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# Analysis of Normal Penetration of Ogive - Nose Projectiles into Thin Metallic Plates

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***Abstract*—**In this note, a theoretical model for analyzing of normal penetration of the ogive – nose projectile into metallic targets is presented .The failure is assumed to be asymmetry petalling and the analysis is performed by using the energy balance and work done .The work done consist of the work required for plastic deformation $W_p$, the work for transferring the matter to new position $W_d$ and the work for bending of the petals $W_b$. In several studies, it has been shown that we can neglect the loss of energy by temperature.

In this present study, in first, by assuming the crater formation after perforation, the value of work done is calculated during the normal penetration of conical projectiles into thin metallic targets. Then the value of residual velocity and ballistic limit of the projectile is predicated by using the energy balance. In final, theoretical and experimental results is compared.

***Keywords*—**Ogive Projectile, normal impact, penetration, thin metallic target.

## I. Introduction

THE study of the impact of projectiles on thin plates has long been of interest, and several studies on the subject are available in literature. Comprehensive surveys on the subject have been published by Backman and Goldsmith [1], Corbett et al. [2] and Goldsmith [3] which discusses various features of the phenomenon involved.

Most of the experimental impact studies on thin plates in sub-ordnance velocity range were carried out for d/h ratio up to 10 [4-10].

Calder and Goldsmith [4] investigated experimentally penetration the 12.5 mm diameter spherical or cylindro-conical projectiles at a velocity range of 25 to 300 m/s on 1.25mm thick plate. They proposed a simplified model for penetration of rigid-plastic linear work hardening material. They found that the simplifications they made for modeling of perforation phenomena, introduced incorrectness of results at low velocity impact, whereas, the results matched the experimental data at higher impact velocities.

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Corran et al. [5] investigated the effect of projectile mass, nose shape and hardness on penetration of steel and aluminum alloy plates. Blunt and cylindro-conical projectiles of 12.5 mm diameter, were impacted on plates of 1.3 to 5.9 mm thickness in the velocity range of 50 to 250 m/s. The mass of the projectile was varied from 15 to 100 g. They observed that ballistic limit of the plate changes with change of projectile mass and nose shape.

Levy and Goldsmith [6] investigated penetration three nose shapes viz. blunt, spherical and conical on 1.27 and 3.175mm thick aluminum plates and 1.2mm thick mild steel plates in just below and above the ballistic limit. They measured impact load, permanent deflection and strain. The measured peak force and plate deflection of aluminum plate below the ballistic limit shows a good correlation with the values predicted by the model [7] but in the case of mild steel plates, the results show discrepancy.

Petalling is the dominant phenomenon in thin aluminum plates when struck by ogive-nosed or cylindro-conical projectiles at sub-ordnance velocities. Landkof and Goldsmith [8] carried out a theoretical and experimental investigation of petalling of thin metallic plates impacted by cylindro-conical projectiles. A model considering initial crack propagation, plastic hinge motion up to the root of the crack, and petal bending due to hinge rotation is presented. Their model had Good correlation with experimental results that was carried out wherein 12.7mm diameter cylindro-conical projectiles were impacted on 3.175mm thick aluminum plates, between the experimental and theoretical residual velocities except near ballistic limit.

An experimental investigation of normal and oblique impact of a spinning armour piercing projectile of core diameter 6.2 mm, on aluminum, mild steel and RHA steel plates of 6 to 40mm thicknesses were carried out by Gupta and Madhu [9,10]. Residual velocity, velocity drop and crater dimensions were measured. Simple models based on the experimental results were proposed for residual velocity, velocity drop, ballistic limit and critical ricochet angle.

Goldsmith and Finnegan [11] carried out an experimental program of normal impact of cylindro-conical and blunt cylindrical projectiles of 12.7mm diameter, on aluminum and steel plates at the velocity range of 20 to 1025 m/s. Projectiles of hard steel and soft aluminum were used in the study. Velocity drop during perforation was measured and metallurgical examination of the target damage was carried out on selected plates.

N.K. Gupta and al. [12] investigated experimentally penetration ogive nosed projectiles into thin single and two layers aluminum plates.

