A NOTE ON THE FRAGMENTATION OF CONICAL 'LINERS' AND ITS RELATION TO THE THEORY OF 'SHAPED-CHARGE'—II

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1. Introduction

In a previous note (Kothari and Singh, 1953, to be referred to as I), a fragmentation-pattern on a mild steel 'witness-plate' was obtained by base detonating a 'shaped-charge' having an 'inverted' mild steel conical liner of angle 45°. The fragmentation-pattern consists of 'radial streaks' confined within a rather sharply defined annular region (*see* Fig. 2 of I). From the dimensions of the pattern, the values of velocities of collapse have been calculated, which agree (to order of magnitude) with those of Eichelberger and Pugh (1952).

In this note results for the fragmentation of 45° mild steel conical liners of different calibres and of 80° mild steel conical liner are presented. The formation of 'radial streaks' in the fragmentation-pattern is treated in some detail.

2. Experimental Work

A. Conical 'liners' of angle 45° and of different base diameters (referred to as calibre and denoted as D, thickness of liner $0{\cdot}032D$) were machined from rods of mild steel. The 'inverted' conical liner was soldered at one end of a gas pipe. The liner was snug fitted (bearing-fit) in a recess machined in a massive mild steel block (Fig. 1). High explosive (70 TNT, 30 Tetryl) was cast in the equipment. On base

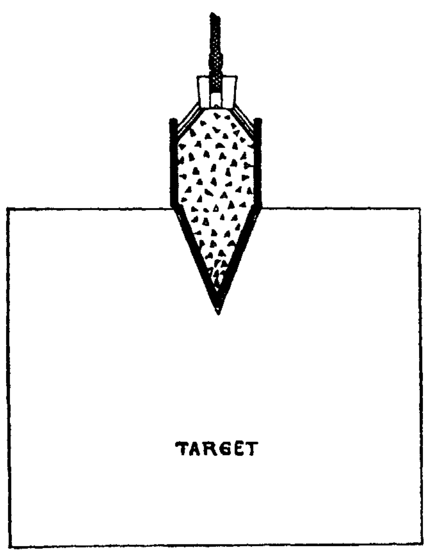

Fig. 1. Lay-out of the equipment with an inverted 45° mild steel conical liner, whichi bearing-fit in a recess machined in a mild steel block.

detonating the equipment, the recess was found to have enlarged and the liner was also recovered. The recovered liners are photographed (Fig. 2). The cracks on the surface of the recovered liners are nearly parallel to the axis of propagation of detonation and the liner splits up into wedge-shaped strips.

B. The experimental set-up was the same as described in Part I, except that the conical liner was made of two metals (half of the conical liner towards the base made of copper and the other half towards the apex of mild steel or vice versa). On base detonating the equipment, the fragmentation-pattern (Fig. 3) was obtained which consisted of two annular rings. The outer ring is formed by fragments of the metal towards the base and the inner ring by fragments of the metal towards the apex of the liner.

In another experiment, annular rings of metal were removed at predetermined places in the mild steel 'witness-plate'. On base detonating the equipment, a fragmentation-pattern (Fig. 4) was obtained.

C. The equipment having an 'inverted' conical liner (material—mild steel, calibre—2·0 in., angle—45° and thickness—0·032*D*) was detonated on a cardboard 'witness-plate' (placed one above the other and clamped together). The fragments penetrated deep into the cardboard target and the co-ordinates of the holes were as expected by the mechanism of collapse of the liner (refer Part I). In some holes, one fragment was found and its surface was dull (slight bluish tinge); in some others, many fragments were recovered from each hole and often it was possible to fit these together to form a single fragment (the broken pieces had a clean surface appearance); and in the remaining holes, many tiny (passing 14 mesh, B.S.S.) fragments were found. Some of the fragments at the periphery of the pattern penetrated as much as $3\frac{1}{2}$ in. of cardboard. The fragments were separated into different sizes and photographed (Fig. 5). The percentage recovery of fragments, i.e. total weight of fragments/weight of original conical liner was about 66%.

