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# An Evaluation of Energy Absorption by Bullet Resistant Glass and its Mechanical Properties

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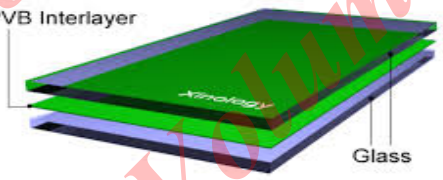
***Abstract:-In this research, the investigation is done to increase the energy absorption capacity of BRGLC by varying its thickness. For this purpose we use interlayer of PVB, PU and PC. This research shows that by introducing PVB, PU, and PC layers, the energy absorption capacity of BRGLC can be increase.***

***Keywords:-Polycarbonate, Polyurethane, Polyvinyl Butyral Ethyl Vinyl Acetate, Bullet Resistant Glass, Laminated Composite***

## I. INTRODUCTION

Last fifteen years, a lot of scientific work has been performed in the field of BR Glass. Most of the researchers have used various methods for improvement in BR Glass, using various types of material and testing procedure. More over the main objective of researchers is to reduce the thickness of BR glass, maintaining same strength to protect from penetration of bullet. Many researchers who have worked on BR Glass just try to improve the strength without comparison of various standards which are given by NIJ standards 0108.01, EN 1063, TBRL testing procedure.

No. of test have been performed with different composition of interlayer of BR glass.




## II. OBJECTIVE

In the present work we have discussed an experiment analysis of mechanical properties of bullet resistant glass and the effect of size, thickness and type of bonding interlayer on bullet resistant glass as per EN 1063. The various mechanical properties were found by impact test, compression test and bending test applied on bullet resistant glass. Compression and bending tests were conducted on universal testing Machine and impact test was conducted by ballistic impact test. Load applied and deflection were varied throughout the experiment to determined mechanical properties which were found by UTM and type of weapon, caliber, fired distance, bullet velocity and no. of fired were varied throughout the experiment to determined impact applied on bullet resistant glass.

Research objectives of present study are:

1. Evaluation of bullet resistant glass mechanical properties
2. Find the absorbed impact energy of bullet resistant glass by ballistic test

## III. LITERATURE REVIEW

Linden et al. [1] 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. B.Wang and S.M.Chou [2] Describe a combined experimental and semi-empirical investigation of the penetration resistance of fiber glass reinforced plastic plate under ballistic impact has been under taken the ballistic test being carried out using 7.62mm armour-piercing rounds. Grant et al. [3] constructed more than one layer of glass composite laminates. The glass composite laminates consisted of glass as the outer layer backed by Poly Carbonate (PC) with a thin adhesive transparent bonding interlayer of Poly Urethane (PU) in between.L.M. Numes et al. [4] Describe bullet proof laminates were obtained using 30 plies of glass fiber reinforced epoxy matrix composites the ballistic performance of these laminates was varied by modifying the properties of constituents laminate or by the changing laminate assembly. Uwe [5] 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. P.S.Venkatanarayanan and A. Joseph Stanly [6] describe the five different types of six layered GFRP laminates were prepared from three type of resin system and compared for their intermediate velocity bullet impact response. Dr. Ignatius Calderone et al. [7] examine the design of laminated glass to meet various structural loads, engineers generally make simplifying assumption or make reference to procedure given in various standards. Australian standard, allow the total glass thickness to be used for short term load duration but for medium or long term load durations it gives relationships for load sharing factors for the glass components. P. J. Hazell and M. R. Eward [8] studied the penetration of the lead antimony-cored 7.62 mm and 51mm bullet into a glass-faced polyurethane elastomeric polymer resin. The result craters in the resin contained elongated bullet core material that had a significant amount of porosity. M. A. G. Silva et al. [9] explained the experimental and numerical simulation of ballistic impact problems on thin composite laminated plates. Issam and Omar [10] studied the position 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 interlayer's is more significant than the increase of number of glass layers.

Constituents of BRGLC

There are four main constituents of BRGLC

1. Glass:- Glass is defined as an "Inorganic production of fusion that has been cooled to a rigid condition without crystallization.

2. Poly Vinyl Butryal: - Poly Vinyl Butryal (PVB) is resin usually used for applications that required strong binding,

optical clarity, adhesion to many surfaces, toughness and flexibility.

3. Polyurethane:- Polyurethane ( PU) is a polymer composed of a chain of organic units joined by carbamate (urethane) links.

