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Recent study on the effect of blast loading on composite structures

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Abstract. The paper discusses recent study on the blast loading on composite structures for building, land, air and marine vehicle structures. A blast loading, and explosion phenomenon was discussed. Both numerical analysis using explicit finite element analysis and experimental study were carried out. In the numerical analysis, a LS-DYNA was used extensively, while in the experimental analysis, a TNT solid explosive was used. Composite structures were manufactured using prepreg carbon/epoxy laminates in an autoclave machine. Comparison between these two analyses was done. The study is important in understanding the blast phenomenon and its effect on composite structures, to be able to design safer composite structures.

1. Introduction

The widespread of terrorist attack or during the war in the form of bomb blast cautioned researchers worldwide on the developement of infrastructures and vehicles that could sustain the blast. The blast loading may cause severe damage to structures, such as building, land vehicle, ship and aircraft. A 5 psi blast overpressure will develop a wind speed of approximately 163 mph, that may result in building collapse and fatalities. A 20 psi blast overpressure will cause a windspeed of 502 mph and the fatalities will reach 100% [1]. TNT was mostly used in the bomb devices. The amount of overpressure depends on the mass of TNT used and also the distances. A 100 Kg TNT explosion at a distnace of 15 m will produce an overpressure of 39 psi, that produce severe damage on most building [2]

Several researches have been done on the study of blast loading on structures. Gebbeken [3] studied the effect of TNT blast on building structures and the method to increase the the building resistance to blast loading, while Verna [4] studied the effect of blast loading on masonry structures. The development of land vehicle technology especially in the armoured vehicle requires researches to develop lightweight structures that is able to withstand the blast loading. Giversen [5] studied the the behaviour of composite structures due to blast loading in armoured land vehicle structures, while Avachat [6] studied of blast loading on marine structures using composite materials and Abada [7] used sandwich structure made with aluminium foam and steel plate faces for its marine vehicle. For aircraft structures, Burns [8] analyzed and modelled containment box in an aircraft subjected to blast loading.

The literature studies above showed that blast loading may produce severe damages on structures, such as on building, and also land-sea-air vehicle. Therefore, the study is becoming very necessary and

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important. The paper will discuss some important issues concerning the effect of blast loading on composite structures and its current research in Indonesia.

2. Explosion and Blast Phenomenon

An explosion is defined as a large-scale, rapid and sudden release of energy [2]. Explosive materials can be classified according to their physical state as solids, liquids or gases. Solid explosives are mainly high explosives for which blast effects are best known. Examples include trinitro-toluene (TNT) and ANFO.

The detonation of a condensed high explosive generates hot gases under pressure up to 300 kilo bar and temperature of about 3000 – 4000 deg C. The hot gas expands forcing out the volume it occupies. Consequently, a layer of compressed air (blast wave) forms in front of this gas volume containing most of the energy released by the explosion. Blast wave instantenously increases to avalue of pressure above the ambient atmospheric pressure. This is referred to as the side-on overpressure that decays as the shock wave expands outward from the explosion source. After a short time, the pressure behind the front may drop below the ambient pressure, as seen Fig. 1. During such a negative phase, a partial vacuum is created, and air is sucked in. This is also accompanied by high suction wind that carry the debris for long distances away from the explosion source.

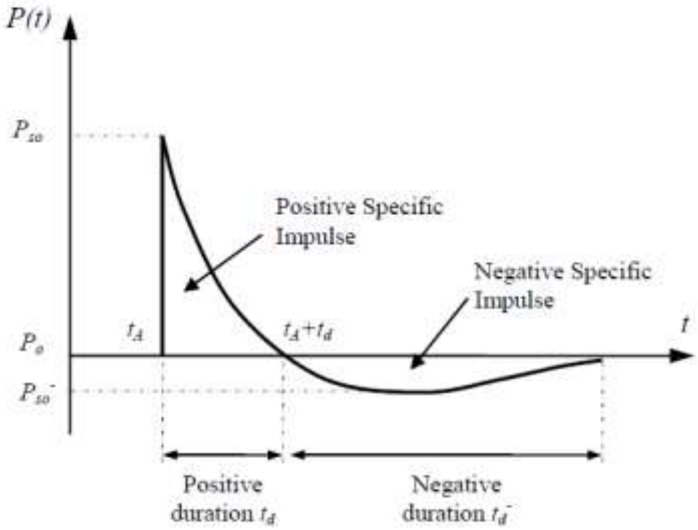

Figure 1. Blast wave pressure – Time history [2]

Figure 1 shows a typical blast pressure profile. At the arrival time t_A, following the explosion, pressure at that position suddenly increases to a peak value of overpressure, P_{so}, over the ambient pressure, P_o. The pressure then decays to ambient level at time t_d, then decays further to an underpressure P_{so}-, creating a partial vacuum, before returning to ambient conditions at time t_d + t_d-. The quantity P_{so} is usually referred to as the peak side-on overpressure, incident peak overpressure or merely peak overpressure [2].