D. The equipments having 'inverted' conical liners (material—mild steel, angle—45° and thickness—0·032*D*) of different calibres were detonated on mild steel 'witness-plates'. The dimensions of the fragmentation-patterns indicate that the angles δ_0 and δ_1 (δ represents the angle between the collapsing liner element of the liner and normal to the original liner surface, δ_0 and δ_1 denote the value of δ for the liner element near the base and the apex of the liner respectively) are 9·4° and 4·4° respectively and are independent of the calibre within the experimental error.

E. The equipment having an 'inverted' conical liner (material—mild steel, calibre—3·0 in., angle—80° and thickness—0·096 in.) was detonated on a mild steel 'witness-plate' (distance of the base of the liner from the witness-plate = 4·5 in.). A typical fragmentation-pattern, which consists of a ring is shown in Fig. 6. The metal in the ring is scooped out in a radial direction and each radial streak has got a scaly appearance. The calculated values of δ_0 and δ_1 are 9·7° and 8·4°.

3. Discussions

A. In the experiments described in section (A) above, on base detonating the equipment, there takes place a plastic expansion of the cone material but the expansion of the cone is retarded by the mild steel block. In the recovered conical liners, there are cracks which are nearly parallel to the axis of propagation of detonation. We assume, that in case of those experiments, where we get a fragmentation-pattern on a mild steel 'witness-plate', the material of the cone undergoes plastic expansion and the cracks appear parallel to the axis of propagation of the detonation wave and thus the liner splits up into many wedge-shaped strips.* On further

* Dr. S. Paterson (1954) also suggested in a personal communication to Professor D. S. Kothari that the radial streaks are cut by wedge-shaped strips of the conical liner.

