MACH REFLECTION PARAMETERS FOR PLEXIGLAS CYLINDERS

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The "collapsing air gap" method has been used to investigate the development and limiting parameters of the Mach reflection of a conical convergent shock in plexiglas cylinders arranged along the axis of a detonating explosive charge. The diameters of the cylindrical specimens varied from 15 to 100 mm. It is shown that on the stationary interval of development of the triple-shock configuration, where the velocity of the head wave is equal to the detonation velocity, there is a linear relationship between the diameter of the head wave, its radius of curvature, and the diameter of the cylinder.

In [1, 2] it was reported that Mach reflection had been experimentally detected in the case of conical convergent shock waves generated in cylindrical specimens of copper, iron, aluminum, plexiglas, water, and porous NaCl by the detonation of surrounding charges of explosive. There follows a description of measurements of the parameters of the heat wave in plexiglas cylinders with diameter δ = 15–100 mm using various explosives (TNT, RDX, and cast Composition B 40–60) in accordance with the method proposed in [2]. The experimental setup is illustrated in Fig. 1, where 1 denotes a mirror, 2 the elements of the composite plexiglas cylinder, 3 air gaps, and 4 a layer of very porous magnesium oxide intended to reduce the effect of the impact of the detonation wave at the bottom of the cylinder on the generation and development of the head wave. The shock configuration and its evolution were recorded from the luminescence of the air gaps by means of an SFR-1 speed photorecorder operating in the slit regime (the arrows indicate the path of the rays registered by the photorecorder). The length of the cylindrical specimens was 5–6 times greater than their diameters, and the diameter of the charge was three times greater than the diameter of the specimen, in order to avoid distortions as a result of unloading at the lateral surface of the charge.

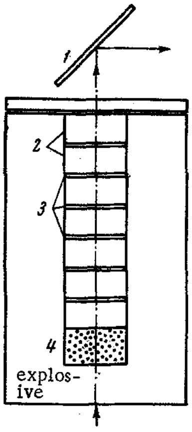

Fig. 1

As seen from Fig. 2, a convergent conical shock wave with Mach reflection at the vertex of the cone is generated in the cylindrical specimen. The photographs were used to measure the cone angle α, the velocity D^* of the head (Mach) wave, its diameter d, the radius of curvature R, and the angle φ between the axis of the cylinder and the tangent to the surface of the head wave at the triple point O (Fig. 3).

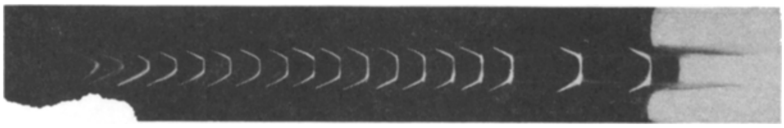

Fig. 2

In order to determine α from the photographs, we measured the time interval between the instants of passage through the gap of the base of the shock cone and its presumed vertex. The axial component of the shock cone velocity is equal to the detonation velocity D; therefore

$$\alpha = \operatorname{arc\,tg} \delta / 2D\tau.$$

In finding R and φ it was assumed that the head wave has the shape of a spherical segment. From the photographs we determined the height h of the head wave and its velocity D*. The value of h was determined from the time interval between the instants of passage through the gap of the base of the head wave OO and its vertex. Then

$$R = \frac{1}{2}\left(\frac{d^2}{4h} + h\right), \quad \varphi = \frac{\pi}{2} - \arcsin\frac{d}{2R}.$$

In a single experiment the scatter in determining D* was ±1.5%, and for d it was ±4%. The determination of α, R, and φ involved additional constructions; therefore in these cases the scatter reached 5%.

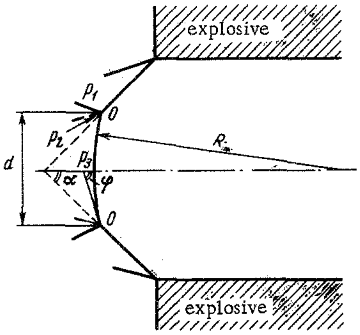

Fig. 3

The evolution of the head wave can be divided into two stages: a nonstationary stage, in which the head wave is generated and then increases in diameter and radius of curvature (on this interval D* > D), and a stationary stage, in which the parameters of the head wave have attained their limiting values and are constant, the velocity of the head wave becoming equal to the detonation velocity (Fig. 4). The length of the nonstationary interval is 2–3 cylinder diameters, if RDX is used as the explosive; for Composition B it is 3-4 cylinder diameters, and for TNT the length is approximately equal to the cylinder diameter.

