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# Performance of Sentry Glass Plus (SGP) Interlayer Laminated Glass Subjected to Air Blast Loading

[1]Lee Wei Szer, [2]Mohammed Alias Yusof, [3]Norazman Mohamad Nor, [4]Ariffin Ismail.

[1,2,3,4] Faculty of Engineering, University PertahananNasional Malaysia, Kem Sungai Besi 57000, Kuala Lumpur, Malaysia

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## Abstract

This paper presents the result of the field blast test conducted on the laminated glass with Sentry Glass Plus ( SGP ) as an interlayer and laminated glass with PVB interlayer as control sample. The objective of this research was to investigate the blast resistance of laminated glass with SGP interlayer and laminated glass with PVB interlayer. In this research a field blast testing was carried out using ASTM F 1642-04 to obtain the blast related data and also to investigate the behaviour of the laminated glass subjected to air blast loading. The blast test result shows that laminated glass with SGP interlayer and laminated glass with PVB interlayer able to withstand the peak overpressure of 337.84 kPa and reflected pressure of 4688.43 kPa. Therefore, there is potential for the SGP interlayer to be use as an interlayer in the blast proof glass.

**Keywords;** *Field blast test, SGP interlayer, Laminated glass, Air blast loading*

## I. INTRODUCTION

Glass is arguably, the most remarkable material ever discovered (Michael Wigginton, 2014). Glass has been used in construction since 2000 years ago (FatemehPariafsai, 2016). While in recent years, the application of glass in the field of construction has been widely developed because of the advantages of using glass has over other materials in building construction. The use of glass as a component of a building structure has been increasing since its initial introduction as a building material as windows in the early 19th century (MohdKashif, 2018).

Today, most of the amazing buildings' facades are constructed using ordinary glasses and without much protection from damages, especially from terrorist attacks. As reported in mass media, attacks and bombings of buildings and infrastructures have become a global phenomenon. For examples of the terrorist attacks in Norway (2011), Belgium Airport (2017) and Sri Lanka (2019) shows that most of the building façades are capable ofwithstanding the blast loading from the explosions. This results in glass breakages, thus producing sharp structures. Most of the building façades are made up of laminated annealed glasses and also tempered glasses. This type of glasses will break into pieces. Laminated glass with PVB interlayer have potential to resist blast and most of the researches have investigated on the properties of laminated glasses using PVB interlayer.

In the recent development of the laminated glass industry, there are also several interlayers such as Sentry Glass Plus (SGP) have been developed. Currently, there is only limited research conducted on the laminated glasses using PVB and PU Resin. However, there is no research conducted to study the blast behaviour of laminated glasses using SGP as an interlayer. Therefore, this research will study the behaviour of laminated glass with PVB and SGP interlayer subjected to blast loading.



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## II. MATERIALS AND METHODS

The mechanical properties of the laminated glasses were carried out. According to ASTM D 638-10, stress-strain diagram obtained. Modulus of rupture of laminated glass was obtained based on ASTM C158-02. Lastly Compressive strength was determined based on ASTM C39. The results of the test were tabulated in Table 1.

**Table 1 Mechanical Properties of Laminated glass panel**

| Laminated Glass | PVB | SGP |
|---|---|---|
| Stress-Strain Diagram (MPa) | 1.51 | 10.01 |
| Modulus of Rupture (MPa) | 65.29 | 104.39 |
| Compressive Strength (MPa) | 840.0 | 1432.33 |

The field blast test was conducted using ASTM F 1642 04 (2010) Standard test method for glazing system which is subjected to air blast loading. In this experiment, a total of two interlayer of glass panels consisting of 6.76mm of laminated glass with PVB interlayer and 6.89mm of laminated glass with SGP interlayer with the size of 900 mm x 1100 mm were prepared by Aneka Glass SdnBhd for fabrication. Both the glass panels were subjected to 400 g of C4 at a standoff distance of 1380 mm.

