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Experimental Investigations on Composite Material Casualty of Plates under Multi-Fragment Impact Load Conditions

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Abstract*— The aim of the present work is to study the damage behavior of different plate materials with different thicknesses subjected to impact loads, by using explicit finite element code LS-DYNA. Numerical simulations of the impact were conducted by using an explicit finite element code LSDYNA. In this project, target plates of 3mm and 6mm thickness of materials Titanium and Aluminum are made to impact by Tungsten fragment with different velocities 300, 500, 700 and 1000 mm/ms.To visualize the damage of the respective target plate, kinetic energy and residual velocity of this fragment is plotted on impact. It is found that the element size significantly affects the numerical results; hence a sufficiently refined mesh is used. Kinetic energy plays an important role in damage studies. As kinetic energy absorption leads to higher in the damage target, therefore higher initial velocities are required for the fragment in order to create the necessary damage in the target. In this work an attempt is made to study the residual velocity and kinetic energy of fragment is plotted for different initial velocities and energy absorption is measured.

***Index Terms*— Projectile, Target plate, Multi-Fragment impact, Tungsten, Aluminum, Titanium, Velocity drop, KE drop.**

I. INTRODUCTION

Structural impact and associated protective systems are widely developed in numerous fields, such as the energy, transport and Military industries [1].Due to impact, there will be considerable changes in the dynamic strength characteristics of projectile/target. Projectile and target experiences different phenomenon like plastic deformation, material failure, cracks formation and propagation when the impact is made with high velocities. In order to get accurate representation of the actual behavior, all these effects need to be accounted in numerical simulation tools.

LS-DYNA is a general-purpose finite element code for analyzing the large deformation dynamic response of structures including structures coupled to fluids[10]. The main solution methodology is based on explicit time integration. A contact impact algorithm allows difficult contact problems to be easily treated with heat transfer including across the contact interfaces. By a specialization of this algorithm, such interfaces can be rigidly tied to admit variable zoning without the need of mesh transition regions. Special discretization is achieved by the use of four node tetrahedron and eight node solid elements, two node beam elements, three and four node shell elements, eight node solid shell elements, truss elements, membrane elements, discrete elements and rigid bodies[12]. A variety of element formulations are available for each element type. LS-DYNA currently contains approximately one hundred constitutive models and ten equation of state to cover a wide range of material behavior. For the present work two constitutive models are chosen which exhibits strain rate effects.

The numerical simulation tool LS-DYNA greatly reduces the time and cost involved in any impact studies and physical tests[11]. These design studies help in understanding the projectile/target behavior during the impact. LS-DYNA is one such tool which predicts the behavior accurately and a great tool in the hands of engineers in optimizing the designs without the need of physical tests. It is a three dimensional analysis code for analyzing the dynamic, non-linear behavior of solid components, structures, and fluids. It uses explicit time integration techniques and incorporates features that simulate a wide range of material and nonlinear geometric capabilities.

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

II. FINITE ELEMENT MODELLING OF TARGET PLATE AND PROJECTILE

A. 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

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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[12]. 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 Discretization of geometry model

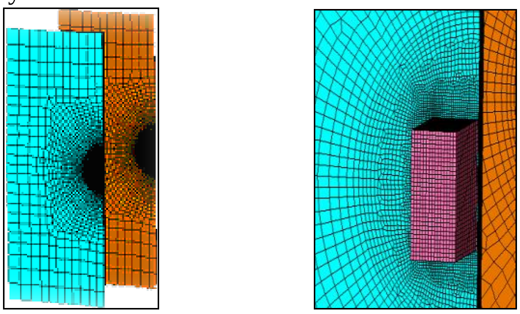

Fig.1 Discretization of geometry model

B. 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 behavior, 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 MAT_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 Titanium alloy and Aluminum 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 [8]. 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.

