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Laboratory Blast Simulator for Composite Materials Characterization

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ABSTRACT

Blasts and explosives have raised serious concerns in recent years due to the fatal injury and catastrophic damage they have caused in the combat zones and due to industrial accidents. Owing to their lightweight and complex damage process, fiber-reinforced composite materials have been found to have higher energy absorption capability and to be able to generate less lethal debris than conventional metals when subjected to impact loading. In order to characterize the blast resistance of composite materials, a piston-assisted shock tube has been modified for simulating blast tests in the laboratory due to its high safety, repeatability, accessibility and low cost. Although real blasts can be simulated relatively easily by using TNT or other chemicals, they, however, cannot be performed in general laboratories like many materials and structures testing due to their potential danger and restriction, hence hindering the design of new materials with high blast resistance. By carefully adjusting the individual components, piston-assisted shock tube has been shown to be able to produce blast waves for characterizing composite materials.

1. INTRODUCTION

In order to simulate blast waves in a general laboratory, high-pressure pressure waves may be used. However, it is imperatively important that the primary characteristics of blast waves, i.e. a blunt shock wave front followed by a trailing wave with an exponential decay, must be closely resembled in the simulated blast waves. Figure 1 shows a typical blast wave profile. It consists of a shock wave and a decayed trailing wave.

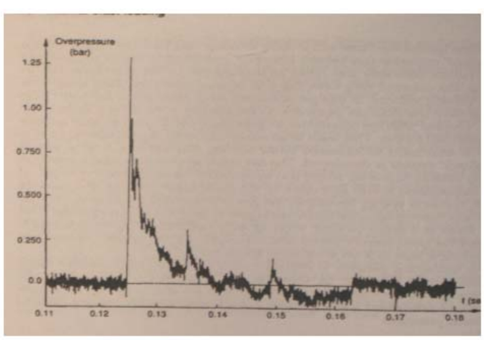

Figure 1 – A typical pressure history from a real blast.

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Among the facilities capable of generating shock waves, shock tube [1-4] is perhaps the most commonly available. The shock tube was originally developed as a supersonic wind tunnel. Figure 2 shows a three-section, piston-assisted shock tube and a testing chamber. Details of the shock tube can be found in Reference [5,6]. Figure 3 shows a typical pressure history generated from the shock tube without the piston. Clearly, there is a shock wave right in the beginning. The high pressure of the shock wave lasts a long duration of 6ms. It is because of this extended long range of constant pressure at high speed, approximately 5 Mach, the shock tube is useful for supersonic aerodynamic investigations.

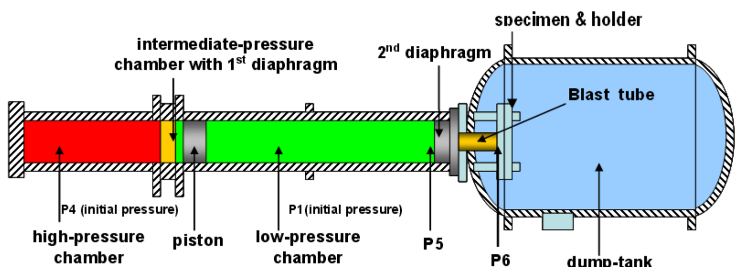


Figure 2 – Schematic of a piston-assisted shock tube and the associated blast tube and testing chamber.

Although a shock tube can provide a shock wave, its pressure level may not be high enough for simulating blast waves which usually have ultra-high pressure levels. When compared with the real blast wave shown in Figure 1, the profile of the pressure waves generated from the shock tube is also lack of an exponential decay immediately after the shock wave. In order to increase the pressure up to a useful level, a piston may be inserted in the shock tube, as also shown in Figure 1, to increase the pressure level significantly. Figure 4 shows a typical pressure history from the shock tube with a piston. The pressure peak is now significantly higher than that generated without a piston due to the compression of the gas located in front of the piston by the piston. And the pressure wave has a rapid decay right after the peak.

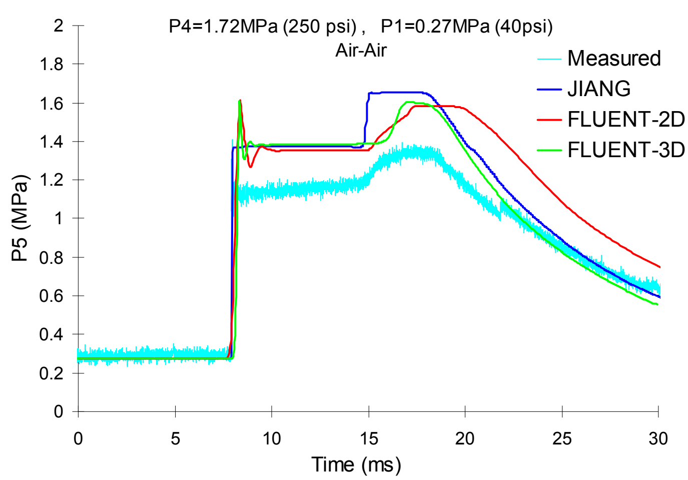


Figure 3 – Typical pressure histories from both experimental measurement and computational analyses by FLUENT.

