SOME DESIGN AND FUNCTIONAL ASPECTS OF SQUASH HEAD SHELL

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ABSTRACT

The important factors affecting the design of a HESH shell have been discussed, with special reference to the nature of explosive filling, effect of spread of filling, problems of fuze design and angle and velocity of impact.

Introduction

Of the three common anti-tank weapons—Kinetic energy projectile (AP shot), hollow charge shell (HEAT) and squash head (HESH), the last has some distinctive advantages over the other two types. Unlike the solid Kinetic energy shot and HEAT, the efficiency of HESH is practically unaffected over a very wide range of angle of attack. The perforative efficiency of the HEAT is also affected by spin; the thickness of armour which can be penetrated by a rotated HEAT shell is about half the static penetration obtainable with the same shell. The best performance of a hollow charge shell is, therefore, obtainable when it is fin-stabilized. As fin-stabilized projectiles are less accurate than the spin-stabilized ones, the chance of hitting a tank with the former is comparatively less, particularly at ranges over 1000 yds.; this is further aggravated by a severe limitation on chamber pressure (and hence the muzzle velocity) imposed by the low design strength of the fins. The performance of the HESH, on the other hand, is practically independent of the angular velocity of the shell and hence its design characteristics can be kept practically the same as that of an ordinary High Explosive (HE) shell, thus ensuring a high initial velocity of projection, which combined with spin-stabilization, yields a higher probability of hitting upto the maximum operational range. Apart from defeating the tank-armour, the structural damages caused by the HESH are much more severe than the other two types of anti-tank projectiles. It is these characteristics which have enabled the HESH to gain such quick popularity during the post-war period and it is now considered as the most versatile anti-tank weapon by most of the countries of the world.

Functional aspects

The HESH is a high capacity (20% or higher), base fuzed HE shell which defeats the armour by scabbing unless the armour is too thin, in which case the HESH blows a large hole in it. The mechanism of scabbing is illustrated in Fig. 1. On impact with the armour, a certain portion of the thinner walls at the nose of the shell is squashed longitudinally so as to facilitate rapid spreading of the explosive filling. The base fuze is designed in such a way as to initiate detonation only when the spread of explosive is optimum. The detonation of the squashed charge causes only a shallow depression on the front face of the plate and at the same time sets out a compression wave through the plate material. The compression wave is reflected off the rear face of the plate as a wave of tension, the characteristic scabbing occurring over the reflecting area only when the intensity of the tension wave is higher than the tensile strength of the plate. Insufficient intensity of the tension wave due to the squashed charge being below the required optimum, would only result in a bulge or in an undetached scab.

The details about the optimum thickness of the squashed explosive charge which is essential for scabbing a particular thickness of armour can be derived from trials in which the explosive plaster is formed on the plate by hand and then detonated statically. Charge thickness above this optimum value results in the blowing of a hole instead of scabbing. The area of the squashed charge is also an important factor and the results of static trials show that there is a critical area for each thickness of plate below which the plate is not scabbed, although the thickness of the plaster charge is the optimum required for the particular armour thickness. Areas of charge larger than this critical minimum produces bigger scabs. Results of limited static trials, conducted at Armament Research and Development Establishment (ARDE) Kirkee, show that the area of the scab is about one and a half times the area of the squashed charge and its weight is proportional to the square or somewhat lower power of the area of the static charge. In order to establish a definite functional relationship between the weight of scab and area of charge, the data from a larger number of trials involving various thickness of armour are required to be analyzed. Although such functional relationship would provide a useful indication of the expected performance of a HESH shell of given calibre, the actual performance under dynamic conditions is expected to be different. This is because the conditions under which the explosive plaster is formed, vary at different angles of attack and at the different striking velocities obtainable at different ranges.

Design for optimum results

Some dynamic trials carried out (by ARDE, Kirkee) with modified 25 Pr. Base Ejection (BE) Smoke shell filled to the nose have shown the tendency of the filling to explode when it is nipped between the plate and the nose of the shell during the initial stages of impact. Such premature initiation of the explosive charge causes only a circular depression on the front face of the plate without any effect on the rear face. The provision of a padding or cushion of inert material (like coal-tar pitch) at the nose followed by the explosive filling, is expected to prevent such premature initiation. But the exact effect of this inert material on the performance efficiency of the HESH shell, has to be studied in future trials arranged for this purpose.

On the basis of the scanty data available from reports of trials carried out in other countries and a limited number carried out by us, an analysis will now be made of the various factors which are likely to affect the design of a HESH shell—

(*a*) *Nature of Explosive filling*—

Plastic explosives (PE) have been found to produce the most satisfactory effect. But this type of filling presents difficulties under mass filling conditions and because of their semifluid nature, they may affect the stability of the shell, particularly under tropical conditions of firing. To overcome this difficulty, various other explosives were tried and RDX/Beeswax 91/9 (RDX/BWX 91/9) was found to be a suitable substitute. The scabbing efficiency of RDX/BWX is, however, slightly inferior to PE, in that it produced a deeper but smaller diameter scab but the break-up of the scab into fragments is quite satisfactory.