4. Poly carbonate:- Polycarbonate (PU), known by the trademark name Makrolon,Lexan and other a perticular group of thermoplastic polymers.They are easily worked, and thermoformed.

Manufacturing process of BRGLC:-

Bullet proof glass can be manufactured by following process.

Cutting:- In this process , a piece of glass was cut from raw material as per required dimension, with some tolerance.

Fig. Cutting process

Grinding:- During the process of cutting some sharp edges were formed on the surface of glass. These sharp edges were removed by the process of grinding. For this purpose a grinder was used.

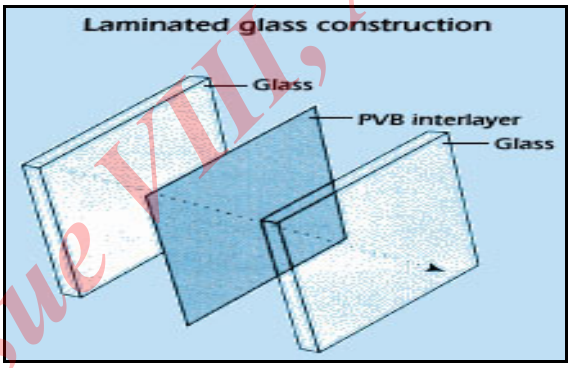
Fig. Grinding process

Washing:- Due to the grinding of glass, small amount of glass in the form of powder is stick to the glass structure. So to remove this powder glass washing process is required .

Drying:- During process of washing some water droplets stick to the glass surface. To remove water droplets from the glass drying process was needed. This process was done by Dryer

Cleaning:- Cleaning is necessary before lamination of glass .This is done by soft cloth and cleaning agent.

Lamination:- As we know glass is highly brittle material, it can absorb only a small amount of energy. To increase this capacity to absorb the energy a PVB, PU and PC layer is added to the glass. For making lamination of glass atmospheric condition are specified and that are vary with altitude.




Rolling and heating:- After lamination process rolling is to done, in this process laminated glass is pressed by roller and removes the air from it and heating of glass remove the moisture from interlayer.

Heating (Autoclave):- After lamination of glass and PVB, composite is turned into bullet resistant glass by adjoining with PU and PC in same lay-up room at same conditions which are described in previous process and placed in autoclave for 4hrs in

temperature and pressure range of $130^0$C to $135^0$C and 1.0Mpa to 1.2Mpa respectively.

Finishing: - After all process final finishing is to be done in this process. Grinding, edge matching etc.

EFFECT OF ABSORBED IMPACT ENERGY ON BRGLC

Methodology to find out Absorbed Impact Energy

An analytical model is proposed to find out the ballistic limit of target material. The model is based on the energy absorption principle. In the developing the model, the following assumption are made.

1. The projectile is rigid and remains un-deformed during the impact. This is confirmed by experiment which showed that projectile retained their shape and mass after impact.
2. Projectile strikes the target normally.
3. There exist friction between the target and projectile.
4. The failure mechanism of composites is uniform throughout its thickness.
5. There is no change in volume during the impact.

The Kinetic energy of a moving projectile of mass M, with the velocity V, is given by

Equation:- $E = \frac{1}{2}mv^2$

Where:-

E = dynamic energy (J)

m = mass of the object (kg)

v = velocity of the object (m/s)

So same impact energy is produced by bullet fired by service weapon, m is the mass of bullet, v velocity of bullet. During the testing of Bullet resistant glass we have used three threat levels which prescribed different projectile and different fire source.

The Initial, final velocities and the corresponding Kinetic energies of the projectiles were calculated from the counter value and thus the energy absorption. After performing the impact test, the surface and internal damages in the target were thoroughly analyzed. The delaminating area was also visualized. This was repeated for all the specimens. The ballistic limit was determined experimentally by conducting the impact test at different initial velocity. The velocity at which the projectile got struck into the target was taken to be the ballistic limit.

Thus the energy absorbed is given by

$E_{total} = E_{def}+E_{del}+E_{fra}+E_{fri}$

Where:-

$E_{total}$ = Total Energy Absorbed during an Impact

$E_{def}$ = Energy associated with global plate deformation

$E_{del}$ = Delamination Energy

$E_{fra}$ = Fracture Energy

$E_{fri}$ = Frictional Energy

During this experiment calculated deformation energy, rest of energies was neglected. The absorbed impact energy in prescribed samples was observed more compatibly to their threat level specified by EN 1063 standards. Bullet proof glass

samples become capable to absorb more impact energy by their increase in total thickness.

