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Blast Wave Initiation of a Sheet Explosive Covered with Metal Plates

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ABSTRACT

Initiation of RDX-based sheet explosive by a normal incident blast wave has been studied. Explosive sheets : (i) bare (ii) aluminium foil-covered and (iii) sandwiched between different thicknesses of aluminium alloy metal plates, were impacted by the blast wave. The blast wave was produced by detonating a cylindrical plastic explosive charge kept symmetrically over the sheet at different stand-off distances in the air for varying the intensity of the blast wave. The values of critical distances, pressures obtained in the case of bare, foil-covered and aluminium alloy metal plates-covered sheet explosives have been fitted to exponential curves. It is observed that the sheet explosive sandwiched between the two metal plates having thicknesses between 4 and 12 mm requires initiating pressures higher than those for bare sheet explosives. If the sheet explosive is, however, covered by thin aluminium foil (0.25 mm) then it is initiated by blast wave of pressure lower than that for bare or sandwiched sheet explosive. Initiation of sheet explosive by a blast wave occurs after a delay of 2 µs when it is covered with thin aluminium foil (0.25 mm) and about 7 µs when it is covered with 4 mm thick aluminium plates.

1. INTRODUCTION

The study of initiation of detonation in explosives by a blast wave is of vital importance to avoid sympathetic detonation in various defence stores and also to design magazines for safe storage of high explosives and ammunitions. A shock wave of rectangular profile, generated by the impact of an explosively accelerated flyer plate, has generally been used to study the shock-initiation[1] of explosives. The pressure of these shocks varied from tens to hundreds of kilobars and existed only for a few microseconds duration. Many investigators have studied the initiation of heterogeneous explosives by such shocks and tried to establish a criterion for shock initiation of explosives. Walker and Wasley[2] proposed energy criterion, according to which the explosive gets initiated only when shock energy in the explosive exceeds a critical value. This critical energy is characteristic of an explosive and indicates its sensitiveness to shock wave.

Generally, the shock wave, required to initiate a heterogeneous explosive, is of intensity in the range of 10-50 kbar. In this range of shock pressure, one can assume the shock impedance of test explosive to be constant. The energy criterion therefore reduces to a relation, P^2T = constant, where P and T denote the pressure and duration of a uniform shock wave explosive. In Reference[3], the criterion $P^n T$ = constant where $n < 2$, has been shown to indicate better agreement with experimental values. Napadensky[4] studied initiation of explosive by low velocity impact and concluded that initiation of explosive occurs at much lower stress levels by the crushing process than by the shock process

In the case of blast wave, the energy in the wave depends not only on its pressure and duration but also on its pressure profile. The pressure profile of a blast wave is not rectangular and its exact shape is dependent on the dimensions and the geometry of the explosives. Its peak overpressureandduration are related through scaling law to reduced distance $Z = (R/W^{1/3})$ where W is mass of the explosive which on detonation produces blast wave and R is the distance between the charge and the point where blast parameters are measured. To the best of the authors' knowledge, the criterion for initiation of explosive by a blast wave has so far not been established.

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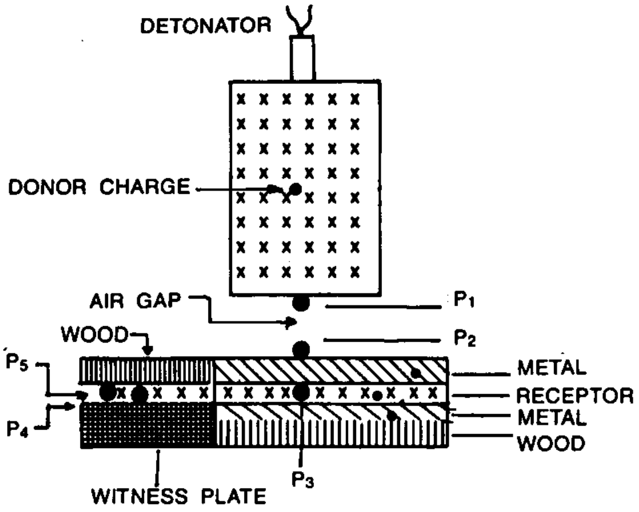

Figure 1. Experimental setup for blast initiation of sandwiched sheet explosives.

