass has been studied by modeling the physics of the problem in Ansys Autodyn 3D. The projectiles are having the constant velocity of 720 m/s. It is inferred that the copper projectile, instead of its low strength, produces more damage to the laminated glass, as long as the depth of penetration and number of cracks are concerned. This shows that the hardness or the strength of the projectile is not as important as the impact energy of the projectile, more the impact energy more will be the extent of damage caused by the projectile.

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