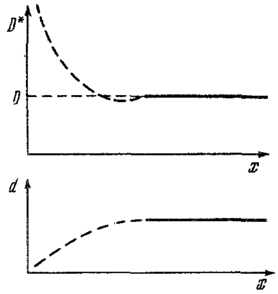

Fig. 4

For the same explosive d and R are proportional to the cylinder diameter (Fig. 5). The results of measuring d, R, φ, and α on the stationary interval are presented in the table for each of the explosives employed. The table also includes the pressure p_1 (kbar), behind the shock cone (single compression), the pressure p_3 behind the center of the head wave, and the pressure p_2 behind the head wave at the triple point O. The shock adiabat of plexiglas used to calculate these pressures was that obtained by the authors in the form D = 2.60 + 1.50 u km/sec.

Reducing the diameter of the RDX charge to 80 mm at a specimen diameter of 50 mm leads to a decrease in the angle α to 44 ± 1°, to a decrease in d to 0.48δ, and to a certain increase in the length of the nonstationary interval, which reflects the influence of the unloading waves at the lateral surface of the charge.

It is interesting to compare the parameters of the Mach reflection for plane shock waves and a conical convergent shock. For this purpose we organized an experiment on the collision of plane shock waves in a plexiglas prism in accordance with the scheme employed in [3]. The collision angle and the amplitude of the incident shock

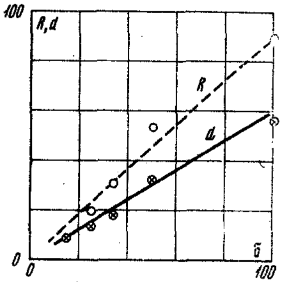

Fig. 5

d/δ	R/δ	$\alpha°$	$\varphi°$	p_1	p_3	p_2
TNT ($\rho_0 = 0.95$ g/cm^3, $D = 4.9$ km/sec)						
0.57	1.1	55	75	45	89	80
RDX ($\rho_0 = 1.2$ g/cm^3 $D = 6.75$ km/sec)						
0.60	0.90	46	72.8	86	220	200
Composition B ($D = 7.8$ km/sec)						
0.62	0.90	42.5	70,5	110	320	271

waves were taken equal to those determined from experiments with cylinders. It was found that in this case Mach reflection takes place. However, the width of the head wave (9–10 mm at a prism height of 50 mm) is much less than in a cylinder of sufficiently large diameter at the same distance from its point of origin. Apparently, this is associated with the intensification of the conical shock as it converges on the axis of symmetry.

This study, like [2], was undertaken in order to clarify the conditions of shock compression of materials preserved in cylindrical bombs. The conclusions of [2] can be supplemented as follows.

The shock cone angle depends on the pressure developed during detonation of the explosive employed and on the detonation velocity. The parameters of the oblique shock wave formed in an inert material by a sliding detonation whose front is perpendicular to the boundary between the inert material and the explosive are determined [4] by the intersection of the unloading polar of the explosion products and the shock polar of the inert material. As a result of the axial symmetry the parameters of each element of the shock cone increase with convergence on the cylinder axis. In [1] it is noted that, as Birkhoff and Walsh have shown, "irregular reflection must always take place in a conical convergent flow of material with a normal equation of state."

Apparently, the Mach reflection observed in plexiglas cylinders is analogous to the irregular reflection of weak shock waves in gases [5], since the polars of the incident and reflected waves do not intersect (the polars were constructed without allowance for the convergence of the wave). Accordingly, the simple theory with a single tangential discontinuity [6] is not applicable here. In view of this and the presence of a radial gradient of the parameters as a result of axial symmetry, it is possible to speak of equality of the pressures behind the head and the reflected shock waves only in the first approximation. As far as the mass velocity distribution is concerned, in the presence of irregular reflection of strong shocks in gases the mass velocity jump behind the Mach wave is greater than the total jump behind the incident and reflected waves. In the case of weak shock interaction the difference is apparently not any less. This fact has been experimentally observed [7].

If the shock adiabat of the cylinder material has a discontinuity and the sliding detonation generates parameters corresponding to the wave-splitting region, two oblique waves are formed [1, 4]. Since the flow behind the first shock front is supersonic relative to the front, there is no reason for the appearance of a Mach reflection. The first wave is not amplified, since any perturbations in the direction of an increase in pressure lag behind the first shock front. In this case the second wave with parameters above the discontinuity on the shock adiabat may give a Mach reflection. If the Mach wave does not outstrip the vertex of the first shock cone, its velocity cannot be equated to the detonation velocity in order to determine the developed pressure, since the material in front of it is already compressed and has a certain velocity. In [1] it was found by the method of reflection of light from a free iron surface that the second plastic shock wave gave a Mach reflection, whereas the elastic wave and the first plastic wave with an amplitude of 130 kbar did not. The Mach wave was located behind the vertex of the cone of the first plastic wave.

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