In the present paper, an attempt has been made to study, experimentally, the initiation of a sheet explosive sandwiched between two metal plates, by a blast wave. The sheet explosive has been covered with different thicknesses of metal plates and exposed to blast wave of different intensities. The experimental setup also ensures that only shock wave, after traversing the metal plate, interacts with the sheet explosive and direct interaction of high velocity detonation products on initiation of sheet explosive is avoided

2. EXPERIMENTAL DETAILS

The experimental arrangement shown in Fig. 1 has been used to study the initiation of sandwiched sheet explosive by blast wave. The blast wave is generated by detonating a donor charge consisting of a cylindrical tetryl-based plastic explosive having density of 1.6 g/cc and contained in PVC tube of length-to-diameter ratio nearly equal to unity. The sheet consists of RDX/Crepe rubber (90:10) explosive of 4 mm thickness, 150 × 150 mm size and density 1.28 g/cc. The particle size of RDX used in the preparation of the sheet is 5 to 6 micron. It is fully sandwiched between two metal plates. The metal plates are of aluminium alloy of different thicknesses. A particular quantity of donor plastic explosive is detonated over a typical sandwich in air at different distances from the receptor sheet explosive. The distance between the donor and the receptor is increased till the maximum distance for detonation of the sheet explosive is obtained. Similar measurements have been

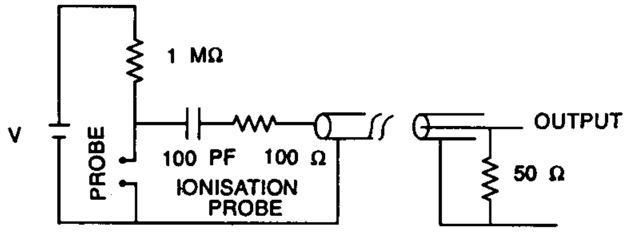

Figure 2. A typical circuit diagram of RC network for generating electrical pulses.

carried out by varying both the quantity of the donor charge and the thickness of the sandwich plates.

Electrical probe P_1 fixed at the end of donor charge, triggers an oscilloscope while probe P_2 records the arrival of the blast wave at the centre of the upper plate of the sandwich. The probes P_3, P_4 and P_5 have been inserted into sheet explosive to measure the delay in initiation of sheet explosive and to determine the velocity of detonation wave. These electrical probes are of shorting type and are made of insulated copper wire of dia 0.4 mm. Two insulated copper wires are twisted to form a probe. The tip portion of each probe is freshly cut and inserted in the explosive to record the arrival of detonation wave. The other end of the probe is connected to resistance capacitance network as shown in Fig. 2. When the shock/detonation front reaches a particular probe, its ionised zone shorts the probes which discharges the corresponding charged capacitor and generates a voltage pulse across the terminating resistance. The voltage pulse is fed to the deflecting plates of a high resolution (approximately 10 ns) oscilloscope. The state of detonation or no detonation of the sheet explosive has also been, for the sake of convenience, determined by means of a witness plate placed under the extended portion of the sheet explosive. The extended portion of the sheet explosive was covered by a wooden plank to protect it from direct exposure of the blast wave.

Two types of experiments have been carried out. In the first series of experiments, the sheet explosive is sandwiched between thicker metal plates varying from 4 to 12 mm while in the second series the sheet is either sandwiched between two metal foils of thickness 0.25 mm or kept bare. The quantity of donor charge has been varied from 100 to 600 g in both the series of experiments. For each combination of donor charge and thickness of sandwich plate, the maximum distance for detonation of sheet has been determined. The distances were measured from the end of the donor

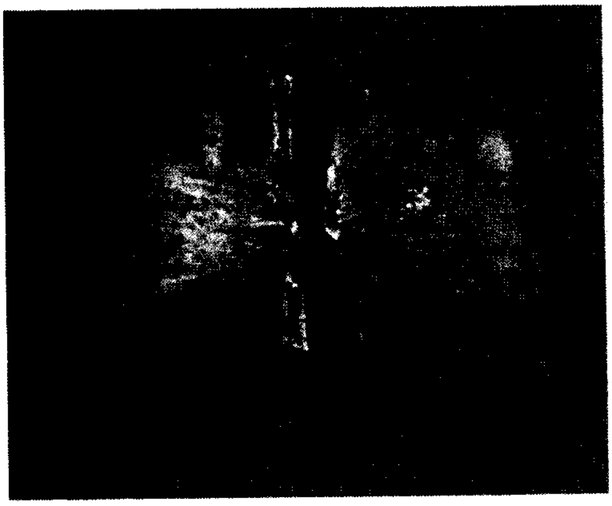

Figure 3a. Broken top plate of 12 mm thickness sandwich in case of no-detonation of sheet explosive with 400 g of donor charge at a distance of 100 mm from the top sandwich plate.