The threat for a conventional bomb is defined by two equally important elements, the bomb size, or charge weight W, and the standoff distance R between the blast source and the target, as seen in Fig. 2. For example, the blast occurred at the basement of World Trade Center in 1993 has the charge weight of 816.5 Kg TNT, while the Oklahoma bomb in 1995 has a charge weight of 1814 Kg at a standoff of 4.5 m [2]. As terrorist attacks may range from the small letter bomb to the gigantic truck bomb as experienced in Oklahoma City, the mechanics of a conventional explosion and their effects on a target must be addressed and studied.

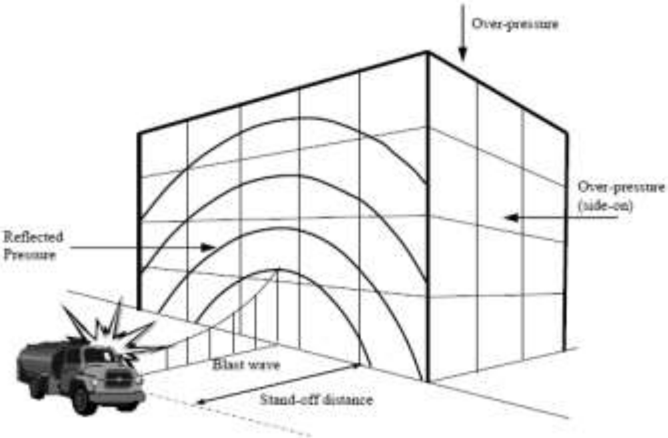

Figure 2. Blast loads on building [2].

3. Shrapnel During Blast Loading

Usually, TNT was also encapsulated by steel cover. Therefore, during explosion, the encapsulated steel will be shredded into shrapnel that travel with the speed of blast wave. The shrapnel will increase the possibility of damage to the surrounding structures. Therefore, in this section, the shrapnel produced during the blast will be studied.

3.1. Experimental Setup

A steel shell with a diameter of 325 mm, length of 823 mm and thickness of 20 mm was filled with 80 kg TNT high explosive materials. The total weight of the system was 250 kg. There are two types of experiments. First is the open-air explosion, to determine the blast and shrapnel velocities after the explosion and second, underground explosion to measure the shape and weight of shrapnel. This study focuses on underground explosion.

3.2. Underground Explosion

Fig. 3a shows the experimental setup, while Fig.3b shows the over ground image after explosion.

(a) (b)

Figure 3. (a) Experimental setup, and (b) after explosion

After the explosion, the shrapnel was collected and measured. Fig. 4 shows the size of the shrapnel after the explosion.

Figure 4. The shrapnel sizes.

3.3. Numerical Analysis

The numerical analysis used LS-DYNA extensively. The steel casing shell was modeled in a shell element. The steel shell element material model used Modified Johnson-Cook steel material model. For the TNT explosive materials, a Smoothed Particle Hydrodynamics (SPH) element was used, using material model MAT_HIGH_EXPLOSIVE_BURN in LS-DYNA. SPH is a meshless numerical method to simulate extreme deformation problems. In this case, the meshless TNT SPH element was covered by a shell element of the steel casing.

The results of the finite element analysis are given in Fig 5. Fig 5 shows the time sequences of blast explosion of steel-TNT from 0 sec until 0.00008 sec. It also shows that the blast explosion happened in a very short time.

