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The Effect of Size, Thickness, and Type of the Bonding Interlayer on Bullet Proof Glass as per EN 1063

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Abstract**—**This investigation presents preparation of sample and analysis of results of ballistic impact test as per EN 1063 on the size, thickness, number, position, and type of the bonding interlayer Polyvinyl Butyral, Poly Carbonate and Poly Urethane on bullet proof glass. It was observed that impact energy absorbed by bullet proof glass increases with the increase of the total thickness from 33mm to 42mm to 51mm for all the three samples respectively. Absorption impact energy is greater for samples with more number of bonding interlayers than with the number of glass layers for uniform increase in total sample thickness. There is no effect on the absorption impact energy with the change in position of the bonding interlayer.

Keyword**—**Absorbed energy, bullet proof glass, laminated glass, safety glass.

I. Introduction

BULLET proof glass or laminated glass consists of two or more glass plies bonded together with an elastomeric bonding interlayer usually Poly Vinyl Butyral (PVB) or Ethyl Vinyl Acetate (EVA). After breakage, the glass remains in the frame when bullet proof glass fractures. This post breakage characteristic of bullet proof glass has made it desirable for use in vehicle windshields, as a safety glass or bullet proof glass [1]. Some constructions have more than one layer of glass. A typical bullet proof glass construction consists of glass as the outer layer backed by Poly Carbonate (PC) with a thin adhesive transparent bonding interlayer of Poly Urethane (PU) in between. Ordinary laminated windshields usually have glass instead of PC as the backing material [2].

The PC is usually coated with an abrasion resistant coating. This can be of two main types: a soft coating that heals after being scratched or a hard coating that resists scratching in the first place.

The effects of both types of coating were examined in various studies. When bullet is fired against such a construction, although the glass shatters, it is still able to deform and slow the projectile enough so that the tough PC is able to prevent penetration of the projectile by bulging plastically [3]-[5]. Commercially available polymer was used as the matrix material. Soda lime silicate is used as fiber and PU is used as adhesive material for PC and Glass Sheet. Uniform thickness was maintained during manufacturing for each set of laminates procedure [6]-[7].

Keller used novel method to measure the delaminating energy in bullet proof glass in the relevant dynamic range. He found that increasing the bonding interlayer thickness improves the penetration resistance of bullet proof glass because more energy can be absorbed in the high speed delimitation process since the bonding interlayer is simply less like to tear [8]. Linden et al. conducted non-destructive testing on two different plate geometries. Perusal of their data indicates that while load duration and elevated temperatures acting individually reduce the structural rigidity of the bullet proof glass, the two factors do not interact, producing a greater combined reduction in bullet proof glass strength [9].

Behr and Kremr used experimental validation of a mechanics based finite element model for architectural bullet proof glass units subjected to low velocity on two gram projectile impacts. The impact situation models a scenario commonly observed during severe windstorms. This study confirmed the ability of an analytical finite element model to predict accurately the peak strains in representative architectural bullet proof glass units as a function of impact velocity [10]. Zang et al. investigated a 3D discrete finite element method (FEM) to study the impact fracture problem of bullet proof glass. The glass and PVB of bullet proof glass plane were discretized to uniform rigid spherical elements. This investigation showed that the accuracy of the 3D model and numerical analysis code were also validated in the elastic range by comparing it with FEM [11].

More recently, Belies compared PVB with stiffer and stronger bonding interlayer Sentry Glass Plus (SGP) material. After breakage of both glass sheets the load decreased to a relatively low level between 2 KN and 3 KN before the broken glass pieces and bonding interlayer started again to build up compressive and tensile stresses, respectively. Subsequently, the load slightly increased again and after reaching the maximum, it decreased significantly to less than 0.3 KN [12]. Weller used experimental study to compare different bonding interlayer materials in bullet proof glass in respect to their structural behavior. The material properties above the verification temperature clearly showed the temperature dependency. The relaxation times fall with increasing temperature and the shear stress gets smaller [13].