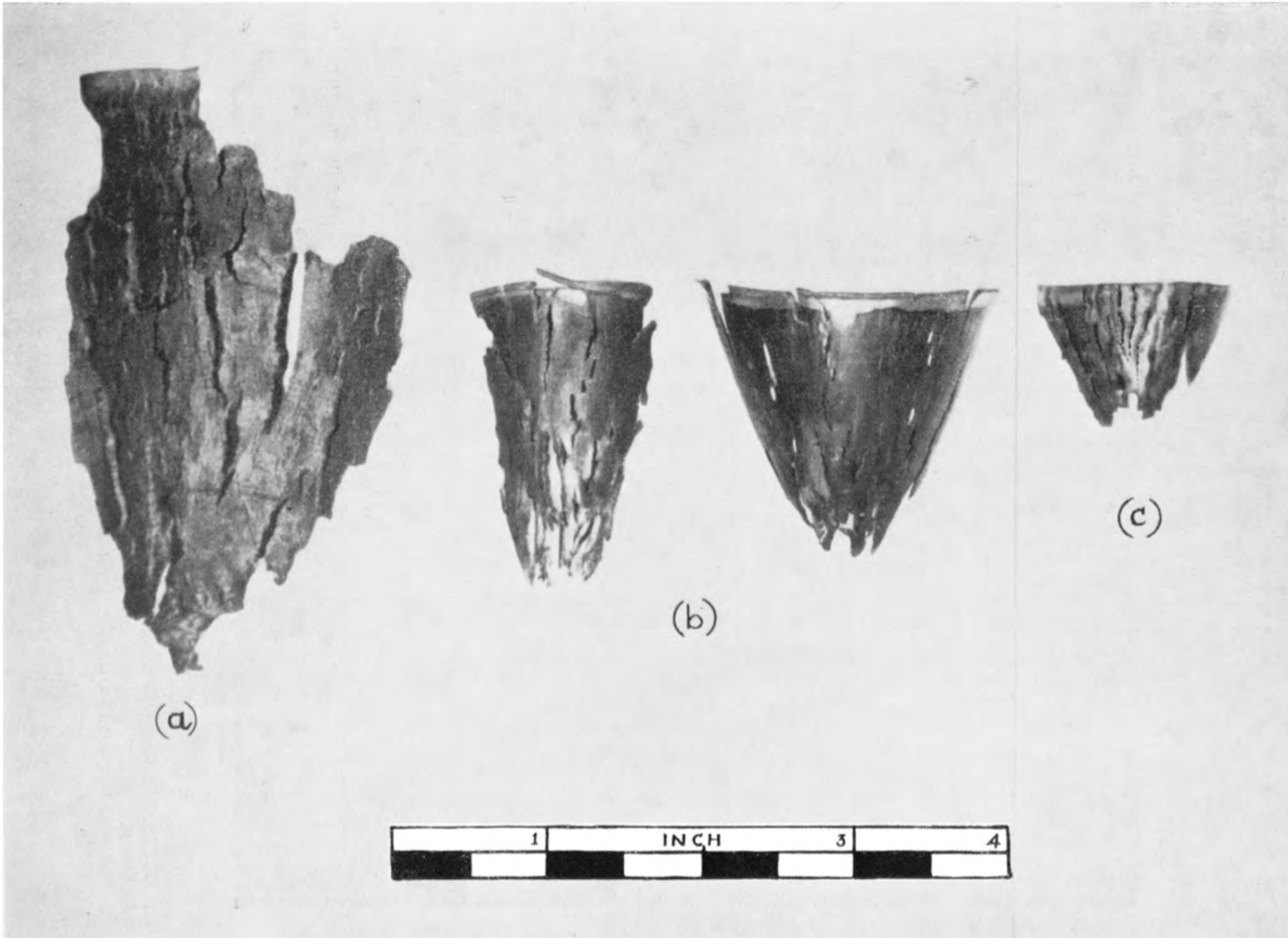

FIG. 2. Photograph of the recovered conical liners after firings showing the cracks nearly parallel to to the axis of propagation of detonation. Outside base diameter of the conical liners before firings are (*a*) 3 in., (*b*) 1½ in., and (*c*) 1 in.