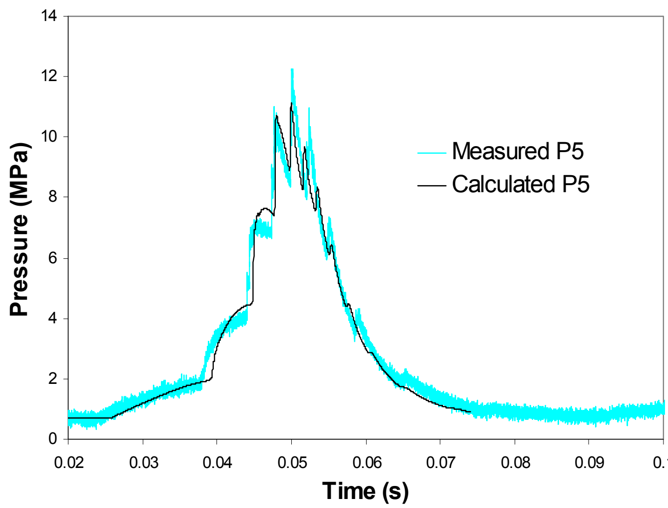


Figure 4 – Typical pressure history generated from a piston-assisted shock wave.

The major defect of the pressure wave generated from the piston-assisted shock tube is the loss of the shock wave. As shown in Figure 4, the pressure increases step by step as the piston is driven toward the right end of the shock tube. The steps are likely formed due to the high driving pressure left to the piston and the low pressure waves reflecting from the right end of the shock tube. In order to modify the pressure wave to resemble a blast wave, i.e. a high-pressure shock wave with an exponentially decayed trailing wave immediately right after it, a diaphragm is required. When the pressure level is approaching the peak, the diaphragm, which is usually made of a metal artificial defect, will be ruptured instantaneously. Accordingly, a truncated wave front like the blunt wave front of a shock wave can be formed. And a simulated blast wave can be achieved.

2. BLAST SIMULATION FACILITY

Figure 2 shows a schematic of a shock tube and a testing chamber. The tube has an inner diameter of 8cm and a length of 610cm. It is divided into three sections. The high-pressure section is 200cm long and located on the left side of the shock tube. The low-pressure section is 400cm long and located on the right side of the shock tube. The intermediate-pressure section is situated between the high-pressure section and the low-pressure section and has a length of 10cm. Two diaphragms are used to separate the tube into three sections, one on each end of the intermediate-pressure section. Depending on the pressure levels in the sections, different metals and thicknesses are chosen for the diaphragms. In addition, the diaphragms are introduced with defects so they can be ruptured instantaneously to form a shock wave. As mentioned earlier, a piston is used to largely increase the pressure level of the pressure wave. It has a mass of 2kg.

In order to transform the generated pressure wave into a blast wave, which has a shock wave with a blunt wave front immediately followed by a rapidly decayed trailing wave, a small tube, so-called blast tube, is added to the end of the shock tube. The blast tube has an inner diameter of 1.25cm and a length of 15cm. Right at the boundary between the shock tube and the blast tube, there is another diaphragm. It is used to hold the pressure wave up to a pre-determined level. Once the diaphragm is ruptured instantaneously, a shock wave will be formed in the beginning of the blast wave. Figure 5 shows the profile of a blast wave coming out of the blast tube. It is calculated based on the computational fluid dynamic program (CFD)

FLUENT and has a spherical shape.

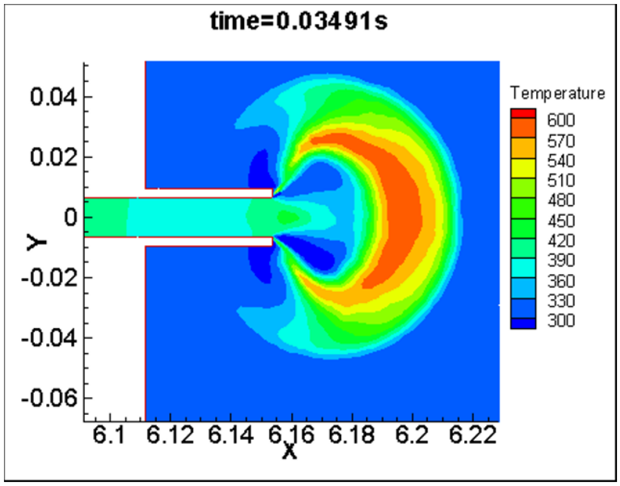


Figure 5 – Spherical shape of a blast wave based on FLUENT simulation.

