RESPONSE OF THIN ALUMINUM PLATES TO PROJECTILE IMPACT

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Summary Experiments and numerical simulations were carried out to study the mechanics of deformation and failure of thin aluminium plates subjected to projectile impact and influence thereon of their layering,projectile shape and angle of impact. Results reveal that their failure mode, deformation and ballistic limit are influenced by the projectile nose shape. Effect of obliquity is insignificant for low angles of incidence but becomes increasingly significant as the angle is increased.

INTRODUCTION

The effect of target layering has been studied by various investigators (e.g.see Corran et al. [1], Dey et al. [2], Teng and Wierzbicki [3], Gupta etal. [4]) and found to have significant effect on the ballistic resistance, depending on the mode of deformation (shearing, petalling, membrane stretching) and relative material strength of the individual layers. The angle of obliquity has also been found to have significant effect on the ballistic limit in the previous studies such as Goldsmith and Finnegan [5], Gupta and Madhu [6]. The phenomenon of interest include the effect on ballistic resistance, projectile path during penetration or perforation, ricochet and critical conditions. The authors have carried out a series of experimental and numerical studies on normal and oblique impact of single and layered thin aluminum plates and based on results obtained we present in this paper some features of the mechanics of deformation and failure of thin aluminum plates subjected to projectile impact and influence thereon of the layering of plates, projectile shape and angle of impact.

EXPERIMENTAL INVESTIGATION

Experiments were carried out with the help of a pneumatic gun wherein 1100-H12 aluminum alloy plates of diameter 255 mm were hit by hardened steel projectiles of 19 mm diameter and 52.5 grams mass. To study the effect of target configuration 1 mm thick single and double layered in contact and spaced plates with layer thickness of 0.5 mm were hit by blunt and ogive nosed projectiles.
To study the effect of angle of incidence 1 mm thick monolithic targets were impacted by ogive nosed projectiles at 0˚, 15˚, 30˚ and 45˚ obliquity and then till ballistic limit was obtained.

NUMERICAL INVESTIGATION

Three-dimensional numerical simulations were carried out using ABAQUS/Explicit finite element code. The effect of configuration was studied with 1 mm thick monolithic, double layered in contact and spaced target with 0.5 mm each layer thickness. The spacing between layers was also varied as 2 mm, 5 mm, 10 mm, 20 mm and 30 mm. Angles of incidence studied were 0º, 15º, 30º, 45º and 60º or until the occurrence of ricochet. The typical finite element model of the projectile and target and material parameters may be seen in Iqbal et al. [7]. Projectile was modeled as rigid and the target as a deformable body. To model the spaced target a predefined spacing was given between both the layers. The contact between the projectile and target was modeled using kinematic contact algorithm and the contacting surfaces of layered in-contact as well as spaced target by general contact algorithm of ABAQUS-6.7-3 [8], and contact of projectile with both the layers was assigned. A coefficient of friction of 0.5 was assigned between the contacting surfaces of layered in-contact target. In case of oblique impact the exact contact region was not known therefore a larger portion of the target was considered as the contacting surface. The target was restrained at its periphery with respect to all degrees of freedom. Eight node brick elements (C3D8R) were used in all simulations. Based on mesh convergence study, it was decided to mesh the monolithic target with 6 elements and each layer in layered with 3 elements over their thicknesses. The aspect ratio of the elements was kept unity in the influenced region, which increased with increase in target obliquity. Therefore a total number of 278616, 354816, 390480, 446760 and 454720 elements were taken in 1-mm-thick aluminum target impacted at 0°, 15°, 30°, 45°, and 60° obliquity, respectively.

CONSTITUTIVE MODELING

The material behavior of 1100-H12 aluminum target was incorporated in the numerical simulations usingJohnson-Cook elasto-viscoplastic material model [9-10]. The equivalent von-Mises stress $\overline{\sigma}$ of the Johnson-Cook model is expressed as;

$$\overline{\sigma}(\bar{\varepsilon}^{pl},\dot{\bar{\varepsilon}}^{pl},\hat{T}) = \left[A + B(\bar{\varepsilon}^{pl})^{n}\right]\left[1 + C\ln\left(\frac{\dot{\bar{\varepsilon}}^{pl}}{\dot{\varepsilon}_0}\right)\right]\left[1 - \hat{T}^{m}\right], \qquad (1)$$

where A, B, n, C and m are material parameters. $\bar{\varepsilon}^{pl}$ is equivalent plastic strain, $\dot{\bar{\varepsilon}}^{pl}$ is equivalent plastic strain rate, $\dot{\varepsilon}_0$ is a reference strain rate and $\hat{T}$ is non-dimensional temperature defined as;

$$\hat{T} = (T - T_0)/(T_{melt} - T_0) \qquad T_0 \le T \le T_{melt} \qquad (2)$$