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Mostly the studies carried out on bullet proof glass and related materials confined to judge the mechanical strength of the resultant composite structure, their performance and behavior when subjected to different temperature gradients. Some studies are also available on analytical and numerical modeling. Study related to conformance of bullet proof glass to ballistic standards is limited. In the present study, three bullet proof glass samples were prepared by commercial available manufacturing process. The samples have a uniform variation of 9mm across each other. All the samples were tested for ballistic tests EN 1063 by state of the art laboratory to ascertain their conformance.

II. Material, Equipment and Experimental Procedure

A. Material

The materials used in this investigation are float glass, PVB, PU and PC. Three samples designated as SampleI33, SampleII42 and SampleIII51 with a combination of Glass, PVB, PU and PC of 33mm, 42mm, and 51mm thickness of dimension 500mm×500mm were prepared as per the description shown in Table I.

TABLE I
Sample of Bullet Proof Glass

Samples	Thickness (mm)				Number of Bonding Interlayer			
	Glass	PVB	PU	PC	Glass	PVB	PU	PC
SampleI33	8.0	1.50	1.25	5	3	2	1	1
SampleII42	8.0	1.50	2.20	5	3	1	3	2
SampleIII51	8.0	1.50	2.20	5	4	2	3	2

B. Sample Manufacturing Process

All the samples were prepared by hand lay-up technique where specified atmospheric conditions were set. The temperature and relative humidity of lay-up room was maintained between 20^{o}C to 25^{o}C and 27 to 30 respectively. Under these conditions these set of composites were packed in a poly bag (without lamination of PU and PC) by attaching nozzles. These nozzles were connected with vacuum pump (760mm of Hg) and placed in chamber where temperature ranged between 105^{o}C to 110^{o}C was maintained by supply of hot air. After 5 hours these composites were removed from poly bag and laminated with PU and PC. Thereafter; all the samples were placed in an Autoclave. Temperature between 130^{o}C to 135^{o}C was maintained by an infrared heater and high pressure compressed air maintained at 1.2 MPa was present inside the chamber. The constructional geometry of final fabricated samples after fabrication and heat treatment are shown in Fig. 1.

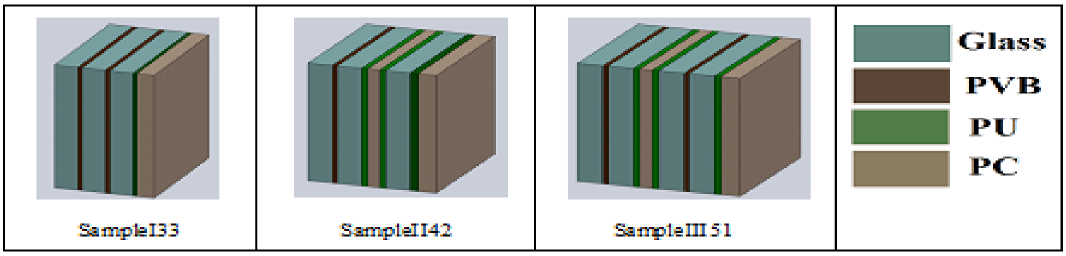

Fig. 1 Samples of bullet proof glass

C. Experimental Procedure

The schematic diagram of experimental set up of bullet proof glass test on the basis of ballistic impact applied on samples is shown in Fig. 2. The EN 1063 or CEN 1063 is a security glazing standard created by the European Committee for standardization for measuring the protective strength of bullet proof glass. The classification levels are numbered in order of increasing protective strength. Thus any sample complying with the requirements of one class also complies with the requirements of previous classes. The different threat levels prescribed are shown in Table II. The protective strength of a Glass shield is rated based on the type of threat level, it is capable of withstanding. There are 7 main standard threat levels: *BR1-BR7* each corresponding to a different type of small arms fire. Additionally, there are two other threat levels *SG1* & *SG2* corresponding to shotgun munitions. To be given a particular rating, the glazing must stop the

Bullet for the specified number of strikes, with multiple strikes placed within 120mm of each other. The glazing should also be shatterproof and produce no spalls after each strike.