Pol and Liaghat [13-15] presented a analytical method to estimate residual velocity and ballistic limit for penetration cylindro-conical projectiles into thin metallic targets with assumption petalling failure mode under oblique impact.

In this present study, by assuming the crater formation and petalling, the value of work done in penetration is calculated during the oblique penetration of the ogive nosed projectiles into thin metallic targets.

The work done in penetration consist of the work required for plastic deformation $W_p$, the work for transferring the matter to new position $W_d$ and the work for bending of the petals $W_b$ . In several studies [16, 17], it has been shown that we can neglect the loss of energy by temperature (friction).

In final, theoretical results is compared with experimental results and theoretical results others investigators.

## II. Analysis

The experimental observation shows that the primary mode of failures in a Thin metallic plate are yielding and petalling in the contact region along with dishing in rest part of the plate, when impacted by ogive nosed projectile. Thus, the total deformation of the plate may be divided into two types of deformation.

1. Deformation of the plate in the contact region of the plate and projectile.
2. Deformation of the plate in remaining part of the plate.

In several studies [8], it has been shown that we can neglect the loss of energy by temperature (friction) and crack propagation. Although this loss of energy isn't important in speeds very higher than ballistic speed, ($V_i << V_r$), but in speeds near to ballistic limit is considerable.

The first kind of deformation is the yielding and formation of petals in the distal side of the thin plates. So, it is reasonable to assume this type of deformation as formation of a crater of diameter equal to the diameter of projectile at the centre of the plate (see Fig. 1).

By considering the Figure (1), the following assumptions can be developed:

1-The only important stress in crater, is circumferential stress, $\sigma_\theta$, and $\sigma_z$ , $\sigma_r$ are equal to zero.

2- The relationship between stress and strain of the target material is as linear hardening $\sigma = Y + \gamma\ \varepsilon$ and the failure is occurred in $\sigma = Y$.

3- Plastic deformation is occurred in constant volume.

The formula to generate of a tangent ogive cone is (fig. 2):

$$r = \sqrt{\left(d\left(C^2 + \frac{1}{4}\right)\right)^2 - (L - x)^2} - \left(d\left(C^2 - \frac{1}{4}\right)\right) \tag{1}$$

A simpler approximation formula to generate a tangent ogive nose is:

$$r = \frac{x}{C} - \frac{x^2}{2L.C} \tag{2}$$

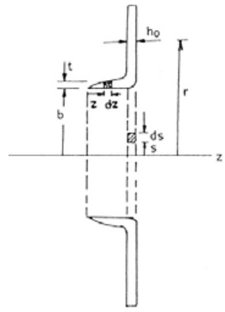


Fig. 1. Crater of diameter equal to the diameter of the projectile

Where x, r are coordinates, x being along the length of the nose, and r being the height (or radius) of the nose taken from the centerline of the nose. The caliber of the nose of projectile is C=L/d.

Where: L=nose length and d=nose base diameter.

The work done in penetration consist of the required work for plastic deformation $W_p$, the work for transferring the matter to new position $W_d$ ,the work for bending of the petals $W_b$ [15].

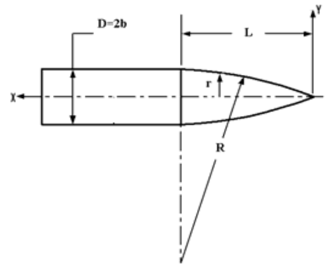


Fig. 2. Ogive osne- projectile

Work done in plastic deformation, $W_p$, for conical and ogive projectiles [2] is,

$$W_p = \frac{\pi}{2} b^2 Y h_0 \tag{3}$$

The work done in transferring the matter to new position or dynamic work done, $W_d$ , is,

$$W_d = \int_0^b F dr \tag{4}$$

Where F is accelerative force. With considering total of mass replaced, m, after time t, as

$$m = \pi \rho h_0 r^2 \tag{5}$$

F will be

$$F = \frac{d}{dt}\left(m\frac{dr}{dt}\right) = m\frac{d^2r}{dt^2} + \frac{dm}{dt}.\frac{dr}{dt} \tag{6}$$