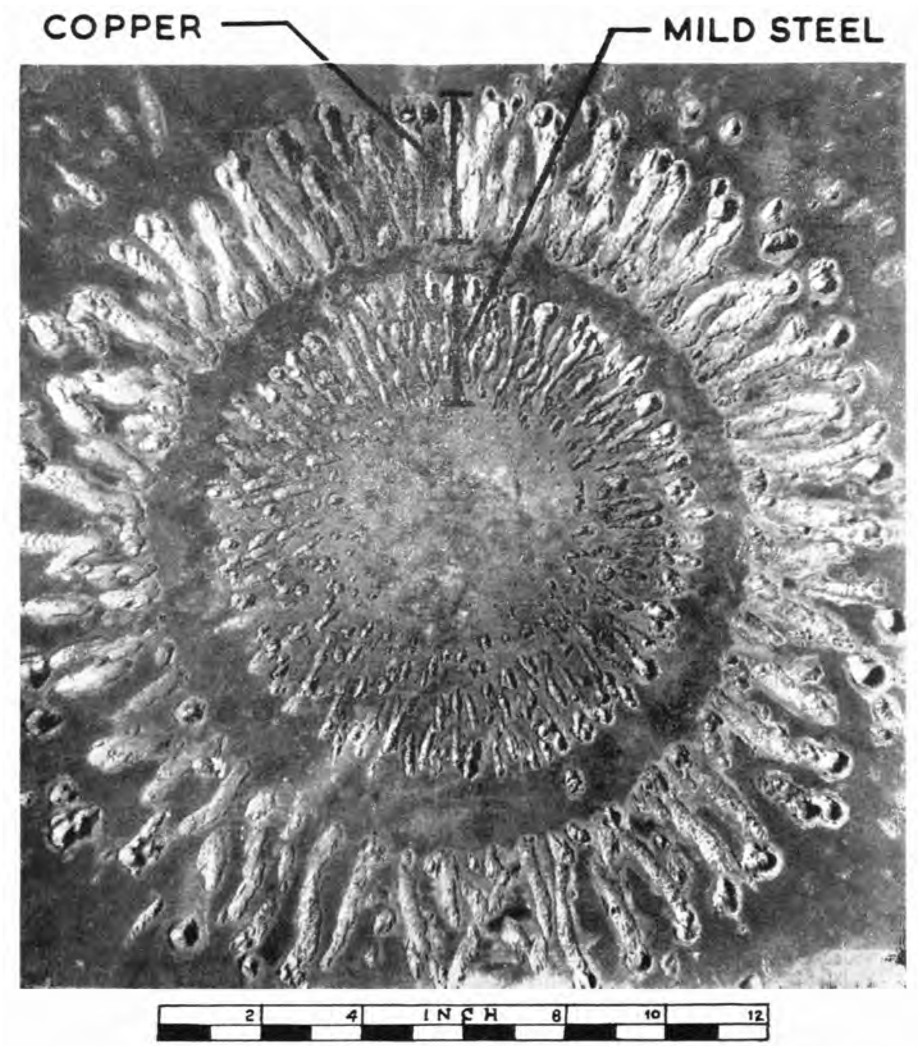

FIG. 3. Typical fragmentation-pattern on a mild steel 'witness-plate' by detonating a 'shaped-charge' having an inverted bi-metallic conical liner (half of the conical liner towards the base made of copper and the other half towards the apex made of mild steel).

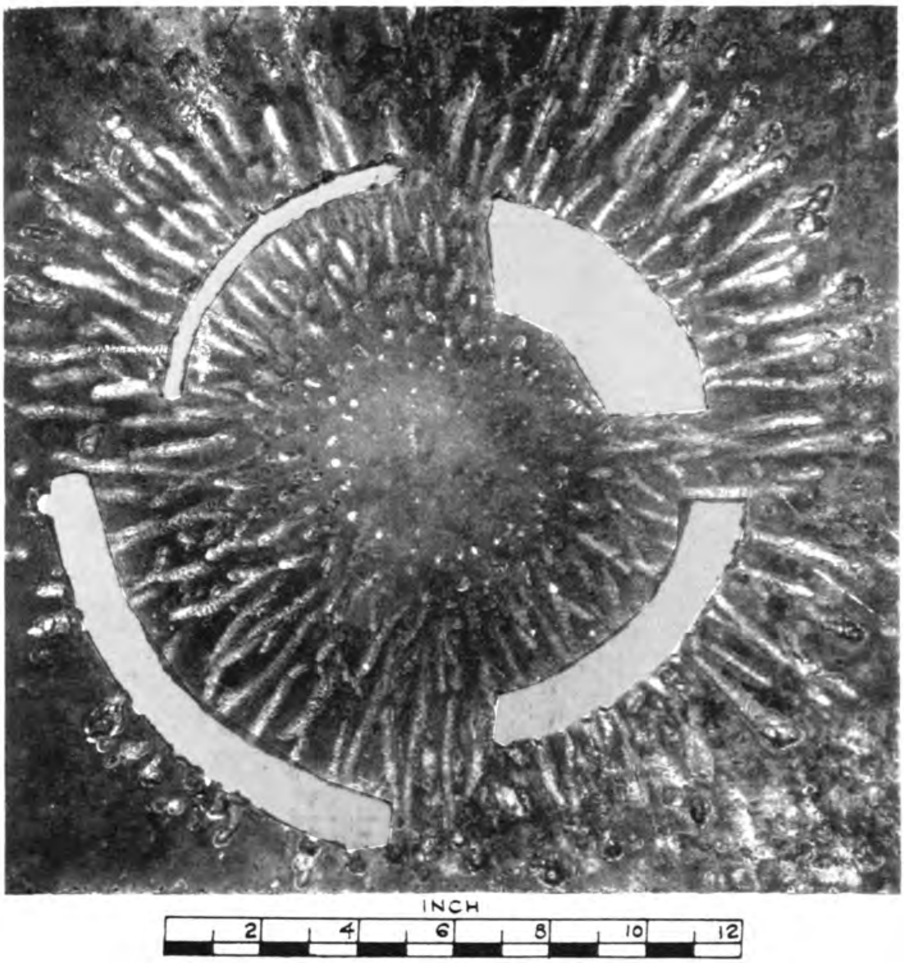

Fig. 4. Typical fragmentation-pattern on a mild steel 'witness-plate' (four annular quarter rings of metal were removed from the witness-plate before the firing).

