Simulation-based study of projectile impact on E-glass/epoxy composite material with different plies stacking sequence

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Abstract

The present paper deals with a simulation-based study of impact of projectiles on composite material plate as a target using LS-DYNA by modeling plates with shell elements and projectiles with solid elements .A finite element method was used for studying the effect of the plies stacking sequences for E-glass /epoxy composite material under impact loading with ballistic velocity on the projectile and the target behavior. Crossply, and angle ply symmetric stacking sequences has been taken herein to investigate. Also the effect of the head shape of projectiles (nondeformable and deformable) on the residual velocities has been taken. It was found that the stacking sequences of the plies play an important rule in the behavior of the composite under impact loading as well as the shape of the projectile head.

Key words: impact ,E-glass epoxy, plies stacking sequence

Introduction:

Nonlinear finite element-based contact–impact analysis is a versatile tool for predicting projectile residual velocities and ballistic limits for impact on armour plates. The main goal of the simulation studies reported by many researchers has been to show that the analysis results can compared versus experimental results .armour plates behaviors under projectile impact has been studied experimentally. The normal and oblique impacts on single and layered mild steel plates with jacketed hard-core projectiles have been studied experimentally by Gupta and Madhu [1]. Oblique impact of projectile on thin aluminum plates have been investigated experimentally by Khan, Ansari and Gupta [2]. Based on the experimental results, the authors of [2] have developed an analytical model for predicting the residual velocity and ballistic limit. Gupta, Iqbal and Sekhon [3] have studied the behavior of thin aluminum plates subjected to impact by blunt and hemispherical-nosed projectiles for velocities in the range of ~60-120 m/s using both experimental and numerical approaches. Corran, Shadbolt and Ruiz [4] have studied experimentally the impact of projectiles at sub-ordnance velocities against mild steel, stainless steel and aluminum plates. There are three basic approaches to analyze ballistic impact problems. They are:

(1) Empirical prediction models, which require lot of experimental tests and results.

(2) Prediction models, which require typical ballistic impact experimental data as input.

(3) Analytical models, which take only mechanical and fracture properties and geometry of the target and projectile parameters as input.

The aim of this investigation is to study the effect of the plies stacking sequences of E-glass /epoxy composite material on the projectile behavior (residual velocities) and the target behavior (stresses) under ballistic velocity impact by different nose shapes steel projectiles (ogival ,flat and semi sphere) with two mechanical behavior ,nondefromable and deformable .

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Damage mechanisms:

Ballistic impact is normally a low-mass high-velocity impact by a projectile propelled by a source onto a target. Since the ballistic impact is a high velocity event, the effects on the target can be only near the location of impact. During the ballistic impact, energy transfer takes place from the projectile to the target. Based on the target geometry, material properties and projectile parameters the following are possible.

(1) The projectile perforates the target and exits with a certain velocity. This indicates that the projectile initial kinetic energy was more than the energy that the target can absorb.

(2) The projectile partially penetrates the target. This indicates that the projectile initial kinetic energy was less than the energy that the target can absorb. Based on the target material properties, the projectile can either be stuck within the target or rebound.

(3) The projectile perforates the target completely with zero exit velocity. For such a case, the initial velocity of the projectile of a given mass is referred to as the ballistic limit. For this case the entire kinetic energy of the projectile is just absorbed by the target.[5].

For the complete understanding of the ballistic impact of composites, different damage and energy absorbing mechanisms should be clearly understood. Possible energy absorbing mechanisms are [6]: cone formation on the back face of the target, deformation of secondary yarns, tension in primary yarns/fibres, delamination, matrix cracking, shear plugging and friction between the projectile and the target. For different materials like carbon, glass or Kevlar, different mechanisms can dominate. Also, the reinforcement architecture can influence the energy absorbing mechanisms.

