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Behavior of laminated glass panels using polyurethane resin as an interlayer subjected to air blast loading

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Abstract: This paper presents the result of the field blast test conducted on the laminated glass panel using polyurethane resin as an interlayer and also annealed glass panel which act as a control sample. The aim of the field blast conducted is to investigate behavior of laminated glass using polyurethane resin subjected to air blast loading. In this research a total four numbers of glass panel which consist of one 7.52 mm thick annealed glass panel and three 7.52 mm thick laminated glass panel was subjected to air blast loading with explosive charge weight range from 225 gram to 600 gram at a standoff distance of 1500 mm. The blast test results showed that the 7.52 mm thick annealed glass was damaged when subjected to peak overpressure up to 250 kPa resulted from 225 gram of explosive. Meanwhile the 7.52 mm thick laminated glass with polyurethane resin interlayer survive the peak pressure up to 650 kPa resulted from 600 gram of explosive. The polyurethane resin interlayer has successfully retained the glass fragments and also reduces the risk of cutting injuries from the glass breakage. The result showed that the laminated glass panel using polyurethane resin as an interlayer has a potential to be used as a blast resistance laminated glass panel.

Key words: Field blast test; Polyurethane resin; Laminated glass; Air blast loading

1. Introduction

Terrorists attack on buildings and infrastructures has become a global phenomenon. In most cases, the terrorists used explosives located in vehicles and blew it up at a close distance from the target. Intensive shock waves are created by this explosion which propagates outward at supersonic velocity accompanied by heat and light that induce pressure on the structural buildings and causes significant damage to the structure and loss of life. There are a number of methods to stop the terrorist attack. One of the methods is gathering information on the terrorist and stopping the attack before it takes place; another way is to protect buildings from damage by incorporating blast resistance design and also retrofitting of the existing structure (Alias et al., 2013) .This area of research is currently receiving more attention from many structural engineers as they began to consider blast loading and also blast resistance materials in their design in order to protect important buildings and structures from such attacks.

Annealed glass is often used in windows due to its low cost; however it is a brittle material that offers little resistance to the blast waves produced by explosions. When it fails it breaks into very sharp fragments that can travel at a very high velocity and causes injuries. Historically, the majority of injuries from bomb blasts have been from flying glass fragments Smith (2001). For increased protection from blast, modern glazing systems use laminated glass panels bonded to robust framing with structural silicone adhesives. Laminated glass consists of interlayers sandwiched between annealed glasses. Polyvinyl butyral (PVB) is the most common interlayer and is bonded between the glass layers by the application of pressure and heat (Hopper, 2012)

Most of the researchers have carried out study on the laminated glass using PVB as an interlayer. In the previous study by Martin et al. (2011), the researchers have done the experimental and numerical investigations of laminated glass using PVB under air blast loading. However Sakula (1997) found that the tensile strength of polyvinyl butyral (PVB) reduces with the temperature thus it may fail under very high temperature. Therefore, there is a need to investigate other alternative material used as an interlayer in the laminated glass such as polyurethane resin which has a better resistance to high temperature. The objective of this research is to investigate the behavior of laminated glass using polyurethane resin subjected to air blast loading. Polyurethane resin (Fig. 1) is an industrial product that used in the production of many products, such as rubbers and medicines. It is suitable for lamination of any type of paper, glass and also foil.

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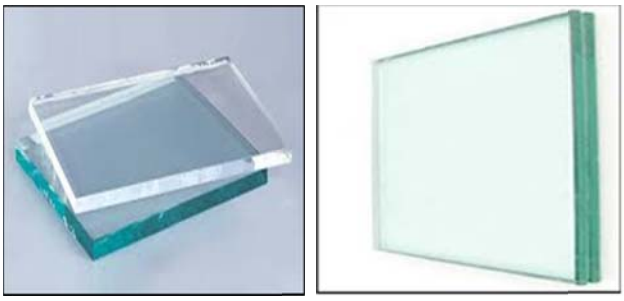
Fig. 1: Polyurethane resin

2. Materials and methods

The polyurethane resin used as interlayer was supplied by Aneka Glass Sdn Bhd. A total five rod specimen for polyurethane resin were prepared and tested to determine the tensile strength according to standard test method for tensile properties of plastic, ASTM D638-10 (2010). The tensile strength of the polyurethane resin was conducted using 5KN universal testing machine. From the test conducted the average tensile strength of the polyurethane resin was 10 MPa. A total four numbers of glass panel were obtain from the Secuglass Sdn Bhd a safety glass manufacture in Malaysia. The glass panels consist of one number of 7.52 mm annealed glass as a control sample and three others sample are made of 7.52 mm thick laminated glass using polyurethane resin as an interlayer. The size of the glass panel was 900 mm x 1100 mm. Fig. 2, shows the sample of annealed and laminated glass used in the experimental works.



