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To cite this article: Heriana *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **508** 012060

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Experimental study on the behavior of glass/epoxy composite plate due to blast loading

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Abstract. The paper discusses the effect of blast loading on the behavior of glass/epoxy composite plate. Woven glass fiber material was used. The composite plate was manufactured using hand lay-up method. The specimens consisted of 12 and 14 plies of woven glass fiber. A TNT explosive material was used. The TNT was in cylindrical shape without metal casting. The weight of TNT was varied, which are 60, 80 and 100 grams. The stand-off distance was 300, 500 and 1000 mm. The glass/epoxy specimen was placed on a rigid test table with fixed boundary conditions. The deflection was recorded using sewing pins in Styrofoam. The deflection contour was recorded, and the maximum deflection was 21 mm. All specimens survived the blast loading, although some delamination was observed after the test using TTU scan.

1. Introduction

The use of light-weight composite material are increasing, especially on land armoured vehicle. Composite material are generally lighter than the metal and steel materials. Therefore, the composite materials attracted attention for engineers who design land armoured vehicle.

One of the requirement of designing armoured vehicle is that the structure should be able to withstand blast loading. Blast explosion of TNT, for example, could severely damage the structure. The severity of damage is determined by the explosive weight and stand-off distance between the structure and blast resource point [1]. For example, 100 kg mass of TNT at 15 m stand-off distance could produce overpressure of 0.27 MPa which can severely damage structure at that radius.

Several researches have been done on the effect of blast loading on composite structures. A numerical analysis and experimental work on carbon fiber composite plate under blast loading was conducted [2]. The work was part of European Carbon Fiber for Armoured Vehicle project. Experimental study was also conducted on slabs retrofitted with steel reinforced polymer composite under blast loading [3] and it was found out that the performances were similar to carbon fiber composite. The effect of fiber orientation on the structural performance under blast loading was investigated [4]. It shows that fiber orientation strongly influenced the energy absorption, while the effect of Young modulus was negligible. Meanwhile, Gebbeken [5] studied the effect of TNT blast on building structures, while Verna [6] studied the effect of blast loading on masonry structures.

The development of vehicle technology for armoured vehicle was the subject of Giversen [7], who studied the the behaviour of composite structures for land vehicle, while Avachat [8] studied the blast loading on marine structures. Abada [9] used sandwich structure made with aluminium foam and steel



plate faces for its marine vehicle. For the use in aircraft structures, Burns [10] analyzed containment box in an aircraft subjected to blast loading. Finally, the optimization study of composite structure under blast loading was conducted [11].

In this paper, experimental works on the glass/epoxy composite plate were carried out to study the behaviour of the plate under blast loading. The deflection countour during blast loading was measured for several explosive weight and stand-off distances. The failure mode was also studied after the blast using Through Transmission Ultrasonic (TTU) scan.

2. Method and materials

2.1. Sample preparation

The specimens were manufactured using hand lay-up method. The woven glass fiber was cut according the the size of aluminium plate mold. The woven fiber plies were laid up one by one and mixed with resin epoxy between its layers. The stacking sequence of layers was balance-symmetric $(0/90)_n$. After all plies had been laid-up, then it was wrapped up with plastic bag and vacuumed. The specimen was then put into the oven and heated up. The temperature rate was 5 deg C per minute until 150 deg C and hold for 90 minutes. The composite specimen size was 400 x 400 mm with only 250 x 250 mm exposed under blast loading. Fig. 1 shows the woven glass fiber and vacuum in the oven.