The total energy absorbed by the target till a particular time interval is

$E_{TOTALi} = E_{KEi} + E_{SPi} + E_{Di} + E_{DLi} + E_{MCi} + E_{Fi}$. [5]

Where:

E_{TOTALi} is the total energy absorbed by the target till time (t_i)

E_{KEi} is the kinetic energy of the moving cone at time (t_i)

E_{SPi} is the energy absorbed by shear plugging till time (t_i)

E_{Di} is the energy absorbed by deformation of secondary yarns till time (t_i)

E_{DLi} is the energy absorbed by delamination till time (t_i)

E_{MCi} is the energy absorbed by matrix cracking till time (t_i)

E_{Fi}. Is the energy absorbed by friction till time (t_i)

Finite element modeling:

Finite element models of a composite material target plate and a steel projectile using (Belytschko) shell 163 and constant solid elements are shown in figures (1) and (2), respectively. The plate is square in shape with a dimension of 200x200 mm and is clamped along the edges. Plates of constant thickness (5.05mm) considered.

Contact-_Eroding_Surface_Surface interface is defined for capturing the interaction between target plate and projectile.

LS-DYNA explicit finite element program with the powerful pre- and postprocessing capabilities of the ANSYS program was used to perform the simulation impacting loading procedure and the damage it caused.

A unidirectional composite material with 40 plies made of epoxy as matrix and E-glass fiber as a reinforcement (the properties are the table 1).

The E-glass/epoxy composite material panel which used herein to investigate it under impact loading by steel projectile was consisted of 40 balanced symmetric stacking sequences plies; each ply with thickness equal to 0.0126 mm [7] and the total thickness of the panel was 5.05 mm. All edges were modeled as fixed. The mesh was consisted form 2135 element and 3102 node (figure(3)), this number provides good accuracy of results .Four different plies stacking sequences were used in this study, as follows:

1-[0/0/……….0/0]

2- Crossply -Symmetric [0/90/0/90/……/90/0/90/0]

3- Angle-Ply Symmetric [45/-45/45/-45/…../-45/45/-45/45]

The projectiles were modeled as rigid (nondeformable) and deformable material (steel) of diameter 6.2 mm and 17 long with three different nose shape, flat, ogival and semi spherical – nose(fig.(4,5,6)) respectively, (the mass was 4 gram approximately. The length to diameter (l/d) ratio of 6.2 mm diameter projectiles is 2.74 with using solid element 164.

The simulation was performed with impact velocity equal to 100,200and300m/s.The total time that's having been taken form the initiation was 0.0004 second approximately.

Result and discussion: we will address here the residual velocity projectile after the collision and effect of the plies stacking sequence of plate (target) on the projectile behavior to add an effect on the form of the head thrown on the nature of the collision and also study the nature of metal projectile (rigid and deformable) on the behavior of the projectile.

First- residual velocities of rigid projectile:

1–Projectile with flat nose:

a - The velocity of the projectile 100 m/s:

figure (7) shows the projectile during the collision with the three types of plies stacking sequence ,note that the plate with plies stacking sequence 0/0….0/0 is the weakest with the observation that the speed of the projectile after impact the target and the other two types is different from the first where the projectile will return and does not occur a penetration of the target.

b-The velocity of the projectile 200m /s:

The actions of the three types of stacking sequences plate seems to be different when impacted by the projectile, figure(8) shows clearly that the plate where the stacking sequence 0/0 to suffer a penetration (fig. (9)) while the plates of plies stacking sequences 45/-45… and 0/90….does not suffering this penetration.

c - The velocity of the projectile 300 m/s:

That the speed of the projectile is sufficient to damage and make penetration of the target in the three types plies stacking sequences (fig. (10)) with noting the residual velocity of the projectile after the collision with the plies stacking sequence 45/-45…-45/45.is the least.

2–Projectile with ogival nose:

Through the figures(11,12,13,) we can say that the projectile behavior is roughly similar to those of flat one with the difference in the amounts of these velocities.

3 – Projectile with semi spherical nose:

As well as the behavior of projectile with semi spherical nose and the nature of velocities are roughly similar to the previous behavior and the figures (13, 14, and 15) illustrate that.

