Reflection of Shock Wave in PUR Foam From Rigid Wall*

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Received February 3, 1993.

Keywords: shock wave, foam, two-phase flow, shock tube.

Keller[1] proposed that a building, a mechanical installation or a body wrapped by a layer of foam plastics may be an efficient means for protection from damage of blast wave. However, the practical effect was beyond expectation. For example, a gunner wearing the foam plastics-padded waistcoat was injured more seriously by the blast wave from a muzzle. Monti[2] took the foam plastics as homogeneous two-phase medium and analyzed it with the theory of dusty flow. The obtained results show that the peak pressure behind the reflected shock wave from rigid wall with foam coat exceeds obviously that without foam coat under the same condition. Gel'fand[3], Patz[4] and Weaver[5] made experimental observations by means of shock tubes and verified the conclusion obtained by Monti. But all the measured peaks of reflected pressure were lower than the calculated ones according to the shock wave theory of dusty gas. Moreover, it is puzzling why in foam the shock wave with discontinual front could not be observed in all of the performed experiments. This note presents an analysis and the results on the above-mentioned two problems.

1 Analysis and Experiment

There may be two factors affecting the measured value of the peak pressures. One is the foam layer length. In two-phase medium, the shock wave has a relaxation zone with a certain length. If the length of foam is shorter than the relaxation length, the pressure behind the shock wave transmitted into the foam cannot reach the equilibrium value. The reflected pressure on the rigid wall will be lower than the calculated equilibrium pressure. The other is the friction between the foam plastics side surface and the shock tube wall. In dusty flow, the friction of shock tube wall has great influence inside the boundary layer, but it exerts no influence over the center flow outside the boundary layer. The friction between the foam plastics side surface and the shock tube wall seriously affects the whole flow field of foam plastics. To avoid this effect, a ~1 mm gap between the foam and the shock tube wall was used in Gvozdeva's[6] experiment. However, the experimental results showed that this method had no effect. In our experiment the solid lubricant was coated on the foam side surface to

* Project supported by the National Natural Science Foundation of China.

reduce the friction between the foam and the wall of the shock tube.

In dusty flow, there are two kinds of shock waves. When the velocity of shock wave is higher than the gas sound speed, the shock wave has discontinual front; when the velocity of shock wave is lower than the gas sound speed and higher than the equilibrium sound speed of the mixture, the shock wave has no discontinual front. In the past experiments, the velocity of shock wave in foam was lower than the gas sound speed. It is comprehensible that only the disperse shock wave without front could be observed. We have paid attention to the problem whether or not it is possible to generate the discontinual front of shock wave in foam under the condition of the velocity of shock wave higher than the gas sound speed. In our experiment, the range of incident shock wave Mach number in air was extended in order to make the velocity of shock wave in foam higher than the gas sound speed.

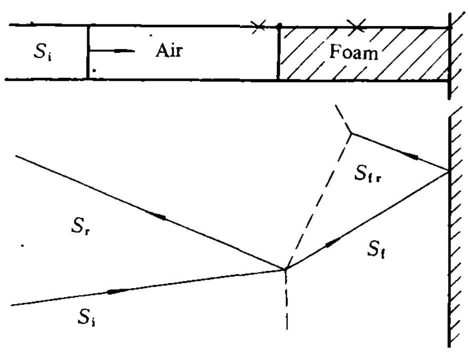

Fig. 1. Sketch map of a shock tube and the wave diagram.

The diameter of shock tube is $\phi 80$ mm in our experiment, as shown in Fig. 1. The range of Mach number of incident shock wave in air is from 1.1 to 7.16. The polyurethane foam (PUR) whose diameter is the same as the diameter of the shock tube was placed at the end of the driven section. Its density is 25.4 kg/m^3. We can see that when the incident shock wave (S_i) in air arrives at the interface of air/foam, a reflected shock wave (S_r) returns back to air and a shock wave (S_f) transmits into the foam. While the transmitted shock wave reaches rigid wall, a reflected shock wave (S_{fr}) is generated.

2 Results and Discussion

2.1 *The Pressure of Reflected Shock Wave From Rigid Wall*

2.1.1 The effect of foam length. Fig. 2 shows the pressure profile recorded at the end wall of a driven section. We can see that the profiles of reflected pressure possess the shape like mountain peaks. The value of pressure is quickly attenuated from the highest point, and its peak pressure depends on the length of the foam, such as $P_{fr}=3.29$ MPa at

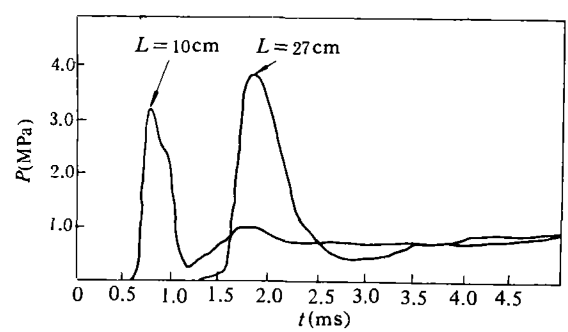

Fig. 2. The reflected shock peak pressures vs. foam length.