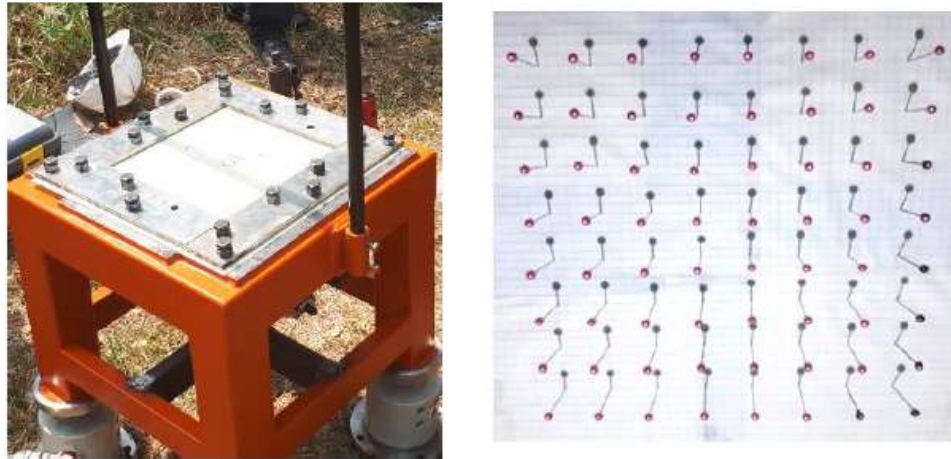


Figure 1. Woven glass fiber (left) and wrapped specimen in the oven (right)

2.2. Method

The blast experiment was undertaken in open air explosion. Fig. 2a shows the table test configuration where the specimen was bolted on the table. The bolted will produce near fixed boundary condition. The high explosive TNT was hanged in the support rod above the center of the specimen.

The maximum deflection was recorded using a simple method called sewing pins pad method as is shown in Fig. 2b. The sewing pins pad was placed under the specimen plate. The pad was made of styrofoam and the sewing pad was stuck in the foam. When the specimen deformed due to blast loading, the deformation will be recorded by the displacement of sewing pins.



(a) (b)
Figure 2. (a) Experimental table, (b) Sewing pins pad

The sewing pins are disposable; hence all specimens must have one sewing pin pad. Before the explosive was detonated, the sewing pins was sprayed with color, then after the blast, the sewing pins were colored again using different color. Thus, principally, the deflection during the blast is measured from the distance between two different color on the pins. From all the sewing pins, the deflection contour could be constructed and digitally visualized.

The specimen after blast loading was inspected using Through Transmission Ultrasonic (TTU) to inspect the possibility of internal damage such as delamination.

3. Results and discussion

3.1. Deflection contour

In all the tests, the specimens did not fail or rupture after the blast loading. Thus, the specimens were able to withstand the blast loading. The displacement of each point measured in each sewing pin can be measured and represented as a contour. Fig. 3 is an example of displacement contour for specimen having 12 layers and 100-gram TNT with 300 mm stand-off distance.

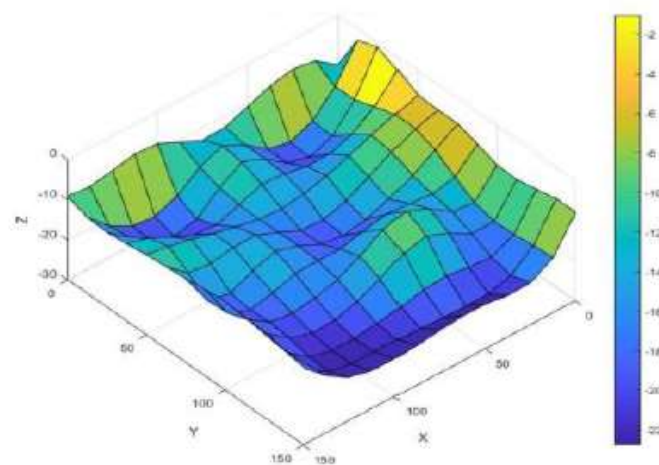


Figure 3. Deflection contour of specimen code S4.

The measured deflection contour may have some error, due to the vibration and or shock wave that causes the sewing pin moves while the deflection happened. This happens mostly at the periphery of the plate. Nevertheless, the maximum deflection at the center of the plate may not be affected by the movement of the pad. Fig. 4 shows the experimental deflection data at the sewing pins for different condition. Table 1 shows the different test condition in Fig. 5.