Blast testing frame was fabricated at the fabrication laboratory of the Faculty of Engineering at the UniversitiPertahananNasional Malaysia (UPNM). The dimension of the testing frame is 1200 mm width x 1500 mm height x 2500 mm length. In this field blast test, there were three types of sensors that have been used to capture the blast related data, which are Piezoelectric ICP® pressure sensor, Piezoelectric ICP® reflected pressure sensor, and also PCBTM pressure probes. Two numbered Piezoelectric ICP® pressure sensors were mounted on both sides of the glass panel and one number of Piezoelectric ICP® reflected pressure sensor was mounted on the middle top of the glass panel. In addition to this, two of pressure probes were located at a distance of 1380 mm. These sensors were connected to the signal conditioning module and then to the DAQ. The blast results were displayed using Lab view program in the DAQ. The testing frame and set up is shown in Figure 1.

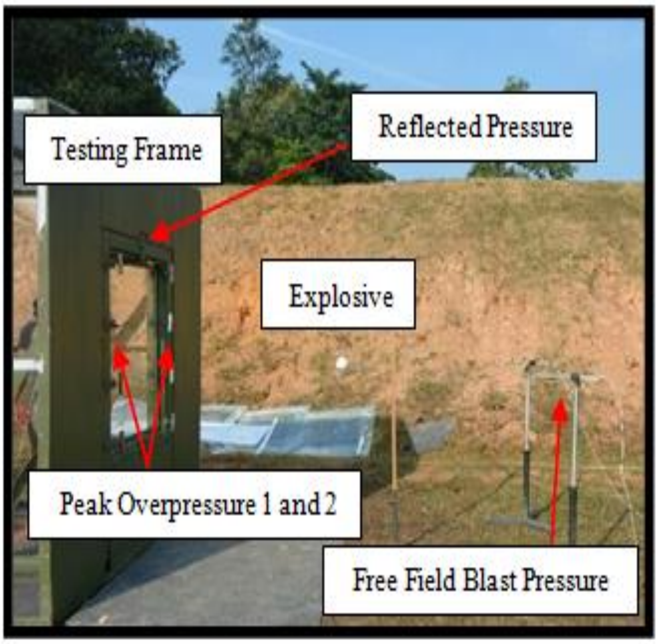
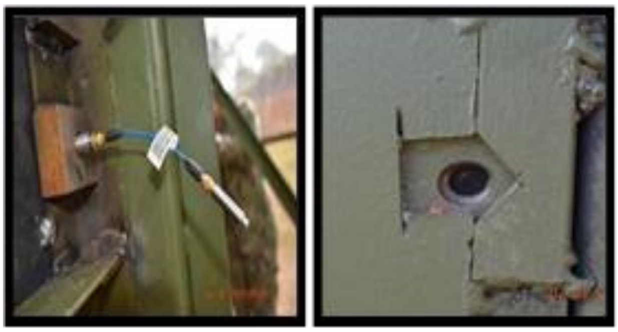



**Figure 1 Test set up**

Piezoelectric ICP® pressure sensor wasused to measure the blast peak overpressure at the blast location. The Piezoelectric ICP® pressure sensor is shown in Figure 2.



(a)Inside view (b) Outside view

**Figure 2 Piezoelectric IP® pressure sensor**



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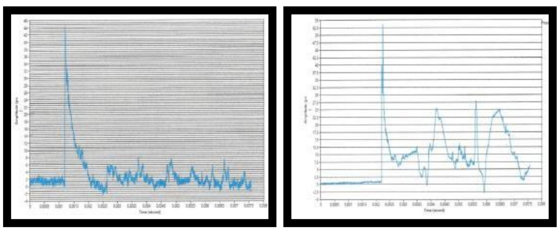
Piezoelectric ICP® reflected pressure sensor was used to measure the reflected pressure that hits the testing frame. This sensor has the ability to capture high frequency up to 1 MHz . It was fixed in the top middle of the testing frame and were connected via cables to the signal conditioning module and passed to the DAQ. The Piezoelectric ICP® pressure sensor is shown in Figure 3.