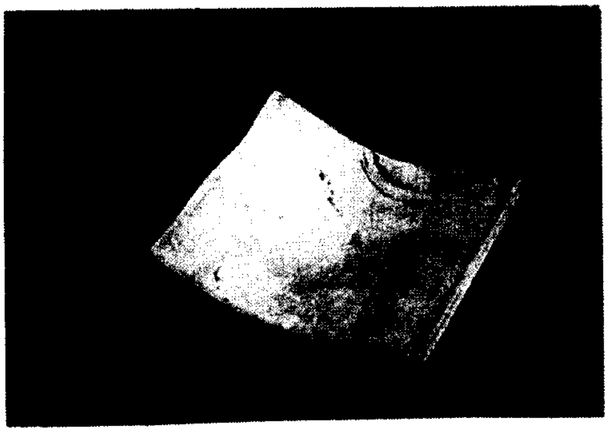

Figure 3b. Buckled bottom plate of 12 mm thickness sand wich in case of no-detonation of sheet explosive with 400 g of donor charge at a distance of 100 mm from the top sandwich plate.

charge. In the case of 400 and 600 g of the donor charges, the distance between donor and the receptor has been increased in steps of 10 mm while in the case of 100 g donor charge the distance was varied in steps of 5 mm till the state of detonation is turned into that of no-detonation. Both the state of detonation and that of no detonation are confirmed by at least three experiments for each combination of the donor and the sandwich. The state of detonation is confirmed by the response of electrical probes and the velocity of detonation obtained in each experiment. It has been observed that in these trials, the sheet explosive does not catch fire or deflagrate in the case of no-detonation. The sheet explosive is either fully detonated or not detonated.

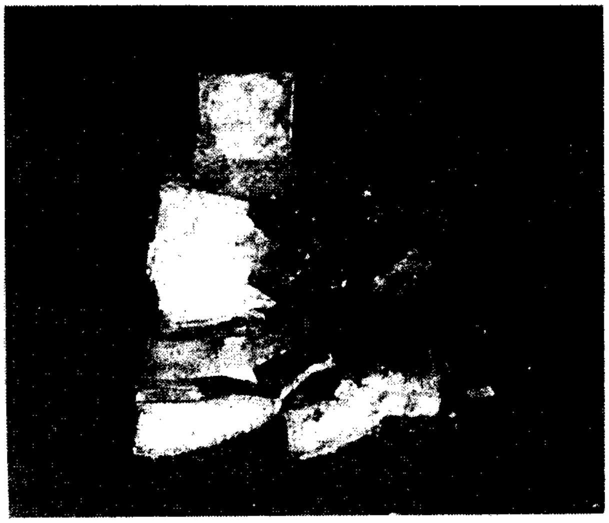

Figure 3c. Recovered sheet explosive pieces in case of no-detonation with 400 g of donor charge and sandwich plate of 12 mm thickness. Distance from donor charge to top sandwich plate = 100 mm.

Typical photographs of the top and bottom plates of the 12 mm sandwich and the recovered sheet explosive piece in case of no-detonation of sheet explosive are shown in Figs. 3(a), 3(b) and 3(c) respectively

3. RESULTS & DISCUSSION

A typical oscillographic record of detonation of the sheet explosive obtained from the experimental setup of Fig. 1 is shown in Fig. 4. The pulses P_1 and P_2 indicate the arrival of detonation wave at the end of the donor charge and that of blast wave at the centre of the sandwich respectively. The pulses P_3, P_4 and P_5 indicate the arrival of detonation at the respective probes in the sheet explosive. The interdistance of these probes and the times of response obtained in a few typical experiments are given in Table 1. The velocity of detonation wave has been determined by using this distance-time data. Taking 5.328 mm/μs as velocity of minimum shock strength in aluminium plate, the time for shock travel in aluminium has been calculated. In order to obtain delay in initiation of the sheet explosive, the calculated time is subtracted from the time observed experimentally between probes P_2 and P_3. Table 1 gives the typical delays in the initiation of sheet explosive covered with aluminium foil of thickness 0.25 mm and 4 mm aluminium plate.