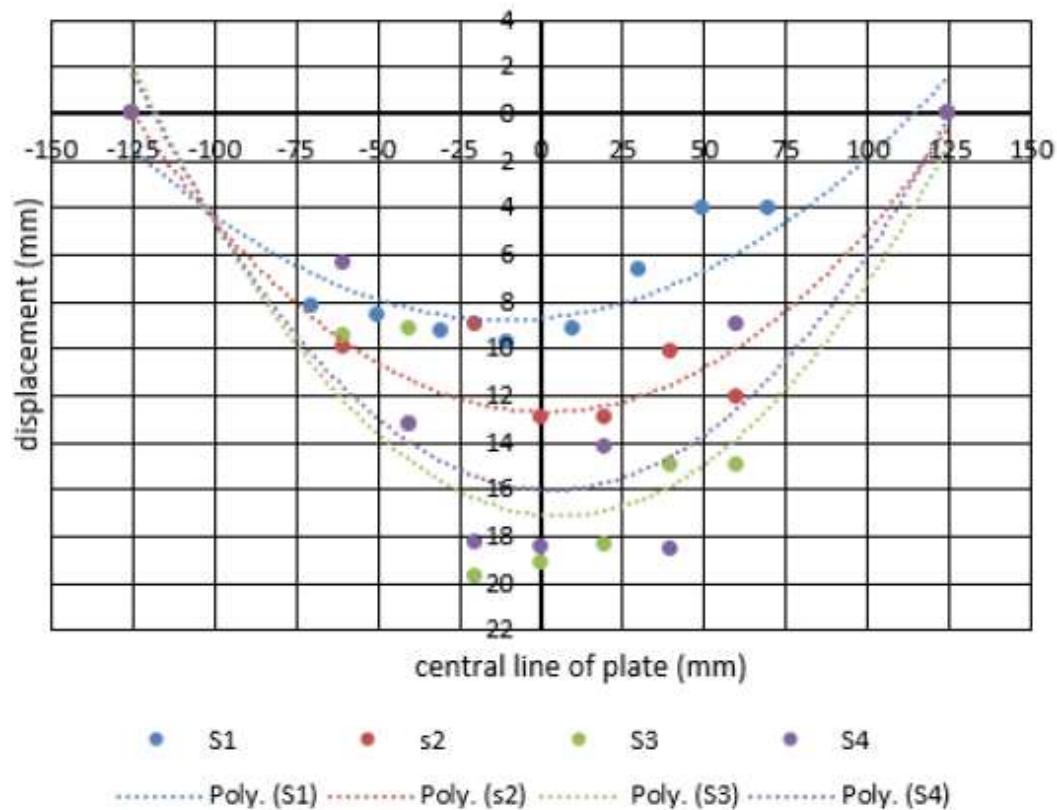


Figure 4. Deflection at the central line of the specimens

Table 1. Code and different experimental setup.

Specimen Code	Number of plies	Weight of TNT (gram)	Stand-off distance (mm)
S1	10	60	1000
S2	10	60	500
S3	12	80	300
S4	12	100	300

The four specimens, S1 until S4 have different number of layers, weight of TNT and stand-off distances as is given in Table 1. Sample S1 and S2 has the same number of plies and weight of TNT but has different stand-off distance. From Fig.5 it shows that these two specimens have different maximum deflection. While sample S3 and S4 has the same stand-off distance and number of plies but with different weight of TNT. It shows that both S3 and S4 has similar maximum deflection.

3.2. TTU results

Fig. 5 shows the resulted TTU non-destructive testing on the specimen after the blast loading. It shows that there are some delamination occurred inside the plate. The delamination was shown in red color.



Figure 5. TTU result of the specimen after the blast loading

4. Conclusion

The experimental study of glass/epoxy composite plate under blast loading of TNT has been conducted. The results show that all the specimen survived the blast loading, *i.e.*, no rupture happened in the specimens. The maximum deflection of the glass/epoxy composite plate using sewing pins pad method was measured in the range of 11 – 22 mm depth. The most important parameter on the maximum deflection is the stand-off distance between the plate and the blast loading source.

5. Acknowledgement

The authors wish to thank the Ministry of Defense, Republic of Indonesia through Defense Research and Development Institute (Balitbang – KEMHAN) in cooperation with Institut Teknologi Bandung who provide the research grant. We also thank PT. PINDAD and PT. DAHANA for providing the test materials and facilities.

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