INVESTIGATIONS ON MATERIAL CASUALTY OF PLATES UNDER IMPACT LOAD CONDITIONS

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Abstract

Impact problems are typical in nature since they involve geometry, boundary and material non-linearity. The impact of projectiles at sub-ordnance velocities against mild steel, stainless steel and aluminum plates has been studied. In this paper, target plates of 3mm thickness of materials Mild steel, Titanium are made to impact by Tungsten fragment with different velocities 300, 500, 700 and 1000 mm/ms. On impact, kinetic energy and residual velocity of this fragment is plotted to visualize the damage of the respective target plate. It is observed that the element size significantly affects the numerical results. Hence a sufficiently refined mesh is used. Kinetic energy is an essential parameter to be determined in order to study damage behavior of target. Higher the kinetic energy absorption, leads to higher is the damage target. So, higher initial velocities are required for the fragment in order to create the necessary damage in the target.

Index Terms: *Projectile, Target plate, Mild steel, Tungsten, Titanium*

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1. INTRODUCTION

The response of any structural element, when subjected to dynamic (impact) loading such as projectile hitting a target is significantly different compared to its response to a static force. Dynamic strength characteristics of projectile/target undergo considerable changes due to impact. When the impact is made with high velocities, projectile and target experience plastic deformation, material failure, and increase in strength, cracks formation and propagation etc. All these effects need to be accounted in numerical simulation tools in order to get accurate representation of the actual behavior.

Simulation of penetration events requires a numerical technique that allows one body (fragment) to pass through another (target). Lot of research has gone into the study of high velocity impact behavior of projectile impact a hard target. Since the duration of the impact is of the order of 1e-4 sec to 1e-3 sec, stress wave propagation effects need to be considered in the problem.

Target damages when it is subjected to impact load by high velocities of fragment. The damage to the target depends on various factors such as:

- The geometric shape of the fragment and Target
- The geometric size of the fragment and Target
- The material of the fragment and Target
- The number of fragments hitting the target
- The velocity of the fragment
- The angle of hit with the normal direction of the target
- The thickness of target

2. FINITE ELEMENT MODELLING OF TARGET PLATE AND PROJECTILE

2.1 Geometric and Finite Element Model

Geometric and finite element modeling is done using Hyper Mesh with user profile LS-DYNA. Finite element Meshing involves dividing the physical domain into small zones called finite elements. Mesh size and element type chosen plays an important role in the accuracy of the results obtained from LS-DYNA. For the present work 103794 elements exists for the model. At impact zone fine mesh is chosen as it involves penetration of elements into other elements.

Eight noded hexahedral elements are considered for both the fragment and target with fully integrated selective reduced property. Wherever necessary, six noded pentagonal elements are used for smooth mesh.

Mesh size plays a very important role in the accuracy of the results. Choosing appropriate element type and the mesh size is utmost important. With increase in mesh quality and size, results tend to converge and stabilize. Lot of effort has gone in choosing the appropriate element type and mesh size for this impact study. The mesh was refined in the impact zone. The mesh density was reduced as the distance from the impact area increased. Care was also taken to maintain correct aspect ratio in the grid especially in and around the impact zone where the aspect ratio of the elements was maintained close to unity. The aspect ratio was allowed to increase towards the periphery of the plate. Fig.1 shows the Discretisation of geometry model

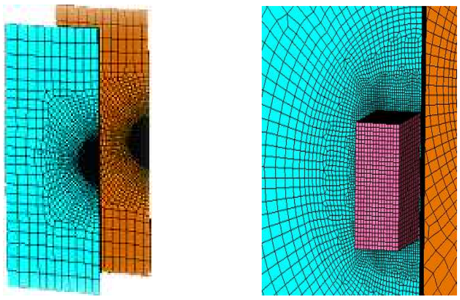

Fig.1 Discretisation of geometry model

2.2 Material Model

Because of the impact, projectile and target undergoes severe deformations, stresses and the induced stresses go beyond yield. To properly depict the projectile/target behaviour, selection of correct mathematical (material) model for the projectile/target are important. These material models depict the material flow (elastic and plastic) and stress wave propagation and strain rate effects. Since stresses cross the yield point, uniaxial stress-strain curve beyond yield and up to failure are required. Definition of material stress-strain curve plays an important role in the accuracy of the results obtained from the programme – LS-DYNA.

The projectile is assigned with AT_PLASTIC_KINEMATIC material model (available in LS-DYNA). This model is suited to model isotropic and kinematic hardening plasticity with the option of including strain rate effects. The target is assigned with MAT_PIECEWISE_LINEAR_PLASTICITY material model. This is an elasto-plastic material with an arbitrary stress versus strain curve and arbitrary strain rate dependency can be defined. Also, failure based on a plastic strain or minimum time step size can be defined. Material Properties.