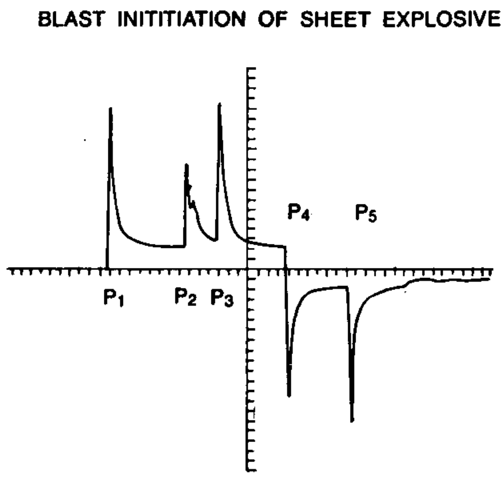

Figure 4. A typical oscillographic record indicating initiation of foil covered sheet explosive by blast wave of 100 g donor charge. Time base, 5 µs/div.

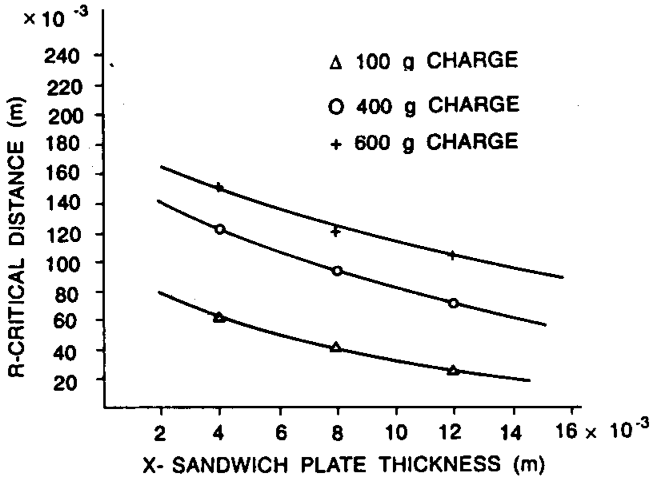

Figure 5. Dependence of critical intiation distance for sheet explosive sandwiched between metal plates of different thicknesses.

Table 1. Distance-time data for blast initiation

Sandwich type	Probes	Distance between probes (mm)	Pulse timings (µs)	Wave velocity (mm/µs)	Delay µs
4 mm *Al* covered	P_1-P_2	25	3.7	6.76	
sheet explosive	P_2-P_3	8+4	8.0	-	7.25
	P_4-P_5	51	8.7	5.862	
Al foil (0.25mm) covered	P_1-P_2	50	7.8	6.41	
sheet explosive	P_2-P_3	4	3.3	-	2.3
	P_4-P_5	40	6.5	6.154	

Table 2. Critical distance and incident blast pressure for initiation of sandwiched sheet explosive

Charge PEK-1 W, (kg)	Weight equivalent TNT W' = W x 0.8657 kg	Critical distance R, (m)	Scaled distance $R_o=R/W^{1/3}$ (m/kg 1/3)	Plate thickness X, (m)	Blast pressure *P*, (kg/cm²)	Time (µs)
0.1	0.08657	0.063	0.1424	.004	264	81
		0.043	0.0972	.008	415	71
		0.027	0.061	.012	615	63
0.4	0.3463	0.125	0.178	.004	197	143
		0.096	0.1303	.008	295	125
		0.075	0.1068	.012	374	116
0.6	0.5194	0.153	0.1903	.004	180	169
		0.123	0.153	.008	241	152
		0.108	0.1343	.012	284	144