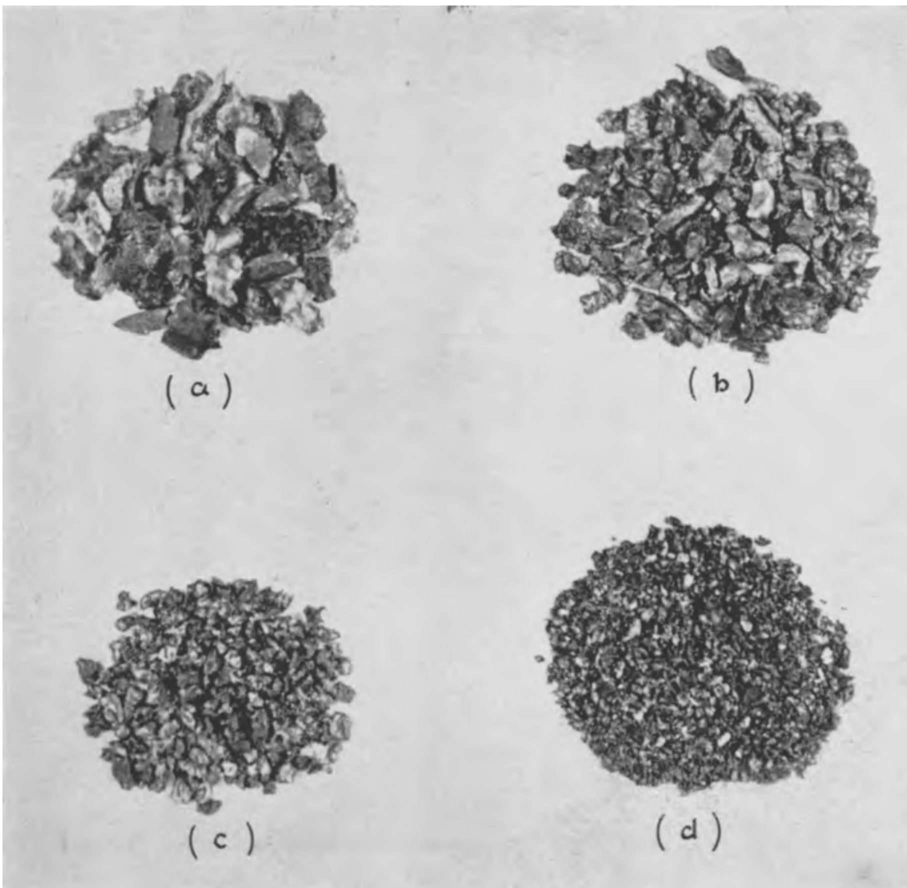

FIG. 5. Fragments collected on a 'witness-plate' of cardboard.

(*a*) 11·3% (mean wt. of a fragment = 0·12 gm.)
(*b*) 28·8% (mean wt. of a fragment = 0·02 gm.)
(*c*) 6·3% (retained on 14 mesh, B.S.S.)
(*d*) 19·9% (passing 14 mesh, B.S.S.)