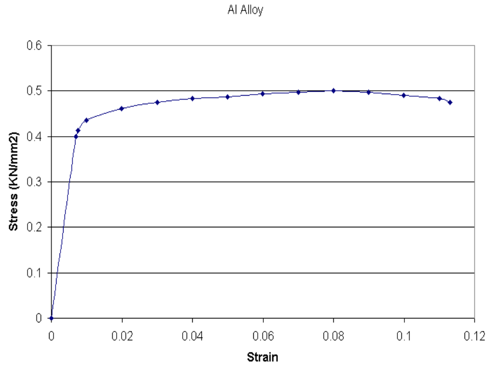

Fig.2 Stress-Strain curve for Al alloy

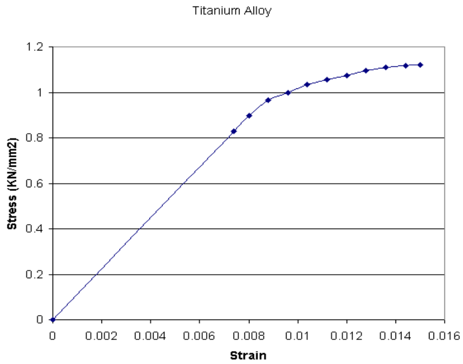

Fig.3 Stress-Strain curve for Ti alloy

C. 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.

D. 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.

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E. 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.

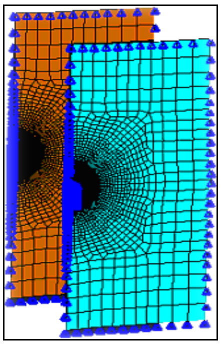

Fig.4 Finite element model with boundary conditions

Table 1 Case studies

	FRAGMENT MATERIAL	IMPACT VELOCITY (mm/ms)	TARGET MATERIAL	TARGET PLATE THICKNESS (mm)	GAP BETWEEN TWO PLATES (mm)
1	Tungsten	300	Ti + Al	3 + 3	100
2	Tungsten	700	Ti + Al	3 + 3	100
3	Tungsten	1000	Ti + Al	3 + 3	100
4	Tungsten	300	Ti + Al	6 + 6	100
5	Tungsten	700	Ti + Al	6 + 6	100
6	Tungsten	1000	Ti + Al	6 + 6	100
7	Tungsten	700	Ti + Ti	3 + 3	50
8	Tungsten	700	Ti + Ti	3 + 3	150
9	Tungsten	700	Ti + Ti	3 + 3	200
10	Tungsten	700	Ti + Ti	3 + 3	250
11	Tungsten	700	Ti + Ti	3 + 3	300

III. 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. The last case 20 is simulated by considering target as a hollow cylindrical cone with a diameter of 290mm and 2.5mm thickness, impacted with a velocity of 700mm/ms by nine cube shaped fragments of 15mm at a time, shown in figure 5. The fragments are assigned with tungsten material properties and target is assigned with titanium material properties.

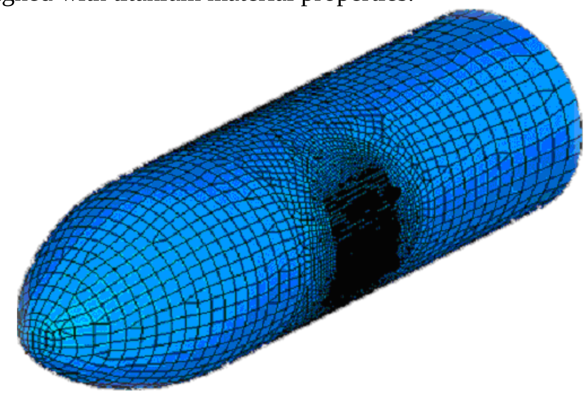

Fig.5 Isometric view of target (hollow cylindrical cone)

IV. RESULTS AND DISCUSSIONS

The following parameters are measured and discussed:

- Velocity
- Kinetic Energy
- Von-Mises stress
- Effective plastic strain
- Damage (measured in terms of hole diameter).