The critical distances for detonation of sandwiched sheet explosive have been presented in Table.2 and graphically shown in Fig. 5. It is evident that in the case of a sandwich of given thickness, the critical distances up to which explosive in sandwich detonates, increases with the quantity of the donor charge. On the other hand, if the mass of the donor charge is kept constant and the thickness of metal plates covering the sheet explosive is varied, then the critical distance for detonation decreases exponentially with increase in the plate thickness. The slope of the exponential curve is, however, dependent on the mass of the donor charge. The values of critical distances obtained in first series of experiments have been fitted to an exponential curve

$$R = A \,.\, W^{1/3} .e^{-(B/W^{1/3})} .\, x \tag{1}$$

where *R* denotes the air gap distance between the sandwich and the donor charge, *x* represents the thickness of the plates in metres, *W*, the mass of the donor charge in kg and *A* and *B* are constants. The value of these constants for three different values of *W* have been obtained as shown in Table 3(a).

Table 3(a). Constants of Eqn (1) for computing critical distances for metal covered sheet explosive

Charge quantity (kg)	A	B
0.1	0.206	47.95
0.4	0.219	47.36
0.6	0.215	37.82

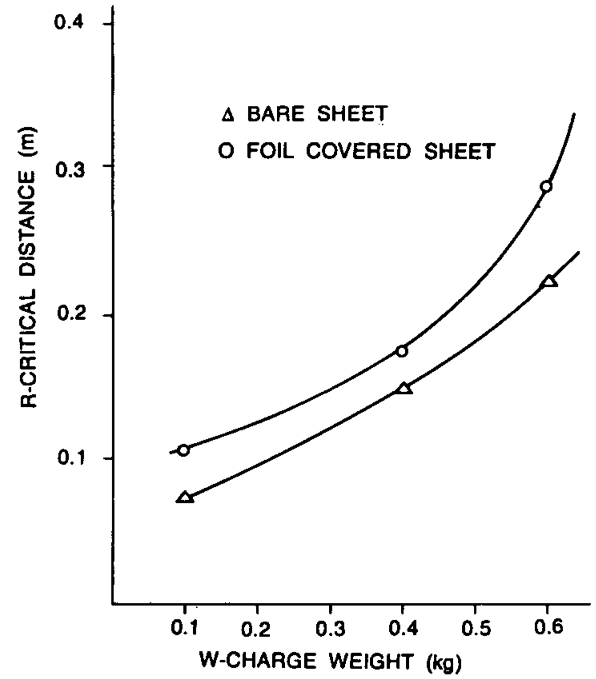

Figure 6. Critical distances for intiation of bare and foil-covered sheet explosive.

Table. 4 and Fig. 6 show the variation of the critical distances, obtained in second series of experiments for bare and thin foil-covered sheet, with explosive mass W of the donor charge. These curves clearly reveal that sheet explosive, covered with metal foils, detonates up to a distance much greater than that for a bare sheet.

The values of critical distance Ro measured from the bottom of donor charge to the top plate of the sandwich have been obtained for different quantities of donor charges and fitted to an equation

$$R_0 = A_0 \, . \, W^{1/3} \, . \, e^{(B_0 \cdot W^N)} \qquad (2)$$

where Ao, Bo and N are constants as given in Table 3(b).

Table 3(b). Constants of Eqn (2) for computing critical distances of bare and foil covered sheet explosive

Type of sheet	A_o	B_o	N
Bare	0.153	1.285	1.632
Foil covered (0.25 mm aluminium)	0.215	2.6116	3.3679

Equation (2) yields the computed values of the critical distances within a maximum variation of 2 per cent from the experimental values.

Table 4. Critical distance and incident blast pressure for bare and thin metal foil covered sheet explosive

Charge Weight PEK-1 W (kg)	equivalent TNT $W' = W x 0.8657$ (kg)	Critical distance R, (m)	Scaled distance $R_o = R/W'^{1/3}$ (m/kg^1/3)	Explosive sheet* Bare (B) Foil Covered (F)	Blast pressure Incident (kg/cm²)	Blast pressure Reflected (kg/cm²)	Time (μs)
0.1	0.08657	0.073	0.165	B	218	1696	87
		0.104	0.2351	F	135	1035	104
0.4	0.3463	0.15	0.2136	B	154	1187	157
		0.175	0.2492	F	124	947	171
0.6	0.5194	0.225	0.2799	B	106	803	210
		0.290	0.3608	F	60	437	250

