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Influence of Target Convexity and Concavity on the Ballistic Limit of Thin Aluminum Plate against by Sharp Nosed Projectile

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Abstract

This paper presents a three-dimensional finite element analysis of thin aluminum shell subjected to sharp nosed projectile impact. Numerical simulations were carried out with the help of ABAQUS/Explicit finite element code. To investigate the influence of convexity and concavity of the target on ballistic resistance 1mm thick target shell curvature angle was varied as infinite (plate), 30°, 60°, 90°, 120°, 150° and 180°. The curvature length was kept constant as 255 mm. The 1100-H12 aluminum target was hit by 19 mm diameter and 50.8 mm length ogive nosed projectile. For each case the target was struck normally at axisymmetric axis by ogive nosed projectile to obtain the influence of curvature on ballistic resistance of the target. The convexity and concavity of the target affected the ballistic resistance in a highly significant way. Convexity increases the ballistic resistance where as the concavity reduces the ballistic resistance compared to flat plate. The highest ballistic limit was found for 90 degree convex shell where as the least ballistic resistance was found for 90 degree concave shell.

Keywords: Concavity, Convexity, Sharp nosed projectile, ABAQUS.

1. Introduction

The field of Impact Dynamics covers a number of problems from different disciplines such as production engineering (blanking and hole-flanging processes) military scientists (ballistics) geologists (remote seismic monitoring and surveying) and vehicle manufacturers. Design of metal shields for protection against projectiles impact has long been of interest in military and civilian applications. Penetration and perforation related problems have been studied for a long time, and substantial efforts have been made by experimental, numerical and theoretical investigations in order to understand the phenomena occurring in the target impacted by projectile. When a single plate is replaced by curved shell (concave or convex) its ballistic resistance changes significantly. Although there were a number of studies dealing with the ballistic behavior of monolithic plates, but their scope was limited when compared to studies of curved plates.

A large number of studies are available to address the mechanics of deformation and ballistic resistance [4,5] of thin metallic plates. The influence of various parameters like projectile shape [7,8,15], incidence angle [15,17] and target configuration [5,6,9,10,18] has been significantly studied. Palomby and Stronge [1] investigate the failure mode of thin plates and shells against blunt nosed projectile and found it as a combination of plugging due to high shear stress and discing due to tensile stress. Shariati and Allahbakhsh [2] analyzed the post-buckling behavior of thin-walled semi-spherical shells against different types of loading. Various vertical compression loadings were applied by a rigid flat plate and rigid bars with circular, square and spherical cross sections. The effects of diameter and thickness on buckling load were studied. Gupta and Gupta [3] reported an experimental and computational analysis of the deformation behavior of the metallic spherical shells subjected to axial compression. Axial compression of aluminum spherical shells of R/t values ranging from 26 to 45 was performed between two parallel platens. Effects of different process parameters on the deformation behavior of the shells were presented.

2. Constitutive Model

A metal plate subjected to projectile impact is a very complex phenomenon due to yielding, plastic flow, isotropic strain hardening, strain rate hardening, softening due to adiabatic heating and damage. Johnson–Cook elasto-viscoplastic constitutive model [12, 13] that considers the all above effect of linear thermo-elasticity, is used to simulate the material behavior of 1100-H12 aluminum.

The equivalent von-Mises stress for the Johnson–Cook model is expressed in the following form;

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

while the failure strain is expressed by

$$\bar{\varepsilon}^{pl}(\frac{\sigma_m}{\bar{\sigma}}, \dot{\bar{\varepsilon}}^{pl}, \hat{T}) = [D_1 + D_2\exp(D_3\frac{\sigma_m}{\bar{\sigma}})][1 + D_4\ln(\frac{\dot{\bar{\varepsilon}}^{pl}}{\dot{\varepsilon}_0})][1 + D_5\hat{T}] \tag{2}$$

$$\hat{T} = (T - T_0)/(T_M - T_0) \tag{3}$$

where

T = current temperature,

T_0 = the room temperature

T_M = melting temperature

A= quasi–static yield stress

B = hardening constant

C = strain rate sensitivity parameter

$\bar{\varepsilon}^{pl}$ =equivalent plastic strain

$\dot{\varepsilon}_0$ = reference strain rate

$\frac{\sigma_m}{\bar{\sigma}}$ =stress tri-axiality ratio

n = hardening exponent,

m = temperature sensitivity parameter.

$\dot{\bar{\varepsilon}}^{pl}$ = equivalent plastic strain rate,

D_1–D_5= material parameters

σ_m = mean stress.

Table 1: Material parameters for 1100-H12 aluminium target.

Modulus of Elasticity, E (N/mm^2)	65762
Poison's Ratio, v	0.3
Density, ρ (kg/m^3)	2700
Yield Stress, A (N/mm^2)	148.361
B (N/mm^2)	345.513
n	0.183
Reference Strain Rate, $\acute{\varepsilon}_0$ (s^{-1})	1.0
C	0.001
m	0.859
T_{melt}(K)	893
T_0 (K)	293
Specific Heat, C_p(J/kg-K)	920
Inelastic heat fraction, α	0.9
D_1	0.071
D_2	1.248
D_3	-1.142
D_4	0.0097
D_5	0.0

3. Numerical Investigation

The present study is based on the numerical investigation of ballistic resistance of curved targets. 1100-H12 aluminum targets of 1 mm thickness were impacted by ogive nosed projectiles of 19 mm diameter and 52.5 grams mass. Three-dimensional finite element model of the projectile and target was made using ABAQUS/CAE. Projectile was modeled as rigid whereas the target was modeled as a deformable body. The contact between the projectile and target was modeled using kinematic contact algorithm of ABAQUS-6.7-3 [11]. Outer surface of the projectile was modeled as the master surface and the contact region of the target as node based slave surface. Frictional effects were not considered between the target and projectile due to small target thickness. The target was restrained at its periphery with respect to all degrees of freedom. Eight node brick elements with reduced integration (C3D8R) were used in all the simulations carried out in this study.