Evaluation of Mechanical properties of BRGLC:-

During the analysis of mechanical properties of bullet resistant glass, samples were tested on Universal Testing Machine. Values of Young's Modulus and Shear Stress of bullet resistant glass are determined.

Methodology to find out Young's Modulus by UTM

This test is named as three point tests which were used measured the Young's Modulus of bullet resistant glass sample. The instrument which was used in this work is Universal Testing machine as shown in Fig. The value of Young's Modulus (E) is calculated from the equation

$$E = \frac{PL^3}{48IS}$$

Where:-

$\frac{P}{S}$ = is the slop of curve that obtained from the relationship between the Load (P) and the deflection (S) of each sample,

L = is the distance between the two supports of the instrument (mm),

I = is the momentum of geometrical bending which can be calculated from the equation

$$I = \frac{bt^3}{12}$$

Where:-

B = is the width of sample.

t = is the thickness of sample respectively.

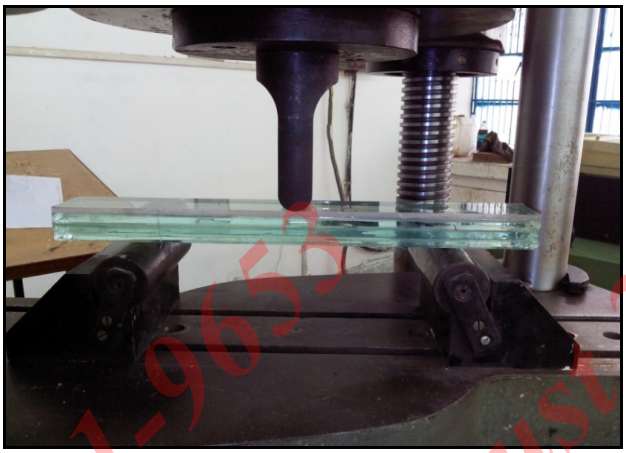


Fig. Sample placed in UTM

Results and Discussion of Bending Test

1. Laminated composite has more Young's Modulus as compare to its respected plain glass.
2. As we increase the total thickness of composite glass percentage increment in Young's Modulus will decrease.
3. Young's Modulus (E) is inversely proportional to moment of inertia ($mm^4$), so as the value of moment of inertia increases, the value of E decreases.

Methodology to find out Shear stress by UTM

One of the most important tests to perform in this regard is the compression test as shown in Fig..

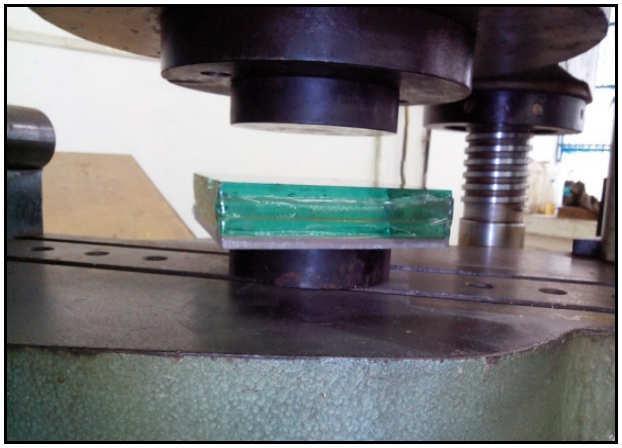


Fig. Compression test

It is used primarily to determine the relationship average normal stress and average normal strain in many engineering materials. This test is carried out to study the compression behavior of bullet resistant glass sample under investigation.

Shear stress (T) of the sample is determined from the following equation:-

$$T = \frac{3p}{4bt}$$

Where:-

B = is width of specimen

T = is thickness of specimen respectively (mm).

P = is the applied load (N).

## IV. RESULTS AND DISCUSSION OF COMPRESSION TEST

1. Shear Stress is more in laminated composite as compare to its respected plain glass.
2. As we increase the total thickness of composite (PVB, PU, PC) percentage increment in Shear Stress will decrease.
3. Shear Stress (τ) is inversely proportional to thickness (mm), so the value of τ will decrease if the thickness is increased.