* B - bare, F - foil covered

The sheet explosive used in this study was subjected to 'gap test' for the measurement of its shock sensitivity[5]. It was found that the shock wave of 11 kbar peak pressure in the explosive could initiate the sheet without delay. The duration of this non-uniform shock wave is expected to be of a few microseconds only

In order to see whether the same order of pressure is generated in the explosive when a blast wave of duration much greater than that of shock wave in the gap test impacts on the metal explosive combination, we assume that the peak pressure and duration of the incident and reflected blast wave can be approximately obtained by assuming the present donor charge equivalent to a spherical charge and by using the empirical relations[6]

$$P_1 - P_o = \frac{14.0717}{(Z)} + \frac{5.5397}{(Z^2)} - \frac{0.3572}{(Z^3)} + \frac{0.00625}{(Z^4)}$$

$$\text{for } 0.05 \le Z \le 0.3 \qquad (3)$$

and

$$T = (W')^{1/3} x \, 10^{-3} \, (0.107 + 0.444Z - 0.264Z^2$$

$$-0.129Z^3 + 0.0335Z^4)$$

$$\text{for } 0.05 \le Z \le 0.3 \qquad (4)$$

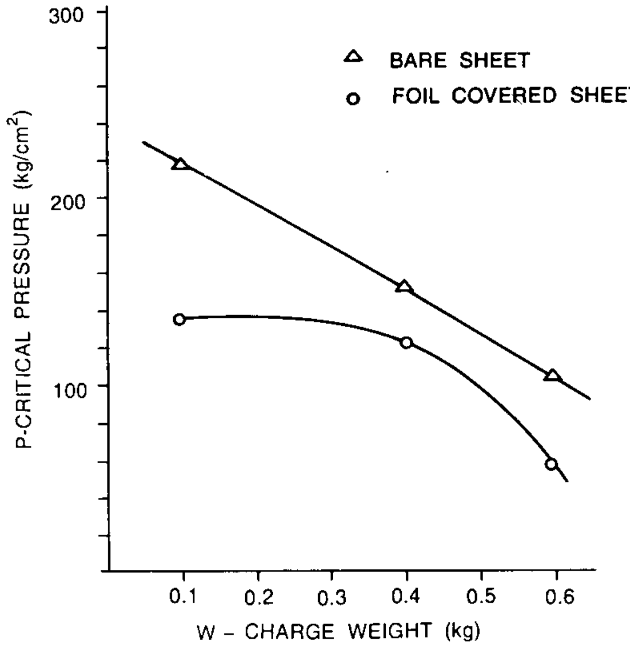

Figure 7. Critical pressures required to initiate bare and foil-covered sheet explosive.

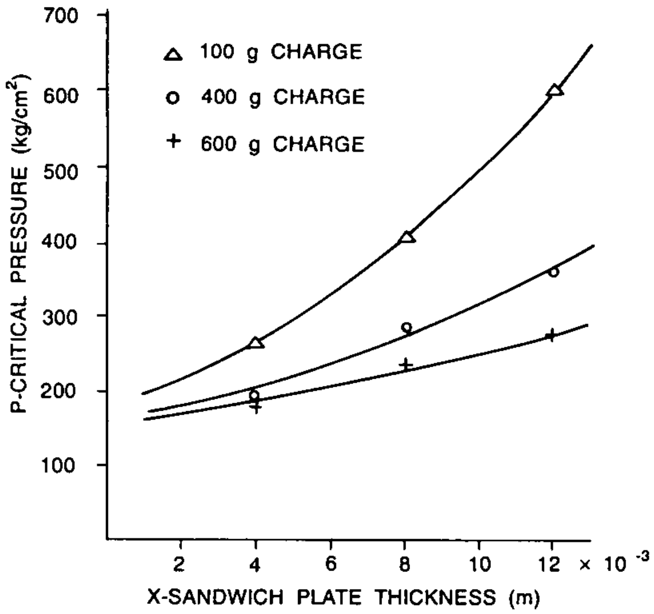

Figure 8. Magnitudes of pressures required to initiate sheet explosive sandwiched between plates of different thicknesses.

