Impact loading and perforation of Plates for development of armor shells – A Numerical Analysis

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Abstract-**In this paper the occurrence of failure after the interaction between the penetrator and mild steel is investigated. The focus on parameters and the types of damage envisaged. The impact was performed at a velocity ranging from 30-830 m/s and the overall numerical analysis was carried out using LS-Dyna software. The overall microstructure of the steel was under heavy impact which caused the adiabatic shear bands in the region close to the direction of penetration. Main failure observed was ductile deformation followed by cleavage after the impact. Cracks due to adiabatic shear band and formation of abrasive wear were seen during the simulation. The perforation mode of the steel was at zero degree and with different velocities from a fixed distance. Three types of damages of plate were mainly identified and the parameters influencing them like velocity and the angle of impact are discussed from the energy point of view.**

Keywords:* Impact dynamics, Perforation Analysis, failure *analysis

I. Introduction

Non-linear Finite element based contact-impact analysis is a versatile tool for predicting projectile residual velocities and its limits for impact on the plates [1]. Impact & impact related problems have been receiving considering attention as a research topic from decades, and substantial efforts has been made in order to physically understand and mathematically describe the phenomena, taking place during impact & explosion [2,3]. The similar kind of analysis is being carried out for ballistic testing of materials at laboratory level. It is not advisable to carry out the actual ballistic tests due to the complexity & cost related problems. Therefore, a general solution technique is to use FE analysis which covers the variety of non-linear ranges of response including large deformation effects and in-elastic ranges of material behavior. This paper deals with the impact phenomena on the plates and its effects with a range of impact velocities.

The radial expansion of a hole from zero diameter to diameter d in a plate thickness h. including integration constant, the work done is approximately,

$$W = p/2\ d^2\ so\ h$$

Where,

so = Effective flow stress measure of material

The penetration of the target plate will be as Fig. 1.

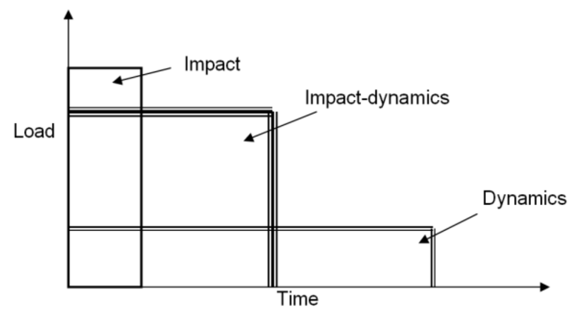

Figure 1:.Load vs. Time curves

To look into impulse response as a short term, high amplitude and highly localized non-linear effect rather relating to the system as a whole are studied. An attempt has been made to classify as local, sub-system and system effects even into the case of components. For this purpose the elemental approach was used and a brief review is presented here specific to impact.

II. Modeling

Finite element modeling of the spatial domain has to be sufficient to represent the geometry of the structure and to capture the structural response characteristics anticipated in the response. In the present analysis, the penetration of a penetrator through an MS plate is considered. The contact interaction involves normal face of the penetrator. The influence of the sliding contact along the bounding surface of the penetrator as it penetrates the plate affects the results. The model involves two main components as penetrator and the target.

A. *penetrator*

The penetrator shown in Fig. 2 is modeled using eight –node brick elements with a rigid material model (Material 20) and given an initial velocity in z-direction. The penetrator penetrates the plates with velocities ranging from 700 m/s to 830 m/s. The penetrator is made of hardened steel with a semi-spherical tip. The mechanical properties of penetrator are: Diameter: 30 mm, Length: 215 mm, Mass: 1.128 kg