We can say, through our review of the results above that the plies stacking sequence plate (45/-45….-45/45) is the best species in terms of penetration resistance and this kind of loading. From the table (2), which summarizes the residual velocities of projectiles with the three types of nose with the three types of plies stacking plates (target) which shows that plies stacking sequences is the best in terms of impact resistance and penetration, while the stacking sequence 0/0 is the weakest as well as the projectile of the flat nose is best able to penetrate and destroy the target of the other two types.

Second: Residual velocities of the deformable projectile:

The velocity 200 m / s have been adopted and as a model for the study with two types of projectiles(flat and ogival noses) and also for three types of plies stacking sequences (0/0…0/0,45/-45…-45/45,0/90…90/0) Figure(16) shows the comparison between the residual velocities for the flat nose projectile impacting plate with 0/00…-0/0 stacking sequences, the residual velocity of the deformable projectile was less than those of the projectiles with a hard metal and this is due to the collision energy will be divided into two parts, absorbs part of the target and part will distorts the projectile ,this distribution will lead to be the residual velocity few. The behavior of the projectile in collisions with plate 45/-45…-45/45 of the sequence is different to the above, where we notice through the figure (17) that there is a great convergence of the projectile residual velocities of the two types (rigid and deformable). With the plies stacking sequences 0/90…90/0 target we note that the deformable projectile reach the zero velocity after the collision in time less than projectile with rigid metal . This is because that part of the energy converted into energy the formation of plastic or elastic depending on the amount of stress generated, by this means the loss of an important part of the kinetic energy of projectiles and the remaining portion is absorbed by the target. (fig.(18)).

Figures (19, 20, and 21) show the behavior of projectile with ogival nose looks similar to the behavior of the flat one.

Third-Stresses:

Nodes have been adopted in the middle of the plate to study three types of stresses generated by the collision. It seems from the figures(22,23,24) that the stresses are (regardless of the type of projectile nose and the type of plate plies stacking sequence) high at the moment of collision and fades with the passage of time, and this means that the wave stresses transmitted from the center of the plate toward the 0utside

Note: Figure (25) illustrate F.E analysis for specific cases (flat and ogival nose).

References:

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woven fabric composites: Parametric studies." Material science and engineering. Vol. 412, Issues 1-2, 2005, pp. 104-116.
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8-Ansys package documents.

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Table (1) Properties of E-Glass/Epoxy Composite Material [7]

Property	Value
Fiber volume ratio	0.55
Density kg/m^3	2100
Longitudinal modulus GPa	39
Transverse modulus GPa	8.6
In –plane shear modulus GPa	3.8
Major poisons ratio	0.28
Minor poisons ratio	0.06
Longitudinal tensile strength MPa	1080
Transverse tensile strength MPa	39
In –plane shear strength MPa	89
Ultimate Longitudinal tensile strain	0.028
Longitudinal compressive strength MPa	620
Transverse compressive strength MPa	128

Table (2) comprehensive results for residual velocities

Projectile nose type	Plies stacking sequence	Projectile residual velocity after impact velocities m/s		
		100	200	300
Flat	0/0…0/0	82	90.26	150.87
	45/-45…-45/45	-12.64	-31.02	93.48
	0/90…/90/0	15.6	-11.35	191.3
Ogival	0/0…0/0	6.89	49.67	125.14
	45/-45…-45/45	-16.8	-79.11	160.3
	0/90…/90/0	-21.02	-3.98	177
Semi spherical	0/0…0/0	8.2	88.96	162.69
	45/-45…-45/45	-16.92	-53.5	83.1
	0/90…/90/0	-18.6	39.55	206.55