The projectile is assigned with tungsten material properties. Different materials such as mild steel, Titanium alloy were considered for the target. Definition of material stress-strain curve plays an important role in the accuracy of the results obtained from the programme – LS-DYNA. Hence stress strain curves are defined for the target materials. The material properties and stress strain curves defined for the materials are shown in figures 2&3.

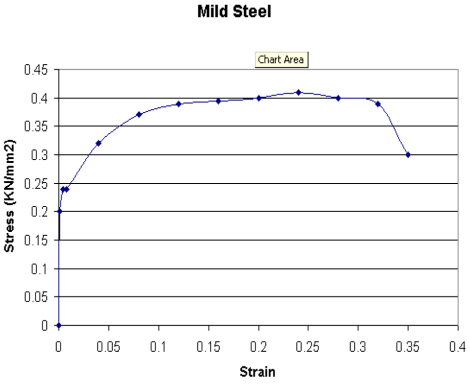

Fig 2 Stress-Strain curve for Mild steel

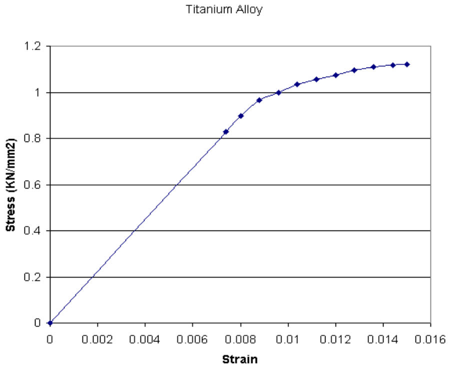

Fig 3 Stress-Strain curve for Ti alloy

2.3 Contact Definition

Contact is the only way of load transfer between the projectile and the target. Eroding surface-to-surface contact with failure is defined between the target and the projectile. The fragment was considered as the master surface and the contact surface of the target plate as the slave surface.

2.4 Loads and Boundary Conditions

Any type of service loads or mechanical loads can be applied to structure or fluid. In this case, the main load is impact pressure, generated due to projectile impact and the resulting stress wave propagation. The impact pressure is transferred to target by contact surface. Proper modeling of contact interface between the projectile and the target is critical for accurate impact load transfer.

The target is constrained in all degrees of freedom along the periphery and projectile is allowed to travel in space freely with defined velocity in a direction normal to the target. For all the solution cases presented in this report only half of the mesh is used, as shown in the figure 4, due to symmetry of the problem.

2.5 Analysis

Once all the necessary steps are completed, simulation is carried out using LS-DYNA. As stated earlier, the impact lasts for very short duration and the maximum damage to the projectile/target is observed during this period. This calls for collection of data (like impact pressure, KE (Kinetic Energy), momentum, deformation, stress, strain, etc) during this period using very small time steps. Several simulations have been carried out before the actual problem was studied. The main objective of these studies is to establish the correctness of the material model used to define the projectile/target, time step calculations, problem setup etc.

After defining all the input data, dynamic impact analysis is carried out using LS-DYNA. Various checks on input data are performed before submitting the job to LS-DYNA. Since LS-DYNA is an explicit code, the time step is determined by the program automatically to maintain the stability and convergence during the analysis.

Various results from the study are extracted and presented in the subsequent pages. Efforts are made to capture the impact data as accurately as possible for the complete cycle of simulation.

2.6 Case Studies

The similar cases for which simulation has been carried out are tabulated in 1. Simulation has been carried out for all the cases and results have been documented.

Table 1 Case studies

S. NO	FRAGMENT MATERIAL	IMPACT VELOCITY (mm/ms)	TARGET MATERIAL	TARGET PLATE THICKNESS (mm)	GAP BETWEEN TWO PLATES (mm)
1	Tungsten	300	MS + MS	3 + 3	100
2	Tungsten	500	MS + MS	3 + 3	100
3	Tungsten	700	MS + MS	3 + 3	100
4	Tungsten	1000	MS + MS	3 + 3	100
5	Tungsten	300	Ti + Ti	3 + 3	100
6	Tungsten	500	Ti + Ti	3 + 3	100
7	Tungsten	700	Ti + Ti	3 + 3	100
8	Tungsten	1000	Ti + Ti	3 + 3	100

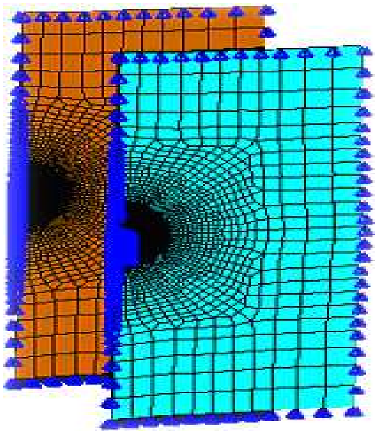

Fig 4 Finite element model with boundary conditions

3. RESULTS AND DISCUSSIONS

The following parameters are measured and discussed:

a. Velocity
b. Kinetic Energy
c. Von Mises stress
d. Effective plastic strain
e. Damage (measured in terms of hole diameter).