(b) *Effect of spread of filling*—

Results of experiments carried out by the Road Research Laboratory in the UK show that the damage done by a plaster charge cannot be appreciably increased by increasing the depth of charge in contact with the plate unless the diameter of the squashed charge is over $\frac{3}{4}$ of the shell diameter. Spread of a lesser degree would produce a small deep scab broken into small fragments. When the filling is forced out along the surface of the plate, thereby increasing the area of the plaster charge, the scab would also widen in diameter but a point will be reached where the outer edge of the spreading plaster will be too dispersed to carry the compression wave efficiently. There is thus a limit to the amount of explosive which can be employed usefully and when this limit is reached it will produce a wide scab, broken in one or two pieces and projected with a velocity of 300 feet per second (F.S.) or higher.

(c) *Problems of fuze design*—

Ideally, the base fuze should initiate the plaster charge exactly when the spread has reached the optimum and before it can spread further. But it is difficult to achieve this ideal, since this time varies in the same weapon at different ranges and at different angles of attack. Hence we have to choose a representative average value of delay for the base fuze so as to achieve the best performance over a wide range of conditions. The present indications are that a base fuze giving a delay in the range of 0·5—1·5 milli-second should give satisfactory performance over a wide range of conditions. As it is not possible to get such short delays by the incorporation of any delay composition, it has to be achieved mechanically by appropriate adjustment of the striker travel and spring strength. Available results of trials with different fuze designs show that the striker travel is not very important unless it exceeds a ciritical maximum of about 0·50 inch. Fuzes with striker travel lying between 0·25—0·50 inch is expected to meet the requirement of a satisfactory base fuze for HESH shell.

(d) *Angle of impact*—

Irrespective of the orientation of the shell, the shock wave emanating from the plaster charge will enter the armour approximately at normal. Hence the angle of attack does not affect the performance of the HESH shell directly but it may bring in the following indirect effects:—

(i) At high angle of incidence, the shell may turn away after crushing some distance on to the plate. Under these conditions, the maximum angle at which a scab could be obtained is expected to increase with velocity because the higher forward energy of shell and filling would cause it to crush further on to the plate before turning away, thus ensuring greater spread of the filling.

(*ii*) At high angle attack, the filling will have a tendency to move along the slope, thus causing uneven spread round the shell.

(*iii*) The projection of the cross-section of the shell crushed on the plate increases with increasing angle of attack. Due to this higher cross-section, the remaining portion of the filling in the shell, which provides a large part of the total energy, is used more efficiently. This is why the performance of the HESH shell is found to be the best within the zone of 30° to 50° attack. But at angle of incidence higher than 50°, the break-up of the shell becomes rather irregular and the chance of lodging of a part of the shell body between the explosive and the plate increases, thus interfering with the propagation of shock waves. The performance of HESH shell is, therefore, expected to fall off at angles of incidence higher than 50°.

(*e*) *Velocity of impact*—

Unlike AP Shot, the performance of HESH remains practically unaffected over a wide range of velocities except, as pointed out before, for the improvement in performance with higher velocities at large angles of incidence. The main advantage of having a shell with the highest possible velocity lies in its increased probability of hitting. There will, of course, come a point with any particular fuze when the striking velocity is too high or the delay obtainable from the fuze is too short (fuze delay inversely proportional to striking velocity) and hence the fuze, under such conditions, will set off the filling before it can spread to the optimum required.

(*f*) *Shape of head*—

The optimum head shape for any particular design has to be determined by a process of trial and error. The head should be provided with a weaker section so as to facilitate collapse of the shell body and spread of the filling before the base is sufficiently retarded to operate the fuze. If the head is too strong, the shell may burst as a whole without any spread of the filling.

Conclusion

From the foregoing discussions, it is quite clear that among other factors, the important parameters affecting the satisfactory design of a HESH shell are the length of the weaker section at the nose (Say 'D' of Fig. 1) which is to be carefully adjusted to ensure optimum spread and the fuze delay (t) to allow for the squashing of this weaker section. The length D is to be determined from analysis of post-impact phenomena and is to be carefully chosen, since a higher value of D would not keep the fuze intact upto the moment of firing. Once this length D has been fixed, the optimum fuze delay to realize efficient scabbing with a shell of striking velocity V is given by D/V. Thus for best performance the delay (t) obtainable with a particular fuze of given striker travel and spring strength is given by $t = D/V$. The design of shell and fuze based on these preliminary estimates may have to be slightly adjusted on the basis of the data obtained at different stages of firing trials before the designs are finalised.

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