HIGH SPEED IMPACT OF SPHERICAL PROJECTILES ON STEEL PLATES

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by

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CERTIFICATE

This is to certify that the thesis entitled "**High speed impact of spherical projectiles on steel plates"** by *Mr. Pranab Kumar Pradhan* has been prepared under our supervision and has attained a standard required for a Ph. D. degree of the Institute. The thesis is a record of bonafied research work carried out by him and its contents have not been submitted to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

The study of impact-perforation phenomena on steel plates resulting due to the high speed impact of rigid projectiles are of interest in the field of military, civil and space applications. This deals with the understanding of the mechanics of penetration cum perforation and non-perforation of the projectiles through the target plates. The perforation potential of the projectile depends upon several parameters namely the mechanical properties of the projectile and target plate material, projectile shape and its mass, the impact velocity, the obliquity of impact and target plate thickness. The resulting macro phenomena due to impact-perforation are found to be studied in terms of i) residual velocity, ii) ballistic limit velocity, iii) projectile velocity drop, iv) projectile momentum loss, v) absorbed kinetic energy by the plate, vi) permanent plate deflection and vii) crater / hole diameter on the plate. Literature indicates that such studies are carried out through the analytical, experimental and numerical methods for large size projectiles. However, research papers on impact of small projectiles impacting on metal plates are not many. Thus, the purpose of the present research is to study the macro impact-perforation parameters for various projectile-target plate combinations. The chosen projectile is rigid sphere and target plate is of ductile mild steel (MS). Investigations are carried out through experimental methods, numerical methods, analytical and empirical models. These methods are used towards studying the above described parameters.

In experiments, initially the studies are carried out to evolve the experimental setup, the test methodology and the instrumentation setup. The primary concern is the measurement of high velocity for the small projectiles in absence of high speed camera. The test methodology is validated with the aid of ballistic kinematics for spherical projectiles. The projectile motion is modeled as two degrees of freedom system and the aerodynamic data of the sphere is used to predict the projectile velocity at the velocity measurement locations. With this scheme, the projectile impact and residual velocities are determined at the location of target plate with satisfactory accuracy. Impact tests were then conducted for the i) monolithic MS plates of thickness 2.5, 4.0, 5.0, 8.0 and 10.0 mm and ii) multilayer MS plates of equivalent thickness of 5.0, 7.5 and 10.0 mm respectively. Projectile in experiments is a steel sphere of diameter of 10mm and the size of each target plate is of 300mm x 300mm.

In numerical studies, AUTODYN software is used for predicting the impact-perforation parameters (namely residual velocity, ballistic limit velocity and plate deflections) for the monolithic MS plates of thickness of 2.5, 4.0, 5.0, 8.0 and 10.0 mm. Initially, the numerical modeling methodology is validated with the experimental results for 4mm thick MS plate. Subsequently, three different rigid spherical projectiles 5.0, 8.0 and 10.0 mm are considered to impact on these plates for predicting the impact-perforation parameters and determining the effect of projectile diameters on these parameters.

Apart from the above, analytical and empirical models namely Recht-Ipson model and THOR model are used to determine the ballistic limit velocity and residual velocity.

Here, only 10mm diameter projectile is considered for impacting on monolithic MS plates of thickness of 2.5, 4.0, 5.0, 8.0 and 10.0 mm.

The results obtained from all the above three methods have been discussed. In this process, the effect of i) projectile impact velocity, ii) target plate thickness (monolithic), iii) layering of plates and iv) projectile diameter on impact-perforation parameters are investigated. Based on the analysis, the empirical relations (as solutions) have been evolved for determining the residual velocity and ballistic limit velocity for the considered combinations of projectile and target plate. Here, for a given projectile curves plotted between the parameter (V_i – V_{bl}) and residual velocity are seen to be independent of plate thickness around the ballistic limit.

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NOTATIONS

a, b	Experiment constants for empirical relations
Ap	Projected area of the projectile
A	Material constant for the Johnson-Cook relation
B	Strain hardening coefficient for the Johnson-Cook relation
C	Strain rate hardening for the Johnson-Cook relation
C_d	Drag coefficient
C_1	Target material constant for THOR model
d	Projectile diameter
$d_{i=1,2,3,4}$	Hole diameter of plate at azimuth positions 0^0, 45^0 , 90^0 and 35^0
$d_{avg.}$	Average hole diameter of plate
D	Drag force
E_1	Percentage of error in projectile velocity measurement
g	Acceleration due to gravity
K	Experimental constant for the projectile shape used in THOR model
$K_{i = 1, 2, 3}$	Experimental constants for the prediction of ballistic limit velocity
l	Length of projectile
m	Projectile mass (context dependent)
m	Temperature softening constant for the Johnson-Cook relation (context dependent)
m_{pl}	Mass of plug
n	Strain hardening exponent for the Johnson-Cook relation
P	Hydrostatic pressure
R	Radius of plate
R_d	Radial distance with respect to impact point
S_{ij}	Deviatoric stress state of the material
t	Plate thickness (context dependent)
t	Time (context dependent)
t*	Plate thickness for which the incident velocity is the ballistic limit
T	Actual temperature of the material for the Johnson-Cook relation

T_0 Material at room temperature for the Johnson-Cook relation

V Projectile velocity

$V_{k=1,2,3..}$ Projectile velocity at the k^{th} location along its trajectory

V_{avg} Average project velocity

V_i Projectile impact velocity

V_r Projectile residual velocity

V_{bl} Ballistic limit velocity

$(V_r)_{avg}$ Projectile average residual velocity

x, y Reference axes system

Y Yield stress of the material

θ Flight path angle

θ_i Projectile impact angle

ρ Ambient air density

$\alpha, \beta, \gamma, \lambda$ Target material constants for THOR model

σ_{eq} Equivalent stress or flow stress of the material

$\sigma_{i,j\,=\,1,\,2,\,3}$ Principal stress components

ε^t Total strain

$\dot{\varepsilon}^t$ Total strain rate

ε^e Elastic strain

ε^p Plastic strain

$\dot{\varepsilon}^e$ Elastic strain rate

$\dot{\varepsilon}^p$ Plastic strain rate

$\varepsilon_{i,\,j\,=\,1,\,2,\,3}$ Principal strain components

Δx Spatial distance along x-axis

Δt Time elapses in covering the spatial distance Δx

ΔV_d Project file velocity drop due to plate perforation

ΔM_l Projectile momentum loss due to perforation through the plate

ΔKE Absorbed kinetic energy by the plate