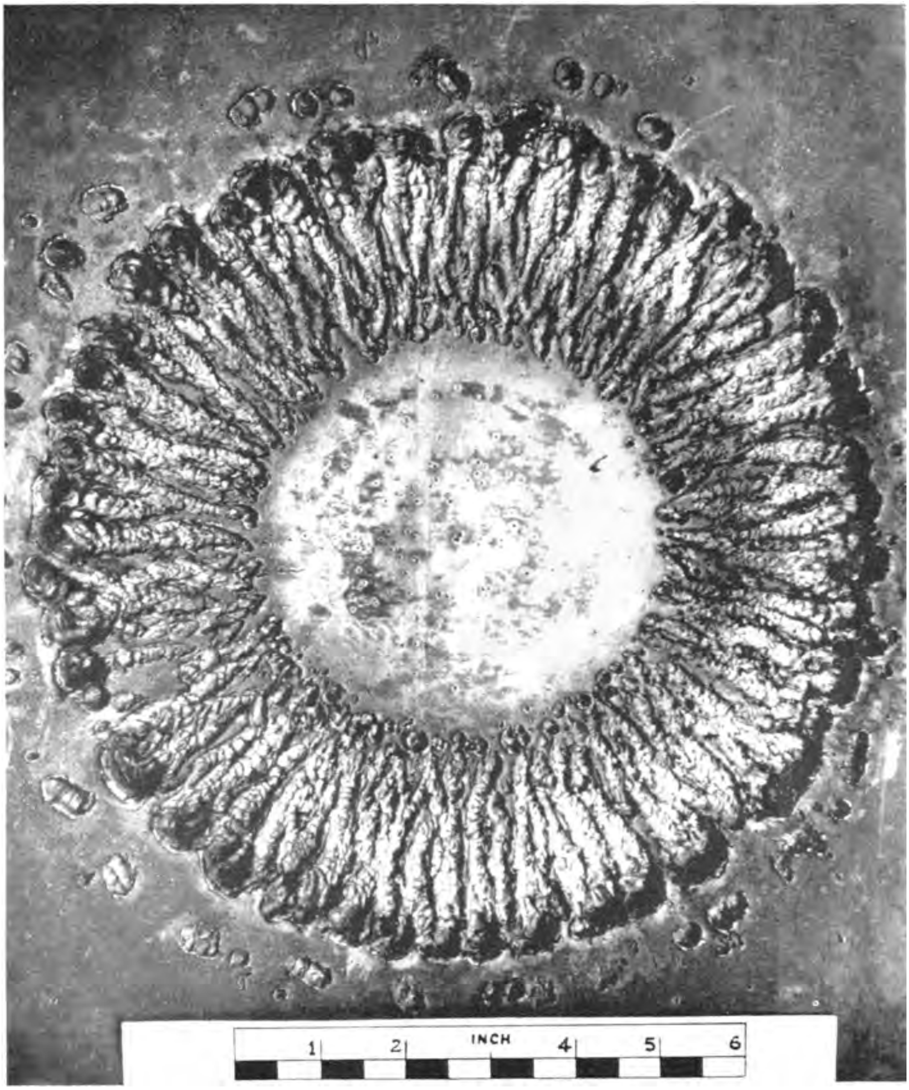

FIG. 6. Typical fragmentation-pattern on a mild steel 'witness-plate' by firing a 80° mild steel conical liner.

expansion, each strip fragments and as such on striking a mild steel 'witness-plate' forms a fragmentation-pattern having the scooping of the metal in a radial direction. As the detonation wave takes a finite time to travel from the base of the liner to the apex, so the fragments arising from the base of the liner start first as compared to that from the apex.

B. The experiments indicate that the outer and the inner circumferences of the ring are due to the impact of fragments from the metal near the base and the apex of the liner respectively. The fragmentation-pattern (Fig. 4) indicates that by cutting a slot in the centre of the ring, the travel of radial streaks cannot be stopped and that adjacent fragments do not affect each other appreciably so far as their impact on witness plate is taken into consideration. This also indicates that the velocity with which a fragment travels is also independent of the velocities of the neighbouring elements.