4. Results and Discussion

The results of present study were shown in table 1 and table 2 in terms of impact and residual velocities for different concave and convex thin shells against ogive nosed projectile respectively. Table 1 shows the maximum decrease in ballistic resistance for 90 degree concave shells where as maximum increase in ballistic resistance were found for 90 degree convex shells, see Table 2.

Table 1: Numerical results for different concave thin shells.

Target thickness=1mm, Curvature Span=255mm, Ogive Nosed projectile [Mass=52.5 g, Diameter=19mm]							
	Numerical Results for different target curvature						
Impact Velocity (m/s)	0°	30°	60°	90°	120°	150°	180°
	Residual Velocity (m/s)						
112.7	95.3	99.7	100	101	101	101	101
65.8	26.6	41.8	43	43.2	43.9	41.7	42.5
57.2	0.0	-	18.3	20.8	22.8	20.7	19.7
51.2		12.6	15.3	15.5	14.5	12.9	5.20
50.7		-	-	-	-	11.2	0.00
50.5		6.1	8.6	10.0	-	-	
50.0		0.0	-	-	5.1	0.0	
49.5			0.0	3.2	0.0		
49.0				0.0			

Table 2: Numerical results for different convex thin shells.

Target thickness=1mm, Curvature Span=255mm, Ogive Nosed projectile [Mass=52.5 g, Diameter=19mm]							
	Numerical Results for different target curvature						
Impact Velocity (m/s)	0°	30°	60°	90°	120°	150°	180°
	Residual Velocity (m/s)						
112.7	95.4	92.8	85.9	84.8	78.0	86.8	77.6
97.2	77.3	68.6	48.4	47.1	42.2	66.2	48.4
87.0	-	40.9	15.2	12.5	32.7	-	40.2
86.5	-	-	5.0	0.0	-	-	-
85.8	-	-	0.0		26.2	-	-
85.3	-	-			20.2	-	-
85.0	-	19.1			0.0	-	38.2
83.0	59.0	4.2			-	40.1	35.6
81.9	57.6	0.0				38.5	27.2

73.3	44.5					28.1	15.5
72.0	-					-	0.0
65.8	26.7					6.6	-
57.3	0.0					0.0	

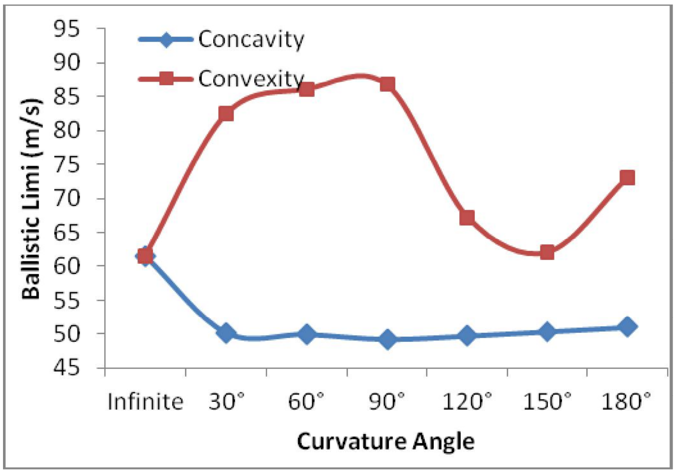

Fig. 1: Variation in Ballistic Limit with curvature angle for convex and concave she.

Fig. 1 shows the variation in ballistic limit with curvature angle. It shows for each curvature angle the convex shell has more ballistic resistance compared to concave shell. The failure of concave shells is dominated by tensile stresses whereas for convex shells compressive stresses dominated the failure mechanism which results the increase and decrease in ballistic resistance respectively. The highest ballistic resistance was found for 90 degree convex shells amongst all convex shells whereas among concave shells the lowest ballistic resistance was found for 90 degree concave shell among all concave shells.

5. Conclusion

The influence of target convexity and concavity were investigated for 1mm thick 1100-H12 aluminum shells hit by ogive nosed projectile. The curvature angle of shells were varied as 0°, 30°, 60°, 90°, 120°, 150° and 180° keeping constant curvature length as 255 mm. The 90° concave and convex shell was found to be most effective for decrease and increase in ballistic resistance. The ballistic limit was found to be 61.5, 50.2, 50,49.25, 49.75, 50.37 and 51.014 m/s for 0°, 30°, 60°, 90°, 120°, 150° and 180° concave shells whereas for convex shells the same was varied as 61.57,82.4, 86.12, 86.7, 67.19, 62 and 73 m/s for mm 0°, 30°, 60°, 90°, 120°, 150° and 180° convex shells respectively.

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