Where r is instantaneous radius projectile. With substitute (2), (5) and (6) in (4),

$$W_d = \frac{2\pi\rho V_0^2 b^4 h_0^2}{3L^2} \tag{7}$$

In Final, Work done in bending of petals estimate by work done in bending of perfect plastic beam with length equal to circumference a circle with radius b (B=2πb), thickness $h_0$, and yield strength Y, during bending equal to π/2. Therefore:

$$W_b = M_p \cdot \theta_p \quad ; \quad \theta_p = \frac{\pi}{2} \quad ; \quad M_p = \frac{YBh_0^2}{4} \tag{8}$$

Therefore

$$W_b = \frac{\pi^2 b h_0^2 Y}{4} \tag{9}$$

The total work done during penetration is equal to:

$$W = W_p + W_d + W_b \tag{10}$$

Therefore:

$$W = W_i - W_r = \frac{1}{2} M \left(V_i^2 - V_r^2\right) \tag{11}$$

Or:

$$V_r = \left(V_i^2 - \frac{2W}{M}\right)^{\frac{1}{2}} \tag{12}$$

If $V_r = 0$, the ballistic limit will be computed.

$$V_b = \left(\frac{2W}{M}\right)^{\frac{1}{2}} \tag{13}$$

## III. Conclusion

The present study is concerned with the response of thin plates to the normal impact of a projectile.In the present theory, by estimating the absorbed energy during normal penetration of ogive projectile into thin metallic targets, ballistic limit, and residual speed can be computed.

The analytical model results were compared with empirical results presented in reference [12].According [12], the plates employed were cut out of commercial purity aluminum (~99%) sheets of thicknesses 0.5, 0.74, 1.0, 1.5 and 2.0 mm. Circular targets of 255 mm total diameter with 205 mm diameter free span were made from these plates and used in as received condition. The projectile were essentially ogive nosed hardened steel with 2.0 caliber radius head, 15mm diameter, 30 mm total length and 55.0 gr. Mass. Strength of the target materials were shown in table 1.

The values of the residual velocity calculated from analytical model presented in this paper and measured experimentally according [12] for 15mm diameter projectile are plotted against impact velocity in Fig. 3 for aluminum plates of all thicknesses employed. The residual velocity increases with increase of impact velocity for each plate. This increase is rapid near the ballistic limit and later the curve tends to become parallel to the asymptote of unit slope.

Results from analytical model are seen to match the empirical results very well except in initial speed near ballistic limit that work done in dashing is significant.

TABLE I
TENSILE STENGTH OF THE ALUMINUM PLATES OF DIFFERENT THICKNESS

| PLATE THICKNESS (MM) | 0.2% OFFSET YIELD STRENGTH (MPA) | ULTIMATE TENSILE STRENGTH (MPA) |
|---|---|---|
| 0.5 | 120 | 125 |
| 0.74 | 130 | 134 |
| 1 | 124 | 130 |
| 1.5 | 115 | 120 |
| 2 | 120 | 126 |

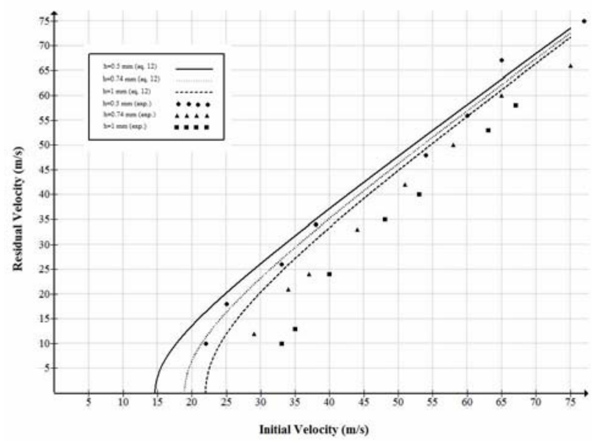


Fig. 3. Residual velocity vis. Intial velocity of projectile

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