# SIMULATION OF LAMINATED GLASS PANELS USING POLYURETHANE RESIN AS AN INTERLAYER (PU) SUBJECTED TO AIR BLAST LOADING

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***ABSTRACT:*** *This paper presents the results for the simulation of laminated glass panels using polyurethane resin as interlayer subjected to air blast loading. In this research a total four numbers of glass panel, which consist of one 7.52 mm annealed glass panel as a control sample and three 7.52 mm laminated glass was subjected to blast loading with an explosive charge weight range from 225 gram to 600 gram of explosive at a standoff distance of 1500 mm . AUTODYN simulation software was used to simulate the behavior of laminated glass subjected to air blast loading. The simulation results show that the 7.52 mm thick annealed glass damaged when subjected to blast peak overpressure up to 245 kPa resulted from 225 gram of explosive. Meanwhile the 7.52 mm thick laminated glass with polyurethane resin interlayer survive the pressure up to 305 kPa and its only damaged when subjected to 630 kPa resulted from 600 gram of explosive. This results show that the laminated using polyurethane resin shows better resistance to blast loading compare with annealed glass.*

**Keywords:** Laminated glass, polyurethane resin interlayer, air blast loading, explosive

## 1. INTRODUCTION

Bombing attack on building has been a very common terrorist tactic since year 1960s. In most of the bombing attacks, the annealed glass which is brittle and offer little resistance to blast will break into very sharps fragments and causes injuries to the public. The majority of injuries from the bomb blast have been from flying glass fragments [1]. This can be seen from the attack on government building in Oslo Norway on 22 July 2011. The explosion killed eight people and injured at least 209 people. This bomb caused extensive damaged on building facade which is made of glass. Damage [2]. Normally laminated glass is used to increase the protection of building facade from the blast. Laminated glass is a type of safety glass that holds together when shattered. In the event of breaking, it is held in place by an interlayer. This interlayer serves to retain the glass fragments, limits the size of opening, offers residual resistance, and reduces the risk of cutting or piercing injuries from the glass breakage [3]. Polyvinyl butyral (PVB) is the most common interlayer used in the laminated glass and is bonded between the glass layers by the application of pressure and heat. However according to J. Sakula [4] the tensile strength of Polyvinyl butyral (PVB) reduces with the increase of temperature. Therefore, there is a need to investigate other alternative material such as polyurethane resin used as an interlayer in the laminated glass which has better resistance against high temperature. The objective of this study is to simulate the behaviour of laminated glass using polyurethane resin as an interlayer subjected to air blast loading. Polyurethane resin is an industrial product that is used in the production of many other products, such as rubbers and medicines. Polyurethane resin ( Fig. 1) is considered versatile because it can be used to produce an array of items, from inks to plastics.

**Fig (1) Polyurethane resin**

Air blast loading is referring to the shock waves that resulted from an explosion. As the explosive detonates, it creates a shock wave. The shock wave expands and then the pressure decrease rapidly. This sudden decrease of pressure creates a vacuum that creates high suction wind around the area and then caused damaged to the surrounding area. This is shown in Fig 2. The maximum pressure occur during the shock waves expansion is known as peak overpressure [5].

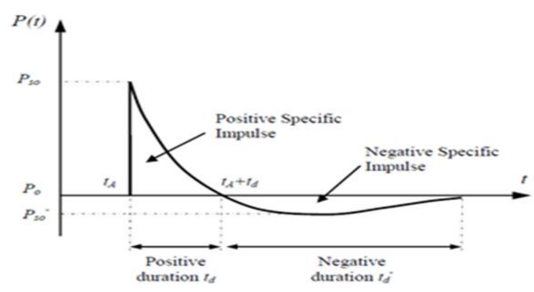


**Fig (2)Typical blast wave profile.**

## 2. METHODOLOGY

The numerical simulation was perform using ANSYSS AUTODYN simulation software. The dimension of the glass model used in this simulation is 7.5mm x 900 mm x 1100 mm. This dimension is based on standard sizing of the glass panel used for testing explosion. According to ISO 16933, Glass in Building Explosion Resistant Security Glazing Test and Classification for Arena Air Blast Loading [6]. In this research a total four numbers of glass panels was subjected to air blast loading as shown in Table 1.This panels consist of one number of 7.52 mm annealed glass which is a control sample and three numbers of 7.52 mm thick laminated glass using polyurethane resin as interlayer was subjected to blast with a different charge weight of explosive ranges from 225 gram to 600 gram at a fix standoff distance of 1500mm.