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where T is the current temperature, T_{melt} is the melting temperature and T_0 is the room temperature. The fracture model proposed by Johnson-Cook [10] takes into account the effect of stress triaxiality, strain rate and temperature on the equivalent fracture strain. The equivalent fracture strain $\bar{\varepsilon}^{pl}{}_f$is expressed as;

$$\bar{\varepsilon}^{pl}{}_f\left(\frac{\sigma_m}{\bar{\sigma}}, \dot{\bar{\varepsilon}}^{pl}, \hat{T}\right) = \left[D_1 + D_2\exp\left(D_3\frac{\sigma_m}{\bar{\sigma}}\right)\right]\left[1 + D_4\ln\left(\frac{\dot{\bar{\varepsilon}}^{pl}}{\dot{\varepsilon}_0}\right)\right]\left[1 + D_5\hat{T}\right], \quad (3)$$

where$D_1 - D_5$ are material parameters, $\frac{\sigma_m}{\bar{\sigma}}$ is the stress tri-axiality ratio and σ_m is the mean stress. The detail of the material model as well as the identification procedure of the material parameters is mentioned in our earlier study Gupta et al. [11].

RESULTS AND DISCUSSION

Experimental and numerical results of residual velocity and for both projectile shapes and their angles of ricochet matched reasonably well. The blunt nosed projectile caused the failure of layered in contact target through shear plugging while the ogive nosed projectile through ductile hole enlargement and petal formation, A consistent increase in the ballistic limit was observed with an increase in angle of obliquity. The failure mode of the target was also found to be affected by angle of obliquity. Under normal impact, a circular hole of diameter equal to that of the projectile was formed along with four equal petals. In the case of oblique impact the hole is elliptic and the four petals are unequal in size. The size of upper two petals decreased and that of the lower two petals increased with increase in obliquity, Fig. 1.

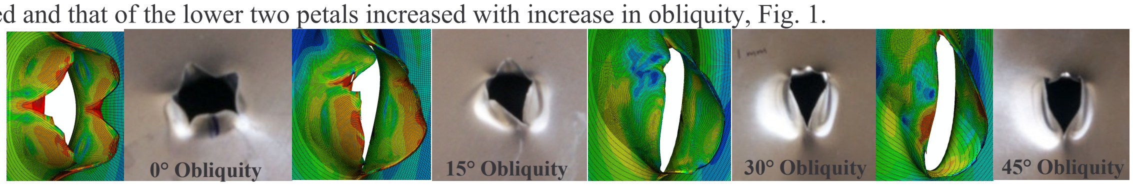

Fig. 1Observed and predicted failure modes of 1 mm thick monolithic target at different obliquity

Both the projectiles experienced highest ballistic limit against monolithic target followed by layered in-contact and layered spaced target respectively. For ogive nosed projectile the ballistic limit of monolithic target was found to be 17.7% and 25.8% higher than that of the double layered in-contact and 2 mm spaced target respectively. The ballistic limit of layered in-contact target was found to be 7% higher than that of the 2 mm spaced target. The ballistic limit of spaced target remained almost similar with variation in spacing. For blunt nosed projectile, the ballistic limit of monolithic target was found to be 2.7% and 8% higher than double layered in-contact and 2 mm spaced target respectively. The ballistic limit of layered in-contact target was found to be 5.2% higher than that of the 2 mm spaced target while, the ballistic limit of 2 mm spaced target was found to be 0.9%, 1.2%, 6.6% and 6.6% higher than 5 mm, 10 mm, 20 mm and 30 mm spaced target respectively.

The numerical results of varying obliquity predicted the deviation of projectile from its central axis away from the plate normal while entering the target and towards the plate normal while leaving the target. The deviation increased (in both the directions, i.e., away as well as towards the plate normal) with an increase in target obliquity and decrease in impact velocity.The Critical ricochet of the ogive nosed projectile occurred between 42°-60° angles of obliquity in the considered velocity regime. Due to very high obliquity the projectile deviated significantly from its central axis and therefore it could not perforate the target. However, it slid over the front surface of the target, deformed it significantly and finally rebounded back. The critical angle of ricochet was found to increase with impact velocity.

CONCLUSIONS

The effect of target configuration, angle of incidence and projectile nose shape was studied on the ballistic limit through experiments and three dimensional numerical simulations. The monolithic target was found to offer highest ballistic limit followed by layered in contact and spaced target. The effect of variation of spacing between the layers was found to be more prominent for blunt nosed projectile. The angle of incidence affected failure mode as well as the ballistic limit of the target.

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