3. BLAST TESTING

For blast testing, a specimen should be solidly held in front of the blast tube with or without a distance from the blast tube depending on the simulation condition. Since the blast wave coming out of the blast tube expands spherically and its pressure level drops rapidly as it moves away from the blast tube, a large specimen with a testing zone of 12.5cm in diameter and bolted around the circumference may be used. On the contrary, if a specimen is held against the blast tube, only a small zone slightly greater than the 1.25cm diameter of the blast tube will be significantly affected. Hence, a specimen with a testing zone of 3.8cm in diameter and bolted around the circumference should be sufficiently large.

Besides the plate specimens mentioned above, beam specimens can also be tested using the blast simulation facility. For example, specimens of 30cm x 10cm can be held at two locations, e.g. each is held at 5cm from each end, and loaded in the middle section, resulting in a three-point-bend type of testing. In this type of testing, a blast tube of 8cm identical to the shock tube can be used. It is also possible to use a blast tube with 8cm in diameter at one end to match with the shock tube and transforming into a vertical slit of 8cm x 1.25cm at the other end. With each type of blast tube, the specimen being tested should be held against the blast tube.

4. TESTING RESULTS

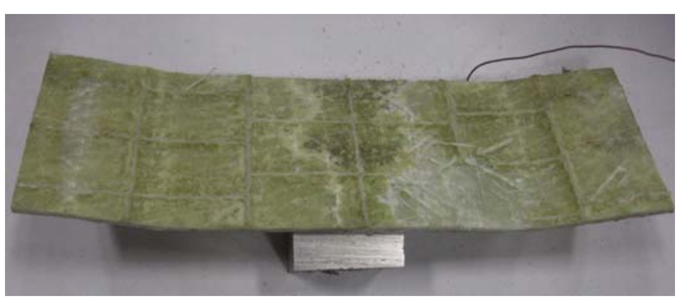
Glass/epoxy composite plate specimens with a thickness of 0.32cm were trimmed to have dimensions of 10cm x 10cm. Each specimen was then clamped by two steel ring holders with eight bolts equally spaced along a circumference of a 7.5cm diameter. A circular opening of a diameter of 3.8cm was left for blast testing. The reason for choosing these dimensions for specimens and specimen holder was because of the advantage of maximizing the use of the pressure waves produced by the shock tube based blast testing facility to identify the composite's resistance to pressure loading. In other words, the pressure waves were concentrated to damage the composite rather than to deform the specimens. Figure 6 shows the image of a damaged specimen. There was a perforation zone in the middle of the specimen surround by delamination and burnout of composite.

Figure 6 – Damaged glass/epoxy composite plate.

In beam testing, each specimen, also of 0.32cm thick was trimmed to be 30cm long and 10cm wide. During the testing, each specimen was simply-supported by two strips. Each strip had a radius of curvature of 0.32cm for supporting the specimens. The distance between the apexes of the curvatures of the two plates, i.e. the span of simply-supported boundary, was 21.3cm.

Each simply-supported specimen was loaded with a pressure wave at the center of its span. The pressure wave had a diameter of 8cm and a maximum pressure around 9.5MPa. Since the simply-supported specimens had a width of 10cm, which was close to the diameter of the blast waves 8cm, the pressure wave leaked out of the specimens when bending occurred. Experimental results for simply-supported specimens subjected to pressure waves are shown in Figures 7.

(a)



(b)

Figure 7 – Damaged glass/epoxy composite beam (a) measured side and (b) loaded side.

5. SUMMARY

The blast testing technique and procedures presented in this study is suitable for screening the blast resistance of potential armor materials. It is a highly repeatable, controllable, accessible and safe technique and can be operated by trained engineers in ordinary laboratories. The cost of running a test has also been demonstrated to be much lower than corresponding real blasts.

The fidelity of the blast testing technique, as compared with the corresponding real blasts, can be concluded based on the similarity between the characteristics of real blast waves and those of simulated blast waves. The characteristics of waves include (1) the blunt shock wave front, (2) the rapid decay right after the shock wave and (3) the spherical wave profile. The damaged morphology of the glass/epoxy specimens due to simulated blast loading was also found to be qualitatively the same as those due to real blasts.

The loading condition, boundary condition and specimen geometry and dimensions can be modified to suit individual testing needs. Measuring techniques for recording pressure, temperature, velocity and deformation of the specimens need to be further developed to identify the fundamental parameters involved in the highly dynamic blast testing.

ACKNOWLEDGEMENTS

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