**Table 1 :** Types of sample and charge weight

| **Number of Sample** | Type of glass | Charge weight (g) | Stand of distance (m) |
|---|---|---|---|
| Sample 1 | Annealed | 225 | 1500 |
| Sample 2 | Laminated | 225 | 1500 |
| Sample 3 | Laminated | 300 | 1500 |
| Sample 4 | Laminated | 600 | 1500 |

A mesh size of 100 mm x 100 mm was selected for the modeling of the glass panels. The element number is 14 x 12 x 42, with the total element number of 7056. The boundary condition of the euler sub grid was set as outflow boundary. Both of the annealed and laminated glass were modelled using ALE solver. The 3D view of numerical mesh model for glass panel is shown in Fig 3.

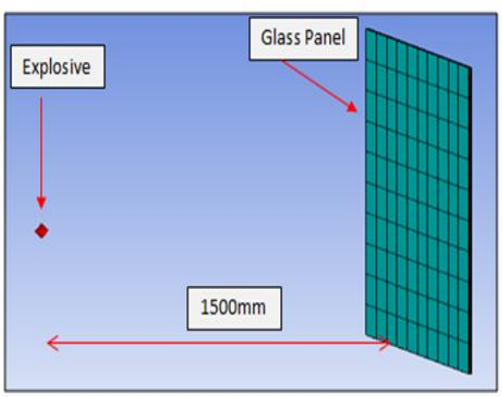


**Fig (3) 3D view of numerical mesh model for glass panel**

The peak overpressure was recorded using gauge 1 and gauge 2 which are located at the both sides of the glass panel. The model set up for blast test is shown in Fig 4.

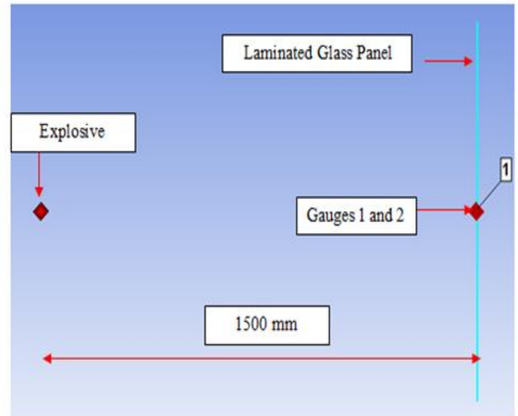


**Fig (4) Test Model set up for the simulation works**

The glass model was modelled with the Johnson Holmquist Strength Continuous model [7]. This is the standard material model for annealed glass in the material library of AUTODYN that describe the behavior of annealed glass. The equation of the strength of glass is shown in equation 1.

$$\sigma^* = \sigma_i^* - D(\sigma_i^* - \sigma_f^*) \quad (1)$$

Where :

$\sigma^*$ is the strength of glass

$\sigma i^*$ is the normalized intact strength

$\sigma f^*$ is the normalized fracture strength

D is the damage scalar

Polyurethane resin was modelled with elastic material model using linear Equation of State (EOS). This material model was used to describe the behaviour of polyurethane resin as interlayer in laminated glass. The material properties such as density (1.265 g/cm3), bulk modulus (6.0 MPa), shear modulus (5.0 MPa), principal tensile failure stress (1.06 MPa) and erosion strain (4.0) were obtained from the material library in AUTODYN software. Air was modeled as an ideal gas. Air was model using Equation of State of known as EOS which the equation for this model were as in Equation 2. The air density used is ρ=1.225 kg/m3 and air initial internal energy used is 2.068 x 105kJ/kg which is obtained from AUTODYN material library.

$$P = (\gamma - 1)\rho e \quad (2)$$

Where;

$\gamma$ = Constant value

p = Air Density

e = Specific internal energy

Jones–Wilkens–Lee (JWL) equation of state was used to model the rapid expansion of high explosive detonation of TNT which obtained from AUTODYN material library. The equation for this model is written in the Eqn. 3.

$P=A(1- \omega/(R\_1 V)) e^{(-R\_1 V)} + B(1- \omega/(R\_2 V)) e^{(-R\_2 V)} + \omega E/V$ (3)

Where;

E = Internal specific energy

V = Volume of the material at pressure divided by the initial volume of unreacted explosive.

A, B, ω, R1 and R2 = Empirically derived constants.

***Simulation Results :***

***7.5mm thick annealed glass subjected to 225 gram of explosive :***

Fig 5 shows the pressure time history graph for the 7.52 mm thick of annealed glass model subjected to 225g of explosive at a stand of distance of 1500 meter. From the graph, it was found that the average peak overpressure resulted from the detonation on glass panels at gauge 1 and 2 is 245 KPa occur at 1.1 ms.