A. For 3mm thickness Ti and Al target plates

The results of first three cases are shown where a 15 mm cube shaped tungsten fragment is made to impact with wide range velocities of 300, 700, 1000mm/ms onto two target plates of size 300x300x3 mm which are separated by 100mm apart. Titanium material property is assigned to first target plate and Aluminum material to second target plate. The velocity and kinetic energy results were listed in the following table 2 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 (as x-axis) and drops (as y-axis). Figures 6 and 7 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 2 Velocity and Kinetic energy drop

	Initial	After 1st plate (Ti)	After 2nd plate (Al)
Velocity (mm/ms)	300	293.80	288.70
	700	687.50	678.13
	1000	988.75	975.63
	1465	1407	1358

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Kinetic energy (kg-mm/ms ^{2})	7980	7750	7310
	16280	15885	15200

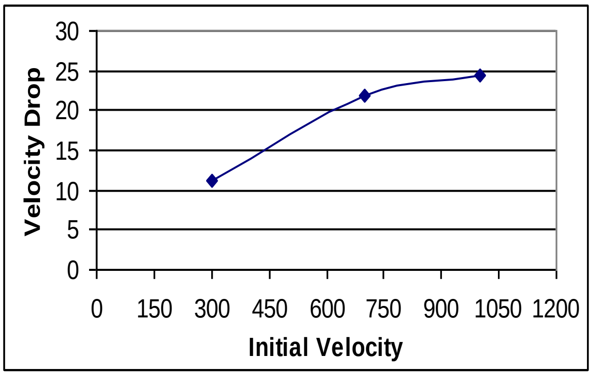

Fig.6 Velocity drop for Titanium and Aluminium plates (3mm)

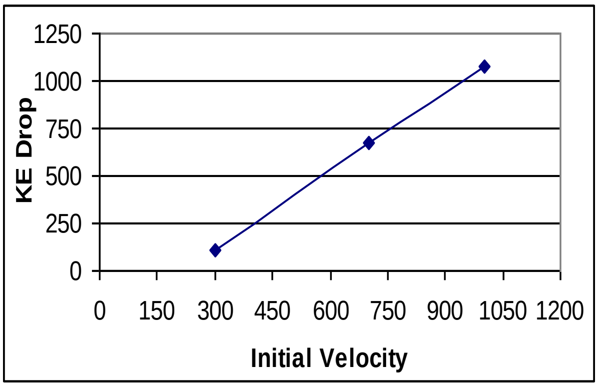

Fig.7 KE drop for Titanium and Aluminium plates (3mm)

Maximum Vonmises stress for the fragment material was found to be 0.5516 KN/mm2. The maximum Vonmises stresses obtained for each case are tabulated. Table 3 shows the maximum Vonmises stress obtained for each case.

Table 3 Vonmises stress

Initial velocity (mm/ms)	Plate 1 (KN/mm2)	Plate 2 (KN/mm2)
300	1.1440	0.4925
700	0.6856	0.3616
1000	0.8581	0.5880

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	1.329e-2	0.1027	0.2197
700	1.268e-2	0.1010	0.2682
1000	1.314e-2	0.0955	0.2704

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 (Ti Alloy) (mm)	Plate 2 (Al Alloy) (mm)
300	15.38	15.800
700	15.48	15.725
1000	15.39	15.825

B. For 6mm thickness Ti and Al target plates

The cases 4, 5 and 6 in this section are similar to cases in section 4.1 but here the thickness of plates is increased from 3mm to 6mm.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.

Table 6 Velocity and Kinetic energy drop

	Initial	After 1st plate (MS)	After 2nd plate (MS)
Velocity (mm/ms)	300	286.25	270
	700	680.50	660
	1000	977.00	955
Kinetic energy (kg-mm/ms ^{2})	1465	1350	1162.5
	7980	7400	6500.0
	16280	15000	13260.0

The velocity drop and kinetic energy drop for each case is calculated. Graphs are drawn between initial velocities (taken as x-axis) and drops (taken as y-axis). Figures 8 and 9 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.