**Figure 3 Piezoelectric pressure sensor**

## III. RESULTS

A total two samples of glass panels were tested under blast loading. In this experiment, 6.76mm of laminated glass with PVB interlayer were used as control sample and 6.89mm of laminated glass with SGP interlayer. The size of the glass panel was 900 mm x 1100 mm. Both the glass panels were subjected to 400 g of C4 at a standoff distance of 1380 mm.

The peak overpressure for pressure sensor one was 310.26 kPa as shown in Figure 4(a). On the other hand, peak overpressure for pressure sensor two was365.42 kPa as shown in Figure 4(b). Therefore, the average peak overpressure resulting from the blast test of 400g of C4 at a standoff distance of 1380 mm was337.84 kPa.



**(a) Pressure sensor 1** **(b) Pressure sensor 2**

**Figure 4 Peak overpressure**

The reflected pressure was measured using reflected pressure gauge located at the top centre of the glass panel frame. The reflected pressure recorded was at 4, 688 kPa as shown in Figure 5.

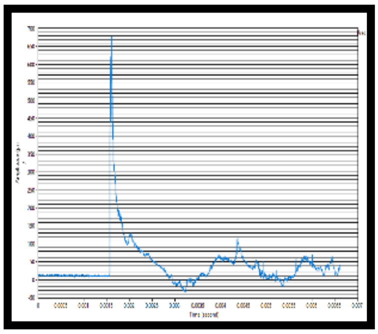


**Figure 5 Reflected pressure**

### 3.1 Sample 1 – Failure Mode of PVB interlayer

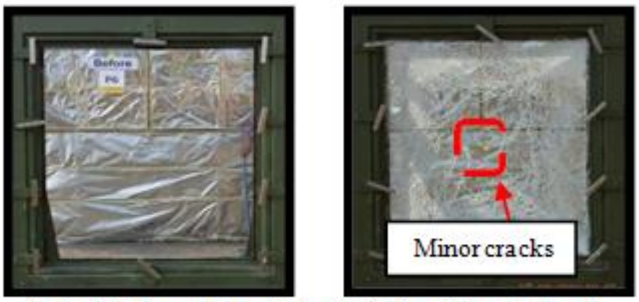

**(a) Before blast test (b) After blast test Figure 6 Laminated glass with PVB interlayer**

The glazing is observed on fracture and the total length of tears in the glazing, plus the total length of pull out from the edge of the frame is 400 mm out of 4000 mm, which is 10% of the total length. Also, there are two perforations caused by glazing fracture as shown in Figure 7. In addition, there was no fragment indents anywhere in a vertical witness panel which is located one meter from the interior face of the specimen.

Therefore, based on the ASTM F 1642- 04, the laminated glass with PVB interlayer fall in category C which is minimal hazard. The deflection of laminated glass with PVB interlayer was 80mm. This sample did not break into pieces and remained intact in the frame. This shows that the 6.76 mm thick laminated glass with PVB interlayer can withstand a blast pressure of 337.84 kPa resulting from a charge weight of 400 g C4.


**Figure 7 Perforations of laminated glass with PVB interlayer**

### 3.2 Sample 2 – Failure Mode of SGP interlayer




**(a) Before blast test (b) After blast test Figure 8 Laminated glass with SGP interlayer before and after the blast tests**

Sample two with 6.89 mm thickness of laminated glass with SGP interlayer was subjected to 400 g of C4 at a standoff distance of 1380 mm. The glass remained intact in frame and less cracks were observed at the glass panel as shown in Figure 8. In addition to this, there was no perforation or fracture observed at the panel. The deflection results from the blast test measured was 50 mm. The results showed that laminated glass with SGP interlayer was able to withstand the peak overpressure of 337.84 KPa and reflected pressure of 4688.43 KPa. Based on the ASTM F 1642-04, the laminated glass with SGP interlayer fall into category B which is no hazard.

## IV. CONCLUSION

The blast test results reviewed that laminated glass with SGP interlayer and laminated glass with PVB interlayer are able to withstand the peak overpressure of

337.84 KPa and reflected pressure of 4688.43 KPa. Laminated glass with SGP interlayer has the best performance rated atB category while laminated glass with PVB interlayer fell in category C

## V. ACKNOWLEDGMENT

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