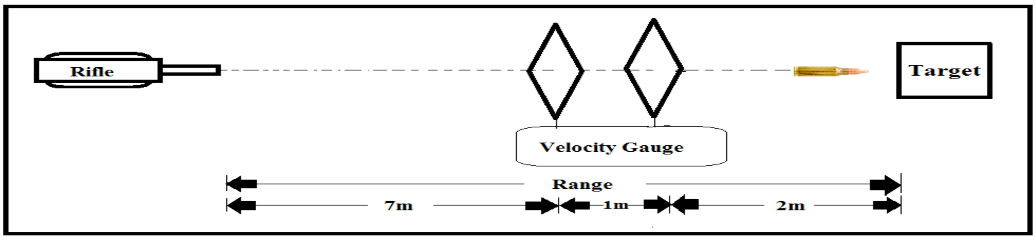

Fig. 2 Experimental set-up for ballistic impact test

TABLE II
EN 1063 STANDARD

Class	Weapon	Caliber	Weight (g)	Range (m)	Velocity (m/s)	Absorbed impact Energy	Shot
BR5	Rifle	5.56x45mm NATO	4.0 ± 0.1	10.00 ± 0.5	950 ± 10	1800 J	3
BR6	Rifle	7.62x51mm NATO	9.5 ± 0.1	10.00 ± 0.5	830 ± 10	3270 J	3
BR7	Rifle	7.62x51mm NATO	9.8 ± 0.1	10.00 ± 0.5	820 ± 10	3290 J	3

III. RESULTS AND DISCUSSION

TABLE III
TEST REPORT

Samples	Measured Thickness (mm)	Measured Weight (Kg)	Class	Measured Velocity (m/s)		Glass/Bonding Interlayer Thickness Ratio
				Maximum	Minimum	
SampleI33	33	17.49	BR5	955.85	943.66	24/09
SampleII42	42	19.67	BR6	836.67	831.18	24/18
SampleIII51	51	24.8	BR7	818.69	815.03	31/19

As per EN 1063; SampleI33, SampleII42 and SampleIII51 conform to BR5. Additionally, SampleII42 meets with criterion of BR6 and sampleIII51 meets with criterion of BR7 as shown in Fig. 3. Bullet proof glass samples become capable to absorb more impact energy by their increase in total thickness. The absorbed impact energy by sampleII42 has increased by 81% from sampleI33 due to the increase in number of bonding interlayers. However, the absorbed impact energy for sampleIII51 has only increased by 3% due to the increase in number of glass layers. The placement of PC at the extreme end, PU to bind glass and PC and PVB to bind glass and glass layers together determine that the effect of increase of number of bonding interlayers is more significant than the increase of number of glass layers. Similar results were also reported by Issam and Omar [14].

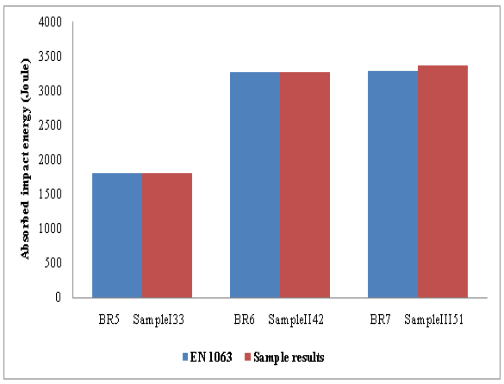

Fig. 3 Absorbed impact energy in various samples

IV. CONCLUSIONS

1. The absorbed impact energy increases with the increase in sample thickness of bullet proof glass.
2. The effect of bonding interlayer weight ratio on increase in absorbed impact energy is more as compared to glass sheet.
3. The position of bonding interlayer doesn't affect the maximum energy stored in bullet proof glass provided that same conditions are maintained.
4. Bonding interlayers can withstand higher absorbed impact energy than glass.

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