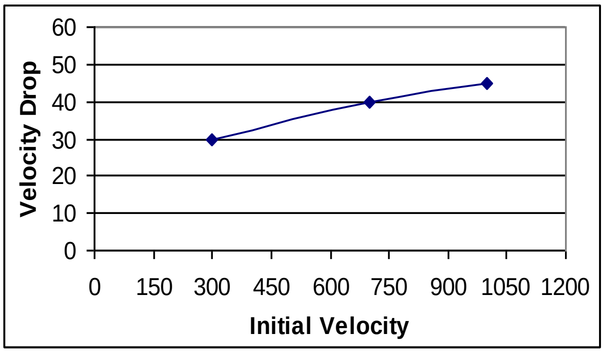

Fig.8 Velocity drop for Titanium and Aluminium plates (6mm)

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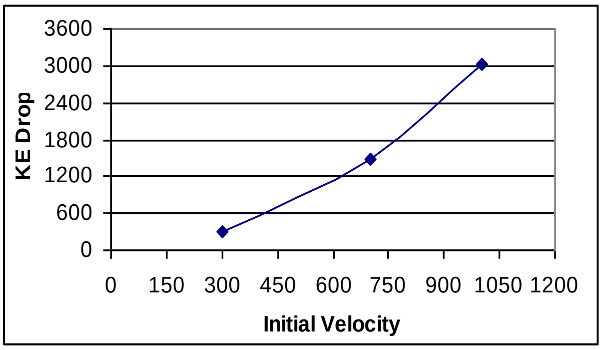

Fig.9 KE drop for Titanium and Aluminium plates (6mm)

Maximum Vonmises stress for the fragment material was found to be about 0.5516 KN/mm^2. The maximum Vonmises stresses obtained for each case are tabulated. 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	1.0780	0.5168
700	0.9629	0.4973
1000	1.4870	0.4896

The maximum effective plastic strains for the target plates and fragment of all the above three cases are measured and listed in the table 8

Table 8 Effective Plastic Strain

Initial velocity (mm/ms)	Plate 1	Plate 2	Fragment
300	1.363e-2	0.1066	0.2554
700	1.326e-2	0.0998	0.2864
1000	1.422e-2	0.0980	0.2744

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 (Ti Alloy) (mm)	Plate 2 (Al Alloy) (mm)
300	15.38	16.63
700	15.60	16.44
1000	15.69	16.06

C. Comparison of 3mm and 6mm thickness plates

The results of two previous sections are compared and described in this section i.e., the velocity drop and kinetic energy drop for 3mm and 6mm thickness plates at each initial velocity 300, 700, and 1000 are compared. Graphs are plotted taking initial velocity as x-axis and velocity & kinetic energy drop as y-axis which is shown in the figures 10 and 11. From figures it can be revealed that as the thickness is increased velocity drop and kinetic energy drop is higher. It can also be said that more kinetic energy is absorbed as the thickness increases.