C. The experiments on the collection of fragments on a cardboard 'witness-plate' indicate that there are two types of fragments. In such cases, where only one fragment is found at the bottom of a hole and the surface is dull (slight bluish tinge) the fragment is denoted as a 'primary fragment'. Obviously the primary fragments arise by the breaking of the liner when the explosive detonates. In those cases where many fragments are recovered from one hole and their clean surfaces can be joined to form a single fragment, the fragments are denoted as 'secondary fragments'. Obviously a single fragment after striking a cardboard target and/or while penetrating the target breaks into many fragments. It is these tiny fragments, which strike the mild steel 'witness-plate' at a tremendous velocity (of the order of 2 to 3 km./sec.) that produce a fragmentation-pattern.

Pearson and Rinehart (1952) recovered the fragments of low-carbon steel cylinders, which were internally loaded with explosive charges. The authors have not published the experimental details of the method of recovery of fragments and also have not discussed the two types of fragments, i.e. 'primary' and 'secondary'.

D. The experiments on firings of 45° mild steel 'inverted' conical liners indicate that the velocities of collapse of the base and the apex of the liner are 2·5 and 1·2 km./sec. respectively and are independent of calibre.

E. The experiments on firings of 80° mild steel 'inverted' conical liners indicate that the velocities of collapse of the base and the apex of the liner are 3·1 and 2·7 km./sec. respectively.

F. The possible bearing of the results on the theory of 'shaped-charge' is that the velocities of collapse are independent of the calibre. Let β represent the half angle of collapse, i.e. the angle which the collapsing liner makes with the axis of the equipment. Let β_0 denote the value of β for the liner element near the apex of the liner (in 'shaped-charges', subscript 0 and I refer to the apex and the base of liner respectively). We assume that

$$\beta_0 = \alpha + 2\delta_0.$$

This indicates that β_0 is also independent of the calibre. The author (1953) has given an explicit expression for the length of jet. It has been shown that the minimum length of jet depends on calibre, δ_0, δ_1 and β_0. As the angles δ_0, δ_1 and β_0 are independent of calibre, therefore the minimum length of jet when fully formed is directly proportional to the calibre of the equipment. The depth of penetration by a jet into a given target depends upon its length and density. The interesting conclusion is that, to a first approximation, in 'shaped-charges' lined with 45° conical liners, the penetration and the calibre are linearly related. The theoretical calculations indicate that in case of 45° and 80° mild steel conical liners, the minimum timings for the complete formation of jets (that is, the time for the detonation wave to travel from the apex to the base of the liner plus the time for the element at the base of the liner to reach the axis) are $6{\cdot}5D$ and $3{\cdot}7D$ μ sec. (where D is in cm.); and the minimum lengths of the jets are $3D$ and $1D$, respectively. This also indicates that the penetration by a jet from 45° mild steel conical liner will be greater than that of 80° conical liner. The author (1954) has shown that in 'shaped-charges', the penetration and calibre are linearly related and 45° conical liners give greater penetration than that of 80° liner.

4. Summary

The results presented above can be partly summarised as follows:

(i) The metal of the conical liner first fragments into wedge-shaped strips, which further fragment and give rise to 'radial streaks'. The outer and the inner circumferences of the ring are due to the impact of fragments from the metal near the base and the apex of the liner respectively.

(ii) The collection of fragments on a cardboard 'witness-plate' indicate that there are two types of fragments—'primary' and 'secondary'. 'Primary fragments' arise by the breaking of the liner when the explosive detonates. A 'primary fragment' after striking a cardboard target and/or while penetrating the target breaks up into many fragments, which are denoted as 'secondary fragments'.

(iii) The possible bearing of the results on 'shaped-charges' is that the length of jet is proportional to the calibre and the minimum length of jet by 45° conical liner is more than that of 80° conical liner.

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Abstract

Recently Kothari and Singh (1953) obtained a fragmentation-pattern by base detonating a 'shaped-charge' having an 'inverted' conical liner. The fragmentation of 45° conical liners of different calibres and of 80° conical liner is described, and the possible bearing of the results on the theory of 'shaped-charge' is presented. The formation of 'radial streaks' in the fragmentation-pattern is also described.

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