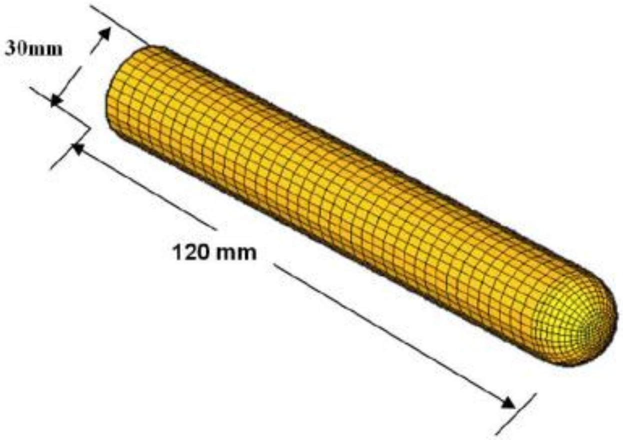

Figure 2: Penetrator with semi spherical tip

B. Target Plate

The plate is modeled using eight node brick elements with Material_Plastic_Kinematic (Material 3). Fig. 3 shows the FE model of the plate. The size of the plate is 500mm x 500 mm with thickness of 25 mm and with total 4356 elements, each having one gauss integration point through the thickness. Due to the large deformations and subsequently large plastic strains are present during the analysis, mesh becomes more and more distorted as deformation increases.

C. *Material Properties*

The material properties assigned to penetrator and plate is as given below. [6, 8]

For penetrator

Material Model: Mat_rigid (Material 20)

Young's modulus: 2.1 e 5 N/mm2

Poisson's ratio: 0.3

Mass density: 7850 kg /m3

For plate

Material Model: Mat_plastic _kinematic (Material 3)

Young's modulus: 2.1 e 5 N/mm2

Poisson's ratio: 0.3

Mass density: 7850 kg /m3

Yield strength: 250 N/mm2

Failure strain: 0.18

Hardening parameter: 1.0

Failure strain is used as the constraint value to release any tied node once the element strain reaches this level. Strain rate effects are neglected for this simulation. Kinematics, isotropic or a combination of both may be specified by varying hardening parameter b between 0 and 1 respectively kinematics and isotropic hardening are obtained. Details of material model as well as identification procedure of various material parameters are presented in Gupta [Ref 3, 4]. In general the equilibrium equation leads to,

$$\delta\pi = \int_v \rho \ddot{x}_i \delta x_i dv + \int_v \sigma_{ij} \delta x_{i,j} dv - \int_v \rho f_i \delta x_i dv - \int_{\partial b_1} t_i \delta x_i ds = 0 \quad (1)$$

The above equation is for virtual work done. [Ref 10]

Mesh of FE interconnected at nodal points on a reference configuration is superimposed and track particle through time, i.e.

$$x_i(X_\alpha, t) = x_i(X_\alpha(\xi,\eta,\zeta), t) = \sum_{j=1}^{K} \Phi_j(\xi,\eta,\zeta) x_i^j t \quad (2)$$

Where Φ j are shape (interpolation) function of the parametric co-ordinates (ξ, η, ζ) ,k

is the number of nodal points defining the element, and is the nodal co ordinate of jth node

in the ith direction

D. Contact

In the present study, the sliding interface with single surface is provided. The target

plat is considered as slave surface and restricted for all DOF. The penetrator is considered as a master surface with a sliding velocity up to 750m/s. Salient features of the contact algorithm

Contact is treated using penalty approach. Once the contact is determined, then an interface restoring force is imposed on the slave node and distributed across the nodes on the master segment. The force depends on bulk modulus, volume, the elements contains the master segment. [Ref 11]

Penetration of the target plate is simulated with element-erosion (EE) approach. With this approach, once the effective plastic strain reaches the specified critical value, the element is removed from the computation. The elements are destroyed due to very high strain rates.

When the element is eroded its kinetic energy gets lost and some mass is also lost, conservation of momentum is insured. [Ref 5]

E. Loading and Boundary conditions Boundary

Conditions are applied to the end nodes of the target plate. All DOF are restricted for plate. Boundary conditions include in-plane, out-of-plane and bending restraints.

The penetrator is provided a velocity of 830 m/s initially.