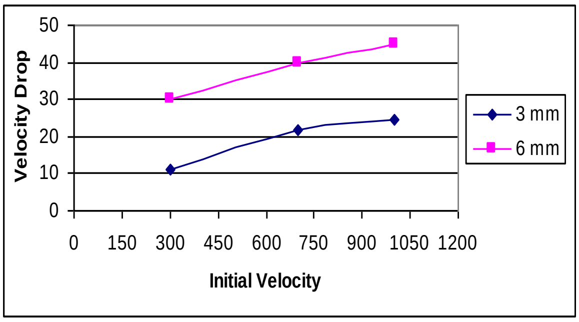

Fig.10 Comparison of velocity drop for 3mm and 6mm thickness plates

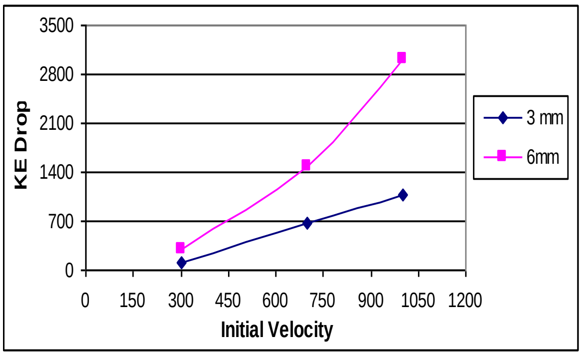

Fig.11 Comparison of KE drop for 3mm and 6mm thickness plates

D. For different gap between plates

In this section, results of 7 to 11 cases are shown where a 15 mm cube shaped tungsten fragment is made to impact with a velocity of 700mm/ms onto two Titanium target plates of size 300x300x3 mm by varying gap of 50, 150, 200, 250 and 300mm between two plates. The fragment is positioned at a distance of 0.5mm from the first target plate for all cases. It is observed that the fragment penetrated easily through two plates by reducing its velocity and kinetic energy.

The velocity and kinetic energy results obtained are listed in the tables 10 and 11.

Table 10 Change in velocity

Gap (mm)	Initial velocity (mm/ms)	After 1st plate (mm/ms)	After 2nd plate (mm/ms)
50	700	691	681.00
100	700	691	680.20
150	700	691	682.00
200	700	691	680.25
250	700	691	680.50
300	700	691	681.50

Table 11 Change in K.E

Gap (mm)	Initial KE (kg-mm/ms^2)	After 1st plate (kg-mm/ms^2)	After 2nd plate (kg-mm/ms^2)
50	7980	7780	7490
100	7980	7780	7450
150	7980	7780	7500
200	7980	7780	7450

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250	7980	7780	7450
300	7980	7780	7510

The velocity drop and kinetic energy drop are calculated from tables 10 and 11 and graphs are plotted with initial velocity as shown in the figures 12 and 13. It is found that maximum velocity drop and kinetic energy drop occurred when gap of 100mm is kept between plates. Hence gap of 100mm is found to be effective.

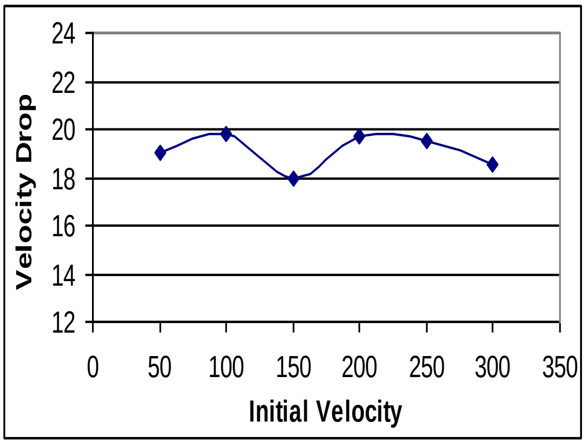

Fig.12 Velocity drop plot for varying gap

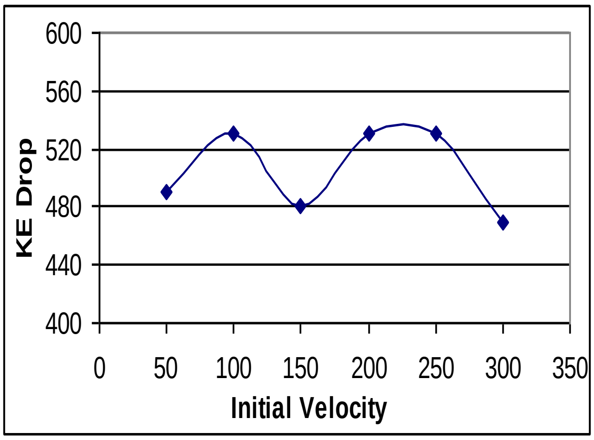

Fig.13 K.E drop plot for varying gap

E. Multi-Fragment impact

This is a last case 12 where, nine, 15mm cube shaped fragments are made to impact with a velocity of 700mm/ms onto hollow cylindrical cone of 290mm diameter with 2.5mm thickness. The fragments are positioned at a distance of 2.5mm from the target. At the impact zone fine mesh is considered as shown in the close view in the figure 14. The Vonmises stress plots are shown in the figures 15 and 16 describing before impact and after impact.

