EXPLOSIVES WITH METAL-LINED CAVITIES

by

Sampooran Singh*

Defence Science Laboratory, New Delhi

ABSTRACT

The jet formation by hemispherical and trumpet liners have been explained by a simple extension of the hydrodynamic theory of jet formation by conical liners. The various phenomena relating to jet formation and penetration have been correlated. The modified theory of penetration provides an accurate description of the variation of depth, velocity and time of penetration with stand off and nature of target material.

Introduction

The basic characters of the jet formation and penetration by explosives with metal-lined cavities (shaped charges) were discovered almost simultaneously by flash radiography in the U.S.[1], England[2] and Germany[3] in 1944. Flash radiographs taken by Clark and Seely in the U.S. and by Tuck in England were interpreted by Birkhoff[4] and Taylor[4], respectively; and a simple extension of the theory of jet formation was presented by Pugh et al.[5, 6] and Eichelberger[7]. The nature of the penetration process was described by Pugh[4], and independently by Mott, Hill and Pack[8, 9]; and a simple extension of the theory was presented by Singh[10] and Eichelberger[11]. The status of the theories of jet formation and target penetration has been reviewed earlier[12]. The present article reviews the published work on shaped charges during the last four years.

Modifications to the Theory of Jet formation

Evans[2] and Kolsky[13] observed that on detonation of explosives with lined hemispherical cavities, the liner progressively turns "inside out" during collapse and suggested that a rather different mechanism is operative here as compared with a conical liner. By a simple extension of the hydrodynamic theory of jet formation by conical liners, Singh[14] explained the successive stages of collapse and the absence of massive slug by hemispherical liners. Singh[15] also explained the jet formation by lined trumpet cavities. The walls of the trumpet liner were assumed to have a fixed radius of curvature having the centre either in the plane through the apex and parallel to the base of the liner or in a plane of the base of the liner; and such a trumpet liner was found to be inferior in performance to a conical one of the same calibre and height. In another paper[16], the jet formation by a modified liner, which was a combination of conical and trumpet liners, was discussed, and the modified liner was found to be superior in performance to a conical one of the same calibre and height.

Pugh et al.[5] showed that the "after jet" was an illusion created by the fact that the last formed jet element travelled at the same speed as the last formed slug element and by the fact that the velocity gradients stretched out all of the jet elements to great lengths. Singh[17] showed that the "after jet" is due to the relatively very long time taken for the later stages of collapse because of the comparatively very low collapse velocity of the lower portion of the liner and the ductile drawing between the last formed jet element and the last formed slug element. Metallographic examination [18, 19] of the extreme edge of the base of slugs show flowed metal, and this suggests that the breaking of the rear of the jet and the base of the slug is due to ductile drawing.

The preliminary spectrographic studies[20] indicate that the metal in the jet was partly in the vapour state and partly in the form of small incandescent fragments. A rough estimation of the temperature in the jet from the intensities of copper lines comes to be 5000°C. The temperature of the metal in a Munroe jet during its flight in air has been estimated to be of the order of five thousand degrees from different theoretical considerations[21].

Modifications to the Theory of Penetration

Recently Singh[22] attempted to correlate theoretically the various phenomena relating to jet formation and penetration into metallic targets by shaped charges. A simple modification of the theory is described which appears to account adequately for the stretching of the jet as it travels in space, the break-up of the jet into particles, the waver of the jet and the strength of the jet and target materials. Explicit expressions for depth of penetration, velocity of penetration and break-up factor for a jet element are given. In order to check the theory, numerical evaluations have been carried out in case of standard M9A1 steel cones for which experimental results of Eichelberger[11] are available. There is a good quantitative agreement between the published experimental values of Eichelberger and the theoretical results. The modified theory seems to explain the variation of depth, velocity and time of penetration with standoff and nature of target material.

Metallographic examination of steel targets attacked by high-velocity jets throws light on the "terminal ballistics" of Munroe jets[23, 24]. The action of an element of a jet in a target is that (1) a crater is formed by the lateral compression of the target as the element of the jet penetrates it; (2) the penetration is accompanied by local heating of a shallow layer of the metal near the crater to a temperature in excess of 723°C and by the heavy plastic deformation of the adjoining region; (3) the shear fractures then appear as an energy relieving process in the region of greatest deformation after an element of the jet is knocked off by the target and the target itself has extended plastically to give rise to the crater; (4) due to the high pressure in the crater (possibly due to the subsequent element of the jet), the metal in the jet is forced into the shear fractures. It appears that the impact of an element of the jet on a steel target initiates a high intensity transient compressional stress wave in the body of the target and the velocity of the stress wave in steel is estimated to be 5500 m/sec. The velocity of the stress wave in steel attacked by the jet is, therefore, greater than the velocity of penetration by different elements of the jet, so that the transient stress wave is always ahead of the surface of impact of the element of the jet on the target.

Rotating Shaped Charges

When a shaped charge rotates about its axis, each element of the rotating liner possesses angular momentum[25] and in consequence the individual elements do not converge upon the axis as the liner collapses since each element has both a tangential and a radial velocity. This effect has been shown to be negligible, a calculation of the radius of a jet element that is newly formed shows that it is virtually independent of the angular momentum of the parent element in the original liner. If we assume that each jet element possesses all the angular momentum of the parent element in the original liner, this results in a continuous spreading (*i.e.* an increase of cross-sectional area) of the jet element as it travels in space. Explicit expressions for the depth of penetration, velocity of penetraton and time of penetration are given[26]. As the angular velocity of the liner increases, the cross sectional area of the corresponding jet element increases and the depth of penetration decreases. The deleterious effect of rotation on penetration increases from the head to the tail end of the jet. The depth of penetration by the rotating charges at 160 revolutions per second is about half of its static performance.

Effects Produced by High Velocity jets in Steel

When a high-velocity jet attacks a steel target[23] the metal in the jet spot-welds on the crater surface. A shallow layer of the metal of the original target at the surface of the crater gets heated beyond Ac_1 point and is observed as martensitic grains surrounded by ferritic grains. The ferrite and pearlite grains of the target show severe distortion and flow in the vicinity of the crater, which decrease with distance from the crater. Shear fractures at approximately 45° to the circumference of the crater were also observed.

In low-carbon (carbon 0·13 per cent) steel[24] and medium-carbon (carbon 0·42 per cent) steel[27] attacked by high-velocity jets, each hardness versus distance curve exhibited a series of plateaus along which the hardness remained constant. The plateaus appear to be related to Neumann bands which are present in steel. These observations suggest the existence of minimum stress and impulse required for this twinning transformation. It seems that for medium-carbon steel the magnitude of critical stresses essential for twinning is higher than that for a low-carbon steel.

Metallographic Examination of Slugs

Copper and steel slugs[18, 19] were recovered by firing shaped charges in deep containers of water. Metallographic examination on the longitudinal and transverse planes shows that the flow of metal had an inward radial component and a component along the cone axis in a direction towards the base of the slug. The apex and the outer surface of a slug were characterized by the presence of deformed structure while the central regions showed recrystallized grains. It seems that the metal near the base of the slug reached much higher temperatures than the metal near the apex of the slug. In steel slug, a series of parallel cracks inclined at approximately 45° to the longitudinal axis are observed. In a region, where grain flow intersects a crack, the tangent to the flow line makes a smaller angle with the axis than does the tangent to the crack.

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