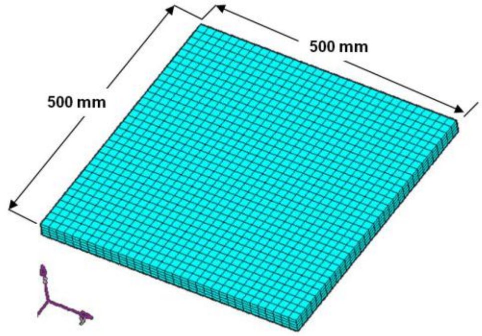

Figure 3: Target plate

III. Types of damage due to impact

Damage occurring in the plate [Ref 7, 9] due to impact of penetrator can be divided into three ways as:

Type 1: Localized shear failure damage

Type 2: Shear and bending damage in 30 to 40 % area of plate

Type 3: Overall failure resulting in a mechanism causing large deflections

A. *Localized shear failure damage*

In the case of localized damage only about 10 % of plate area in around the point of impact is found to be damaged with very low deformation, i.e. stress exceeds the yield strength of plate. Fig. 4 shows this type of damage, which usually occurs at very high velocity.

B. *Damage to the plate due to shear and bending*

Keeping all other parameters constant, and with velocity of range 300-400 m/s, it was found that the damage to plate spreads over 30-40 %in the central region around the point of impact [Ref 9]. Fig. 5 shows the damage examined in the plate with penetrator having velocity of 350 m/s.

C. *Overall failure resulting in a mechanism causing large deflections*

In the case of very low velocity compare to the other two cases, it is observed that the penetrator rebounds back without penetrating the plate [Ref 7]. Fig. 6 shows the overall failure occurred at low speed at velocity 30 m/s.

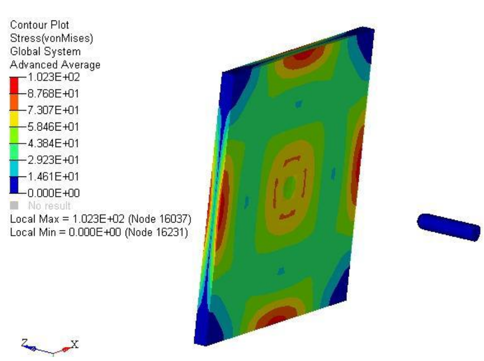

Figure 4: Initial stress generated at velocity of 750m/s

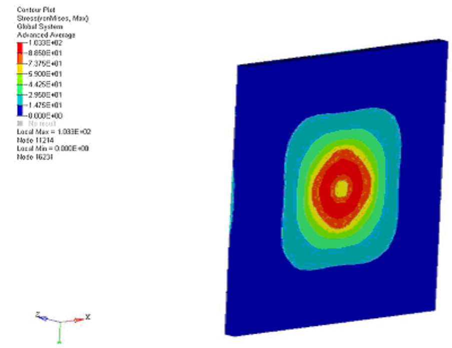

Figure 5: stress (generated at penetrator velocity of 350m/s)

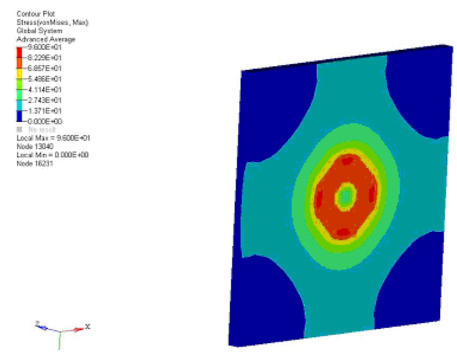

Figure 6: stress (Von Mises) generated at velocity of 30m/s (Rebound effect)

Conclusion

On the basis of simulation of all the three cases, it is observed that the penetrator does not penetrate in the plate at low velocity but it creates large deflections resulting in a rebound effect. At very high velocity, the penetrator pierces the target plate causing the petaling effect to the plate. The damage of the plate depends on the momentum of penetrator.

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