(a) Annealed glass

(b) Laminated glass with polyurethane resin interlayer

Fig. 2: .Annealed and laminated glass with polyurethane resin interlayer

The field blast test was conducted on the annealed glass and also laminated panels according to Explosion Resistant Security Glazing test for arena air blast loading standard. (ISO 16933: 2007). The field blast was conducted at a disclosed military facility. The panels were strongly fixed to the steel frame testing structure which was fabricated at the Fabrication Laboratory of the Faculty of Engineering, University Pertahanan Nasional Malaysia. The size of the blast testing structure in the plan is 1200 mm, face turned towards the blast. The height of the test frame is 1500 mm including a 150 mm thick base. A wooden timber supporting the explosive was erected to hold the charge. The field blast test setup is shown in Fig. 3.

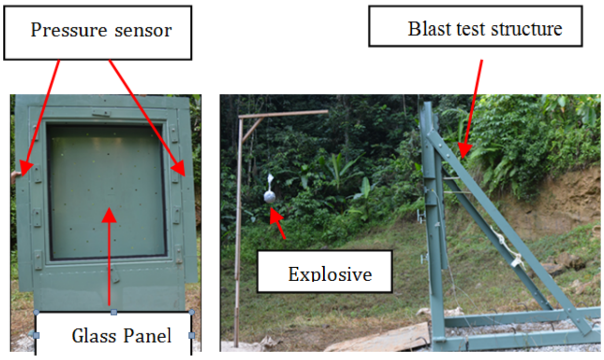


Fig. 3: Field blast test set up

Two numbers of Piezoelectric ICP® pressure sensors were used to measure the peak overpressure resulted from the explosion. These sensors are mounted on both sides of the glass panel as shown in Fig. 3. These sensors were connected to the signal conditioning module and then to the high speed data acquisition module. The peak overpressure test results were displayed graphically using Labview program. The instrumentation used in the experiment is shown in Fig. 4.

The annealed and laminated glass panels were tested using different charge weight of explosive ranges from 225 gram to 600 gram at a fix standoff distance of 1500 mm. The type of sample and explosive weight used in the experiment are shown in Table 1.

(a) Piezoelectric ICP® Pressure sensor (b) High speed data acquisition system

Fig. 4: Instrumentation used in the experiment

Table 1: Type of glass sample and explosive

Item	Type of sample	Explosive weight
Sample 1	Annealed glass	225grams
Sample 2	Laminated glass	225 grams
Sample 3	Laminated glass	300 grams
Sample 4	Laminated glass	600 grams

3. Results

3.1. Sample 1 – Annealed glass panel subjected to 225 gram of explosive

Sample 1 is a 7.52 mm thick annealed glass panel without using laminated polyurethane resin as an interlayer. This sample used as a control sample. Fig. 5 shows the pressure time history graph for 7.52 mm thick annealed glass panel subjected to 225 grams of explosive at a standoff distance of 1500mm. From the graph, it was found that the average peak overpressure resulted from the detonation of the explosive is 250 kPa

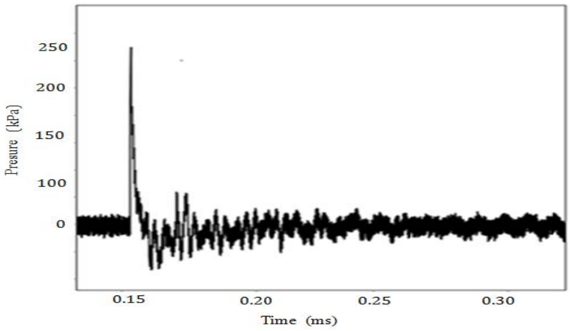


Fig. 5: Pressure time history for 7.52 mm thick annealed glass panel subjected to 225 gram of explosive.

From the blast test it was found that the 7.52 mm thick annealed glass panel had failed and the sample has broken into pieces after the blast test. This result shows that 7.52 mm annealed glass not be able to withstand the blast pressure of 250 kPa resulted from a minimum charge weight of 225 gram of explosive. This is because annealed glass is a brittle material and possesses very low resistance against the blast loading. Fig. 6 shows the damage of the annealed glass panel after blast test.

Fig. 6: Damaged on the annealed glass panel and also glass fragments due to the blast from 225 gram of explosive.

3.2. Sample 2 –Laminated glass panel subjected to 225 gram of explosive

Sample 2 is a 7.52 mm thick laminated glass panel with polyurethane resin as an interlayer. This panel was subjected to 225 gram of explosive at a standoff distance of 1500mm. Fig. 7 shows the pressure time history graph from the detonation of 225 gram of explosive at a distance of 1500 mm. From the graph, it was found that the average peak overpressure resulted from the detonation of the explosive is 255kPa.