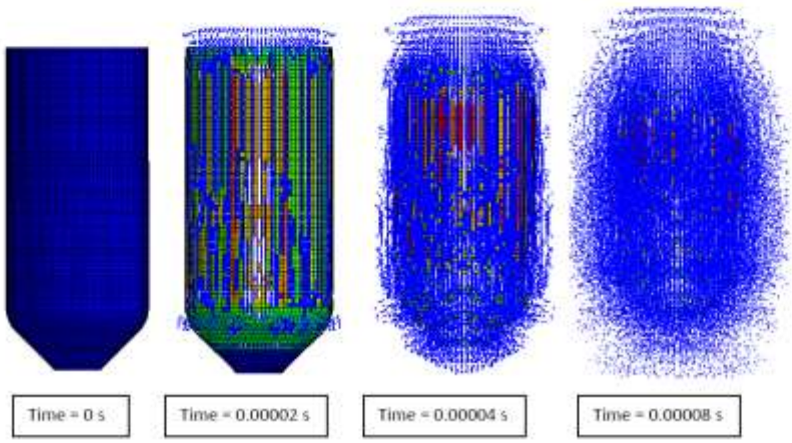

Figure 5. Time sequences during steel-TNT blast explosion.

4. Blast Loading on Composite Structures

4.1. Experimental Setup

The aim of the experimental study was to understand the behavior of composite structures subjected to blast loading. The composite structure was made of glass/epoxy and carbon/epoxy materials. The explosive material was TNT with the weight of 60 gr, 80 gr and 100 gr, and the standoff distance was 30 cm and 50 cm. Fig. 6 shows the experimental setup.

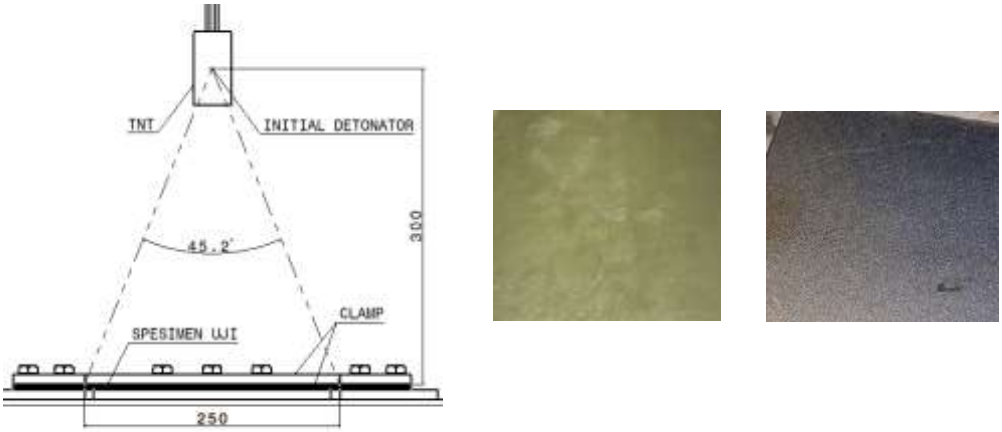

Figure 6. Experimental setup, glass/epoxy and carbon/epoxy plate specimens

4.2. Experimental Results

A sample of test results is given in Fig. 7 for the case of glass/epoxy composite plate under 60 gr TNT with stand-off distance of 30 cm. Fig. 7 shows that the glass/epoxy plate can withstand the blast loading.

(a) (b) (c)

Figure 7. Experimental results (a) after the test, (b) glass/epoxy plate, (c) deformation contour.

Fig. 7 shows that the glass/epoxy plate was survived during the blast loading, with no damages. Table 1 shows the maximum deflection of the plate recorded during test.

Table 1. Maximum deflection

No	Material	Number of Layer	Weight of TNT (gram)	Stand-off Distance (mm)	Maximum Deflection (mm)
1	Glass/Epoxy (0/90)	10	60	1000	13.8
2	Glass/Epoxy (0/90)	10	60	300	15.5
3	Glass/Epoxy (0/90)	12	80	300	20.3
4	Glass/Epoxy (0/90)	12	100	300	22.2
5	Carbon/Epoxy (0/90)	5	100	300	19

The results showed in Table 1 were as expected. The lower stand-off distance will produce higher maximum deflection. The deflection on carbon/epoxy is lower than glass/epoxy as expected, since carbon/epoxy plate is stiffer than the glass/epoxy plate.

5. Conclusion

A recent research on the effect of blast loading on composite structures was discussed and presented. The severity of damages due to blast loading was also discussed. The numerical and experimental results were presented. It shows that shrapnel produced during the explosion of TNT encapsulated by a steel cover should be included in the analysis. Composite plate was able to withstand blast loading on some cases. The research should be expanded into blast loading with higher TNT weight and shorter stand-off distance of approximately 300 – 400 mm.

6. Acknowledgement

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