$L = 10$ cm, and $P_{fr} = 3.85$ MPa at $L = 27$ cm, both with $M_s = 1.7$. If the length of foam is shorter than the length of relaxation zone of the shock wave, the peak pressure increases with the increase of the foam length; when the length is longer than the certain length, the peak pressure is almost constant, as shown in Fig. 3.

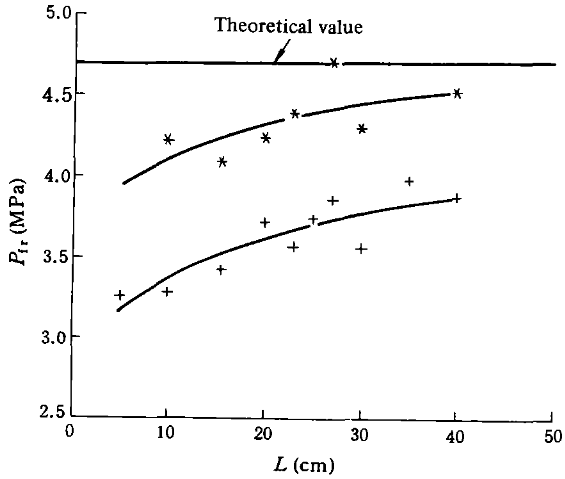

Fig. 3. The comparison of data of reflected peak pressure and theoretical value.

2.1.2 The effect of friction. The friction between the foam side surface and the sidewall of the shock tube affects seriously the value of the peak pressure. The value of the peak pressure with coating of solid lubricant is about 0.5—1.0 MPa greater than that without coating. the measured peak equilibrium pressure value of reflected shock wave under the conditions of friction eliminated and enough length of foam agrees well with the calculated results by the dusty gas theory.

2.2 *The Structure of Shock Wave in Foam*

According to the dusty gas theory, the shock wave discontinuous front should be observed at $M_s > 3.2$ in air and $M_f > 6.5$ in foam ($a_{foam} = 52$ m/s). However, we have never observed discontinuous front of shock wave in our experiments, at $M_s = 3.82$ and $M_s = 7.16$ in air (Fig. 4). In foam plastics, there is only disperse shock wave without discontinual front. This is related to the special structure of foam plastics. In dusty gas, solid particles or liquid droplets suspended in gas are accelerated gradually due to the inertia while shock wave acts on dusty gas. When the velocity of shock wave is higher than the gas sound speed, the shock wave with discontinual front will appear in gaseous phase. The structure of foam is different

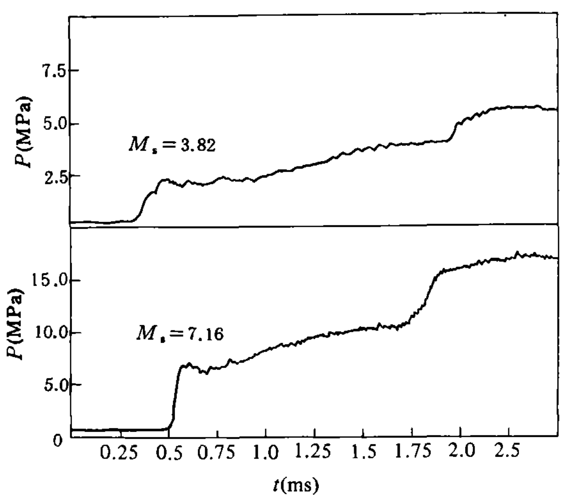

Fig. 4. The pressure profile of shock wave in foam.

from the dusty gas. The gas is full in the foam skeleton, and when shock wave acts on foam, gas must move with foam skeleton together; no discontinual front of shock wave appears in gaseous phase whether the velocity of shock wave is lower than or higher than the gas sound speed.

The characteristics of shock wave in foam are the same as those of dusty gas in equilibrium zone, but they are different in the frozen and the relaxation zone.

3 Conclusions

1. Both the length of the foam layer and the friction between the foam side surface and the side wall of the shock tube affect seriously the value of the peak pressure of the reflected shock wave on the rigid wall. The equilibrium parameters of the shock wave in PUR foam can be calculated according to the theory of dusty gas, but the frozen and relaxation characteristics are different.

2. The shock wave has no discontinual front in foam due to the special foam structure.

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