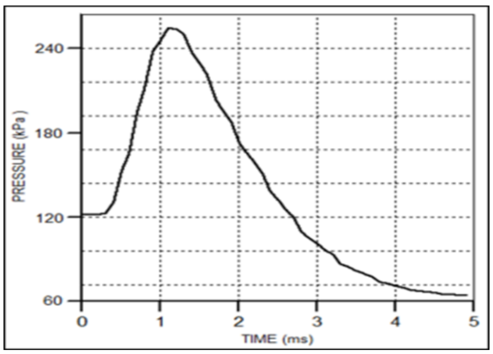


**Fig (5) Pressure time history for 7.52 mm thick annealed glass model subjected to 225g of explosive.**

The simulation results for the damage on the annealed glass panel are shown in Fig 6.

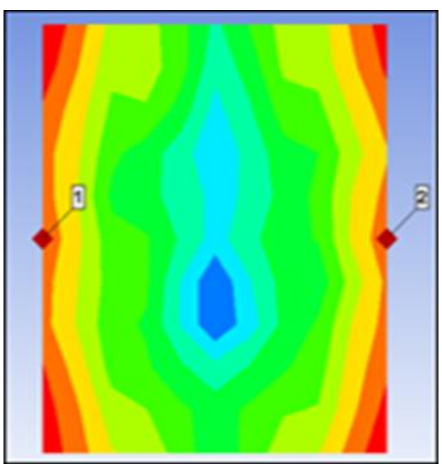


**Fig (6) Results for the damaged on 7.52 mm thick annealed glass model subjected to 225g of explosive**

It was observed the annealed glass panel failed at the edges of the panel when subjected to peak overpressure of 245 kPa occur at 1.1 ms resulted from 225 gram of explosive located at a standoff distance of 1500mm. This is because annealed glass is a brittle material that offers little resistance to the blast waves produced by explosions.

***7.25mm thick laminated glass subjected to 225 gram of explosive:***

The simulation result shows that the a average peak overpressure resulted from the detonation from 225 gram of explosive on the laminated panels located at gauge 1 and gauge 2 is 245 kPa occur at 1.1 ms. However It was observed that there is slightly high stress observed in the middle section of the glass panel which is indicated by the orange color at this section. There is a possibility of a very minor surface crack occurred at this section due to the pressure resulted from the explosion. The panel sustained the blast load up to 245 kPa resulted from the impact of 225 gram of explosive at a standoff distance of 1500mm. The simulation results for the damage 7.52 mm laminated glass with 225 gram of explosive is shown in Fig 7.

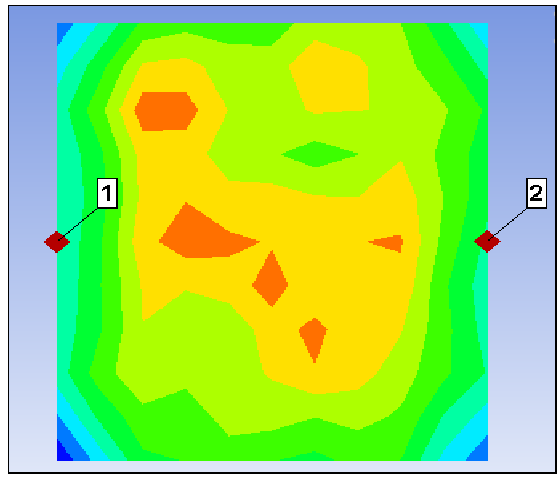


**Fig (7) Results for the damaged on 7.52 mm thick laminated glass model subjected to 225g of explosive.**

***7.25mm thick laminated glass subjected to 300 gram of explosive:***

Fig 8 shows the pressure time history graph for the 7.52 mm thick of laminated glass model subjected to 300 gram of explosive at a stand of distance of 1500 meter. From the graph, the average peak overpressure resulted from the detonation located at gauge 1 and gauge 2 is 305 kPa at 1.45 ms.

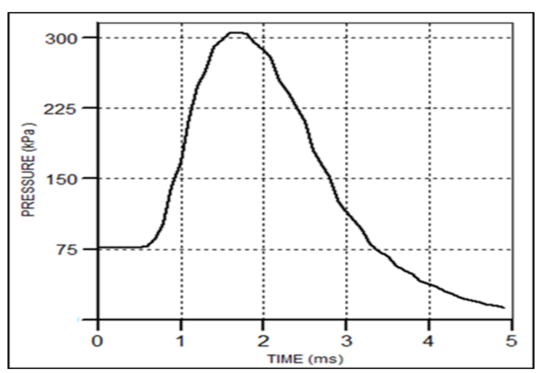


**Fig (8) Pressure time history for 7.52 mm thick laminated glass model subjected to 300g of explosive**

The simulation results for the damage on the laminated glass panel are shown in Fig 9.