## V. CONCLUSION

The absorbed impact energy increases with the increase in sample thickness of bullet proof glass. The position of bonding interlayer doesn't affect the maximum energy stored in bullet proof glass provided that same conditions are maintained. Bonding interlayer's can withstand higher absorbed impact energy than glass. The load carrying capacity increases with increases in total thickness of BRGLC. After introducing bonding interlayer, overall glass composite moves towards ductile material hence improve in strain energy of BRGLC.The Shear Stress increases with increase in total thickness of BRGLC.The magnitude of bending movement is more in BRGLC comparison with glass without bonding interlayer. The optical properties of BRGLC decrease with increase in thickness. The transmission of light in pure glass is more as compared to BRGLC.

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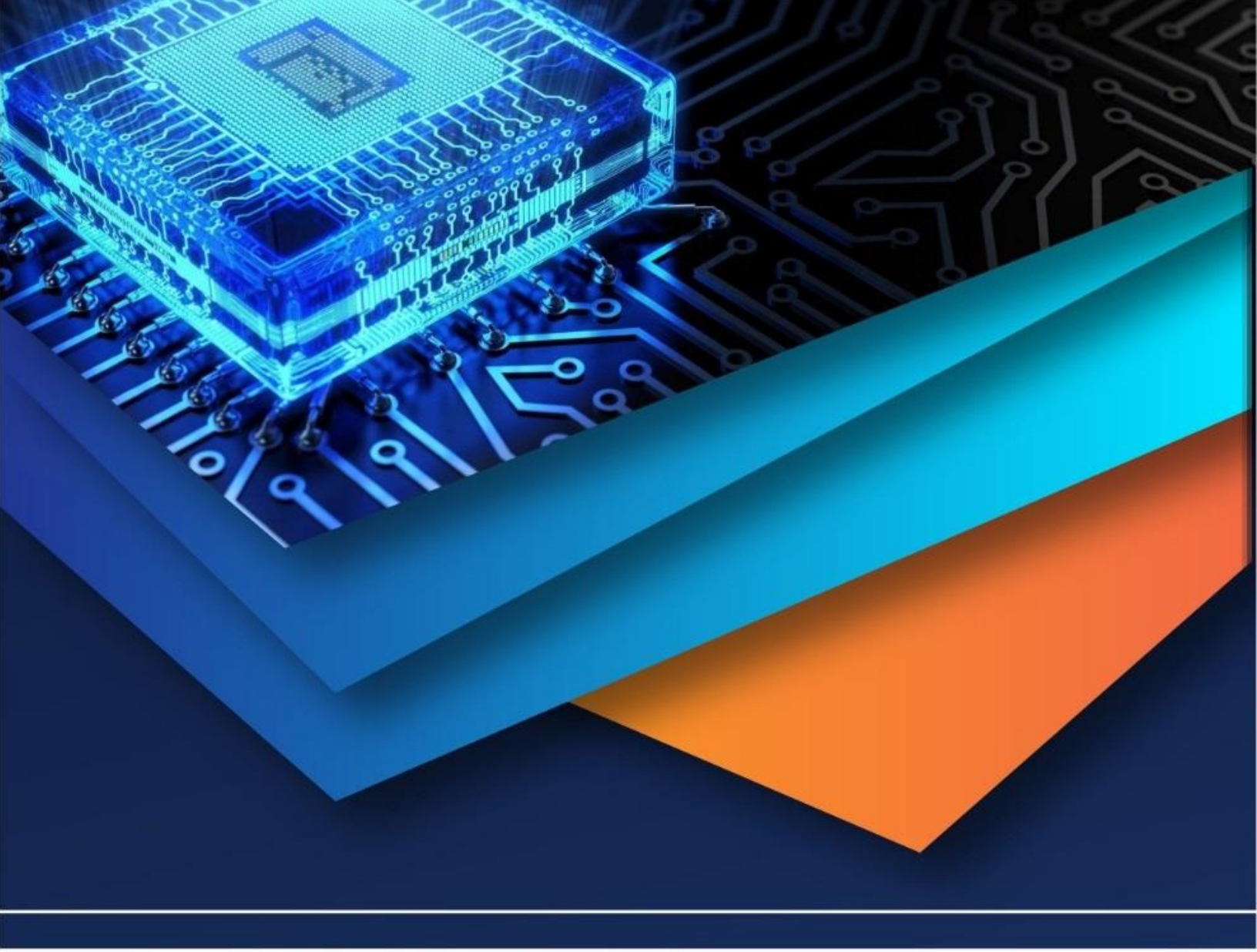

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