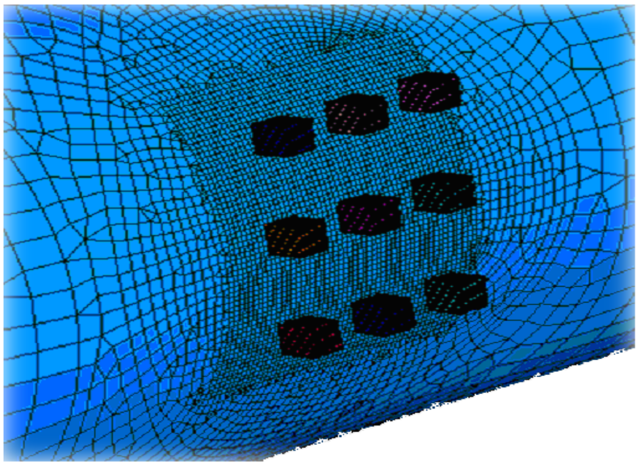

Fig.14 Close view

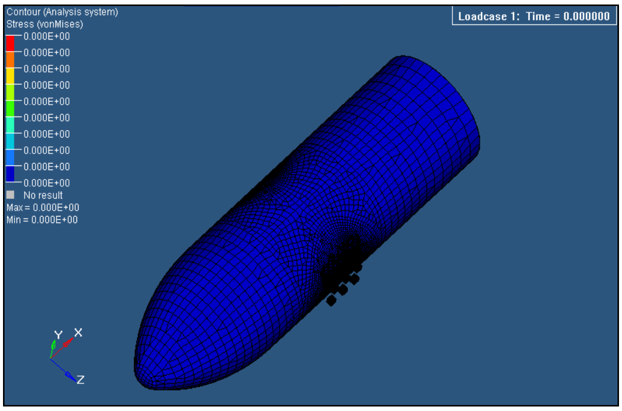

Fig.15 before Impact

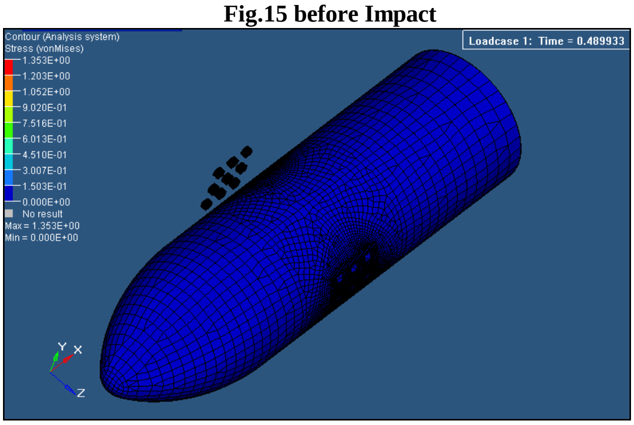

Fig.16 After Impact

V. CONCLUSION

The conclusions of the present work are summarized and presented as shown hereunder

- After analyzing the damage occurred due to various impact velocities for different materials (Ti Alloy, Al Alloy) it has been found that velocity drop changes linearly with respect to impact velocity.
- It is also observed that absorption of energy is more for higher velocities as the kinetic energy drop is increased by the increment of velocity.

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- For same initial velocity, velocity drop follows similar curve in both 3mm and 6mm plates.
- Velocity drop is more in target plates of 6mm when compared to 3mm Plates.
- Kinetic energy drop increased drastically in 6mm plate whereas 3mm plate shows linearly exponential behavior.
- As average hole diameter is found less for the first plate when compared to second plate, it is obvious that more damage occurred in the second plate.
- More than 100mm effective gap was found between two target plates.
- As the gap between plates increases, the velocity and KE drop follows a sine curve.

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