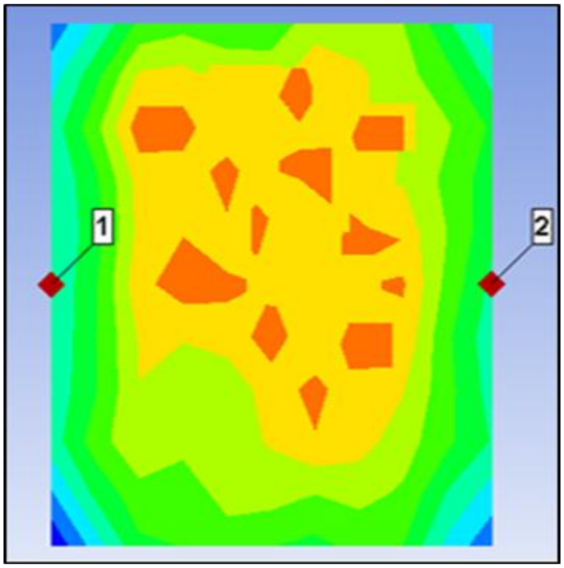


**Fig (9) Results for the damaged on 7.52 mm thick laminated glass model subjected to 300 g of explosive.**

It was observed that there is higher stress distributed at the middle section of the glass panel which is indicated by the orange at this section. There is a possibility of a very minor surface crack occurred int this section due to the pressure resulted from the explosion. The panel sustained the blast load up to 305 kPa resulted from the impact of 300 gram of explosive at a standoff distance of 1500mm.

***7.52mm thick laminated glass with 600 gram of explosive:***

Fig 10 shows the pressure time history graph for the 7.52 mm thick of laminated glass model subjected to 600 g of explosive at stand of distance of 1500 meter. From the graph, the average peak overpressure resulted from the detonation located at gauge 1 and gauge 2 is 630 kPa at 2.0 ms.

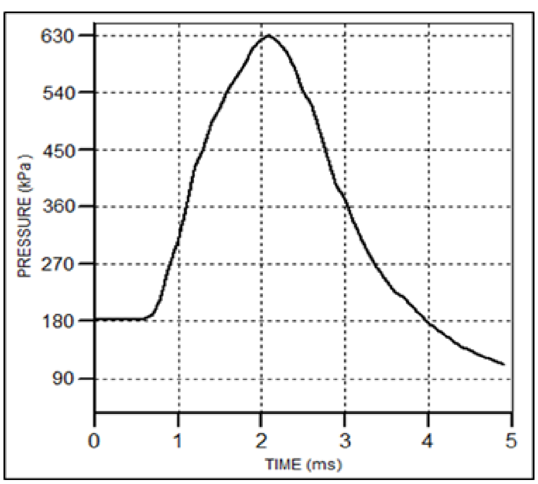


**Fig (10) Pressure time history for 7.52 mm thick laminated glass model subjected to 600g of explosive**

The simulation results for the damage on the laminated glass panel is shown in Fig 11.

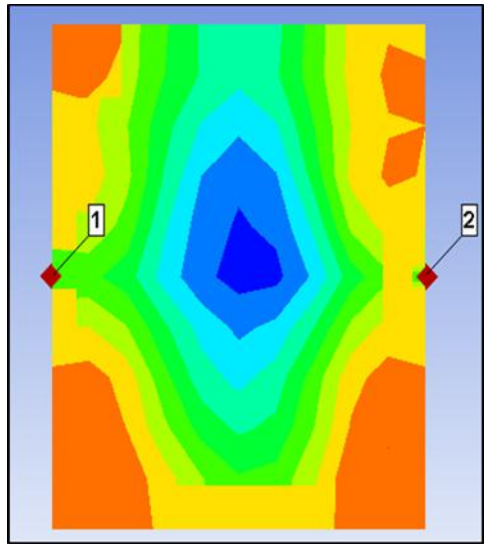


**Fig (11) Results for the damaged on 7.52 mm thick laminated glass model subjected to 600 g of explosive.**

It was observed that there is a high pressure distributed at the edge of the glass panels which indicate that there is high possibility of the glass to damage due the impact of 600 gram of explosive.

## 3. CONCLUSIONS

The simulation results show that the 7.52 mm thick annealed glass was damaged when subjected to blast peak overpressure up to 245 kPa resulted from 225 gram of explosive. Meanwhile the 7.52 mm thick laminated glass with polyurethane resin interlayer survive the pressure up to 305 kPa and its damaged when subjected to 630kPa resulted from 600 gram of explosive. This results show that the laminated using polyurethane resin shows better resistance to blast loading compare with annealed glass.

## 4. REFERENCES

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