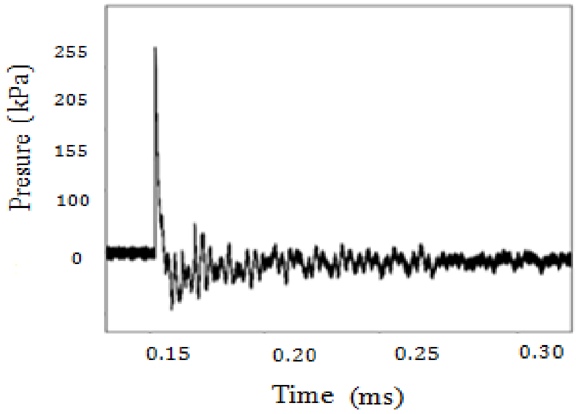


Fig. 7: Pressure time history for 7.52 mm thick of laminated glass panel subjected to 225 gram of explosive.

From the blast tests it was found that there is only minor surface crack were observed at the center and also at the edge of the panel. The laminated glass remains intact in the frame and there is no perforation observes at the panel. This is because the polyurethane resin as an interlayer holds the glass together and absorbed the energy resulted from the explosion. Fig. 8 shows the cracks of the laminated glass panel after blast test.

Fig. 8: Surface cracks on the laminated glass subjected to 225 gram of explosive

3.3. Sample 3 –Laminated glass panel subjected to 300 gram of explosive

Sample 3 is a 7.52 mm thick laminated glass panel with polyurethane resin as an interlayer. This panel was subjected to 300 gram of explosive at a standoff distance of 1500mm. Fig. 9 shows the pressure time history graph from the detonation of 300 gram of explosive at a distance of 1500 mm. From the graph, it was found that the average peak overpressure resulted from the detonation of the explosive is 320 kPa.

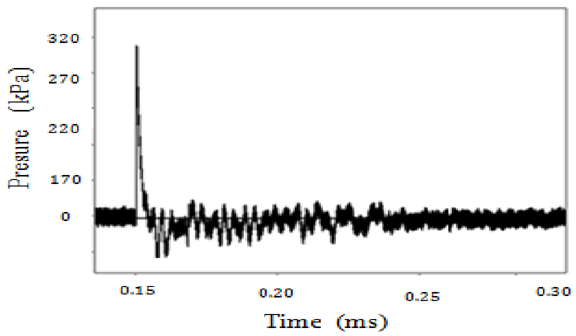


Fig. 9: Pressure time history for 7.52 mm thick of laminated glass panel subjected to 300 grams of explosive.

Sample 3 also did not break into pieces after the blast test. This shows that 7.52 mm laminated glass can withstand the blast pressure from a charge weight of 300 gram of explosive. However, there were more crack lines observed on the top and bottom surface of the glass panel compared with the sample 2. Fig. 10 shows the damage of the laminated glass panel after blast test.

Fig. 10: Cracks on the laminated glass panel subjected to 300 gram of explosive

3.4. Sample 4 - Laminated glass panel subjected to 600 gram of explosive

Sample 4 is a 7.52 mm thick laminated glass panel subjected to 600 grams of explosive at a standoff distance of 1500mm. Fig. 11 shows the pressure time history graph from the detonation of 600 grams of explosive at a distance of 1500 mm. From the graph, it was found that the average peak overpressure resulted from the detonation of the explosive is 650 kPa.

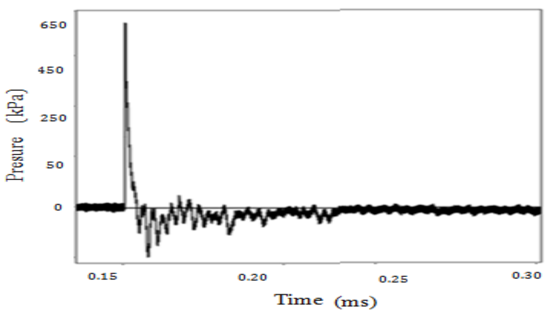


Fig. 11: Pressure time history for 7.52 mm thick of laminated glass panel subjected to 600 grams of explosive.

Sample 4 did not break into pieces after the blast test. This result shows that 7.52 mm laminated glass can withstand the blast pressure of a charge weight of 600 gram of explosive. It was noticed that severe cracks observed around the surface of the glass panel. However, there was no perforation on the surface of the glass panel. This result shows that the glass panel may have reached its ultimate limit in absorbing the blast energy before it fails. Fig. 12 shows the damage of the laminated glass after blast test.

Fig. 12: Damages on the laminated glass subjected to 600 gram of explosive

4. Conclusion

The blast test results show that the 7.52 mm thick annealed glass damaged when subjected to blast overpressure up to 250 kPa resulted from 225 gram of explosive. Meanwhile the 7.52 mm thick laminated glass with polyurethane resin interlayer survive the blast pressure up to 650 kPa with very severe cracks observed around the surface of the glass panel. However, there was no perforation on the surface of the glass panel and the glass panels remain intact in the frame. The polyurethane resin interlayer has successfully retained the glass fragments and also reduces the risk of cutting or piercing injuries from the glass breakage. This results show that the laminated using polyurethane resin have potential to be used as blast resistance glass panel.

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