3.1 Target as Mild Steel

The results of first four cases are shown where a 15 mm cube shaped tungsten fragment is made to impact with wide range velocities of 300, 500, 700, 1000mm/ms onto two Mild steel target plates of size 300x300x3 mm which are separated by 100mm apart. The fragment is positioned at a distance of 0.5mm from the first target plate.

It is observed that the fragment penetrated easily through two plates by reducing its velocity and kinetic energy. The amount of damage caused by the impact of a projectile with target plate is determined primarily by the factor kinetic energy released. Table 4.1.1 shows the change in velocities and kinetic energies of the fragment after impact with two target plates.

The velocity drop and kinetic energy drop for each case is calculated. The drop is given by the difference of initial value and the value obtained after 2nd plate. Graphs are drawn between initial velocities taken as x-axis and drops taken as y-axis. Figures 5&6 show the graph plots for velocity drop and kinetic energy drop. It is found that as initial velocity of the fragment is increased both velocity drop and kinetic energy drop are increased. Hence it can conclude that for higher impact velocities more kinetic energy is transferred.

Table 2 Velocity and Kinetic energy drop

	Initial	After 1st plate (MS)	After 2nd plate (MS)
Velocity (mm/ms)	300	280.00	261.0
	500	476.25	456.0
	700	676.25	653.0
	1000	976.25	952.5
Kinetic energy (kg-mm/ms^2)	1465	1200	970
	4070	3410	2750
	7980	6800	5300
	16280	14000	11300

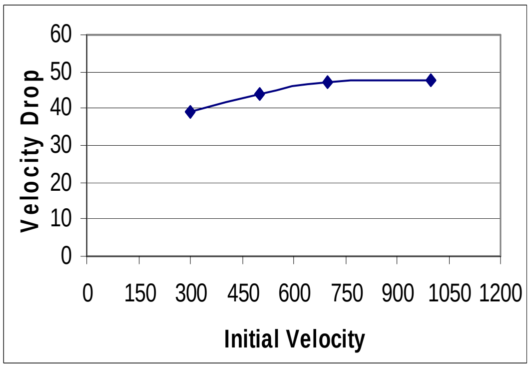

Fig 5 A schematic diagram of Initial Velocity Vs Velocity drop

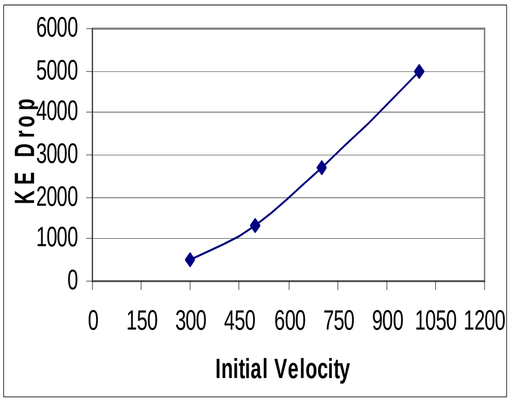

Fig 6 A schematic diagram of Initial Velocity Vs KE drop

Maximum Vonmises stress for the fragment material was found to be about 0.5516 KN/mm2. The maximum Vonmises stresses obtained for each case are tabulated. Much difference is not found when the stresses are compared for all 4 cases. Table 4.1.2 shows list of maximum Vonmises stress obtained for each case.

Table 3 Vonmises stress

Initial velocity (mm/ms)	Plate 1 (KN/mm2)	Plate 2 (KN/mm2)
300	0.4062	0.4078
500	0.4030	0.4078
700	0.4066	0.4054
1000	0.4060	0.4064

The maximum effective plastic strains for the target plates and fragment are measured and listed in the table 4 for all the above four cases but no much difference is found.

Table 4 Effective Plastic Strain

Initial velocity (mm/ms)	Plate 1	Plate 2	Fragment
300	0.3326	0.3315	0.2547
500	0.3259	0.3456	0.2747
700	0.3413	0.3323	0.2800
1000	0.3307	0.3303	0.2800

Damage of the plates due to impact is measured by means of hole diameter produced in the plates. The following table 5 shows the hole diameter produced in the target plates due to impact with fragment.