where P_o is the ambient pressure and $Z = R/W_1$ is the reduced distance. R and W_1 denote distance in meters and TNT equivalent of donor charge in kg, respectively. T and P denote blast duration in seconds and blast pressure in kg/cm^2 respectively. These formula[6] hold good for reduced distances varying from 0.05 to 0.3. The reduced distances in the present study also lie within this range. The values of critical pressures and blast duration obtained from these relations for bare and sandwiched explosives are given in Tables 2 and 4 and plotted in Fig. 7 & 8. It is clear from these figures that if the quantity of the donor charge is kept constant then incident critical pressure required to initiate a sandwich increases with the increase in the plate thickness of the sandwich. On the other hand, if the sandwich thickness is kept constant, then the pressure capable of initiating the sheet explosive increases with the decrease of the explosive quantity in the donor charge. The experimental values of initiating pressure obtained for different plate thicknesses and different quantities of donor charges have been fitted to a relation

$$P = A \, . \, e^{(B/W^{1/3}) \, . \, x} \qquad (5)$$

where P, x and W represent the pressure, thickness of the plate and mass of the donor charge respectively. If pressure, thickness and charge quantity are expressed in kg/cm^2, m and kg respectively, then the values obtained for A and B are shown in Table 5.

Table 5. Constants of Eqn (5) for computing critical pressures for metal covered sheet explosive

Charge quantity (kg)	A	B
0.1	178	48.11
0.4	153	55.8
0.6	149.5	46.05

The experimental values of critical pressures agree with those obtained from Eqn (5) within 2 per cent variation

The variation in critical pressure with quantity of donor charge for initiation of bare and foil-covered sheet explosive, however, follow the relation

$$P = A_O \, . \, e^{(B_O \cdot W^N)} \qquad (6)$$

where A_O, B_O and N are those given in Table 6; The pressure and donor charge quantity are expressed in kg/cm^2 and kg respectively.

Table 6. Constants of Eqn (6) for computing critical pressures of bare and foil covered sheet explosive

Type of sheet	A_0	B_0	N
Bare	2264	-1.78	1.67
Foil-covered (0.25 mm aluminium)	135	-13.89	5.56

The pressure-time analysis of the blast wave reveals that the pressure induced in the sheet explosive by impact of blast wave is about 1.5 kbar (Table 4) which is an order smaller than the shock pressure which initiates this explosive in gap test. Further, the impact of blast wave causes a large deformation in the sandwich plates as well as the sheet explosive. Figures 3A, 3B, and 3C show the state of the sandwich metal plates and the explosive after impact of a blast wave which has peak pressure just below the critical pressure and does not initiate the sheet explosive. Figure 3A and 3B show that the upper plate breaks into two pieces and lower one undergoes a large bulging. The explosive sheet as shown in Fig. 3c gets reduced in thickness and fractured from the centre. The sheet explosive also gets charred along the periphery of the central hole.

These observations indicate that the blast wave which is not capable of generating hot spots by compression effect, initiates the sheet explosive, which is sandwiched between two metal plates mainly by crushing and shearing of the explosive and the friction between the explosive and the metal plates during the process of deformation. This hypothesis is further strengthened by the observation that the critical pressure for bare sheet explosive is greater than that for the thin-foil covered sheet explosive which provides the mechanism for friction. The increase of critical pressure with thickness of the metal plates also supports the mechanism of shear and friction for initiation of the sheet explosive because higher the plate thickness, greater is the amplitude of shock pressure required to deform the plate. The mechanism for initiation of sheet explosive by blast wave appears to be similar to the one observed by H.S. Napadensky with low velocity impact. The delay in initiation of sandwich explosive by blast, however, is much less than those obtained in low velocity impact experiments.

4. CONCLUSION

It may be concluded from the present study that a thin sheet explosive can be initiated by a reflected blast wave, having peak overpressure and time duration, as calculated from Eqns (3) and (4), less than a kilobar and a few hundred microseconds order respectively. If the sheet explosive is sandwiched between two metal plates having thickness from 4 to 12 mm, then it requires initiating pressures higher than those for bare sheet explosive. If the sheet explosive is, however, covered by foil, then it is initiated by blast wave of pressure lower than that for bare or sandwiched sheet explosive.

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