Table 5 Hole Diameter

Initial velocity (mm/ms)	Plate 1 (mm)	Plate 2 (mm)
300	15.910	15.96
500	15.975	16.46
700	16.090	16.87
1000	16.150	16.80

3.2 Target as Titanium

This is similar to section 4.1 but instead of Mild steel material, titanium material properties are assigned to both targets. The velocity and kinetic energy results were listed in the following table 6 showing the change in velocities and kinetic energies of the fragment after impact with two target plates.

The velocity drop and kinetic energy drop for each case is calculated. Graphs are drawn between initial velocities taken as x-axis and drop taken as y-axis. Figures 7 and 8 show the graph plots for velocity drop and kinetic energy drop. Similarly it is found that as initial velocity of the fragment is increased both velocity drop and kinetic energy are increased.

Table 6 Velocity and Kinetic energy drop

	Initial	After 1st plate (MS)	After 2nd plate (MS)
Velocity (mm/ms)	300	293.80	288.30
	500	492.80	485.50
	700	691.20	680.20
	1000	988.75	978.25
Kinetic energy (kg-mm/ms2)	1465	1408	1355.0
	4070	3955	3837.5
	7980	7780	7450.0
	16280	15900	15280.0

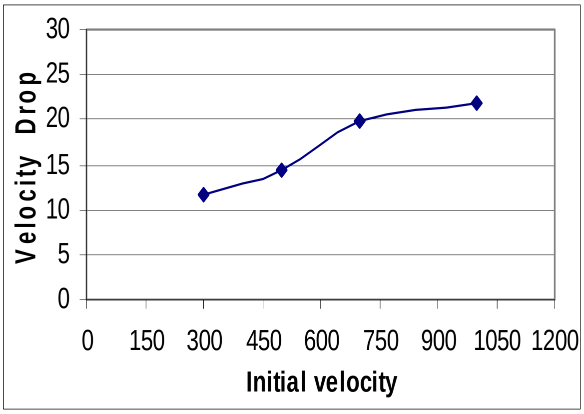

Fig 7 Plot showing Velocity drop

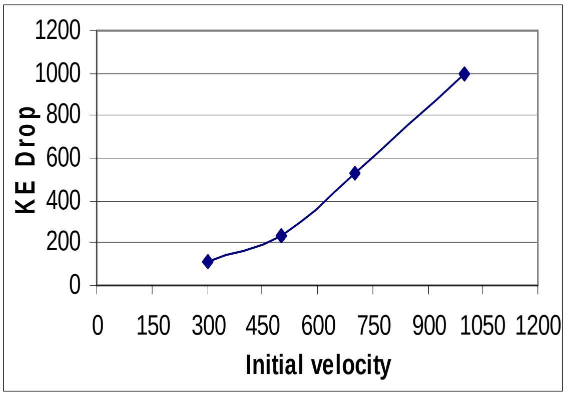

Fig 8 KE drop

Maximum Vonmises stress for the fragment material was found to be about 0.5516 KN/mm2. The maximum Vonmises stresses obtained for each case are tabulated. It is found to be increased as impact velocity is increased for this material. Table 7 shows the maximum Vonmises stress obtained for each case

Table 7 Vonmises stress

Initial velocity (mm/ms)	Plate 1 (KN/mm2)	Plate 2 (KN/mm2)
300	1.081	1.129
500	1.157	1.350
700	1.384	1.423
1000	1.818	1.643

The maximum effective plastic strains for the target plates and fragment are measured and listed in the table 8 for all the above four cases but no much difference is found.

Table 8 Effective Plastic Strain

Initial velocity (mm/ms)	Plate 1	Plate 2	Fragment
300	1.366e-2	1.294e-2	0.1925
500	1.335e-2	1.297e-2	0.2440
700	1.403e-2	1.416e-2	0.2763
1000	1.416e-2	1.324e-2	0.2826

The following table 9 shows the hole diameter produced in the target plates due to impact with fragment.

Table 9 Hole Diameter

Initial velocity (mm/ms)	Plate 1 (mm)	Plate 2 (mm)
300	15.475	15.77
500	15.385	15.77
700	15.485	15.67
1000	15.485	15.68

CONCLUSIONS

The conclusion of the present work are enumerated and presented as shown hereunder

- The deformations caused due to various impact velocities for different materials were analyzed. It has been found that velocity drop is increased as the impact velocity is increased.
- The kinetic energy drop is increased by the increment of velocity i.e. energy absorption is more for higher velocities.
- For Mild steel material velocity drop and kinetic energy drop is high compared to Tungsten and Aluminium material.
- Velocity drop is less when target plates of 3mm are used, when compared to 6mm Plates.
- More damage i.e. average hole diameter is found for

the second plate compared to first plate in all the cases.
- Effective gap was found to be about 100 mm between two target plates.The increasing order of effective plastic strain is Ti Alloy, Al Alloy, Tungsten and Mild steel.

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