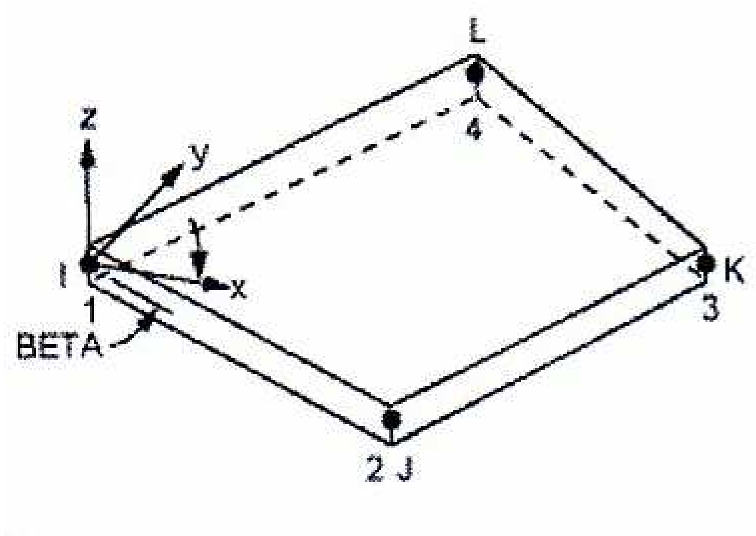


Fig.(1) shell element 163 which used in the simulation[8]

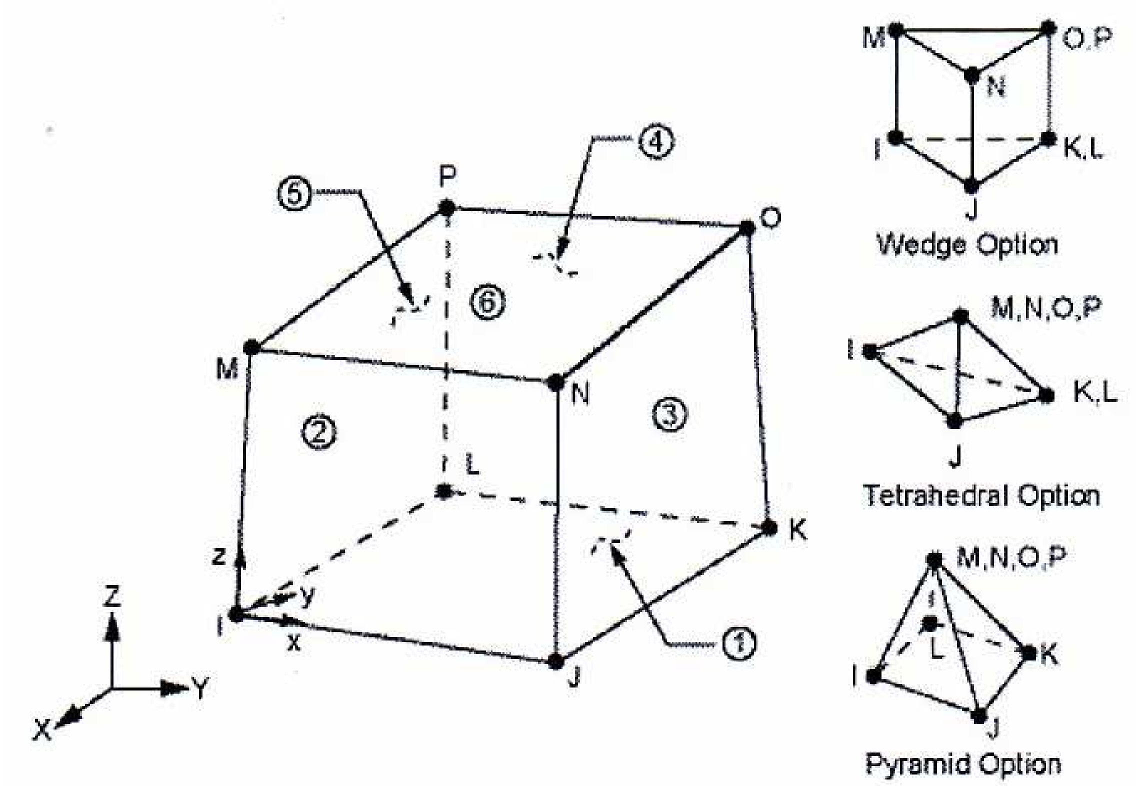


Fig.(2) solid element 164 which used in the simulation[8]

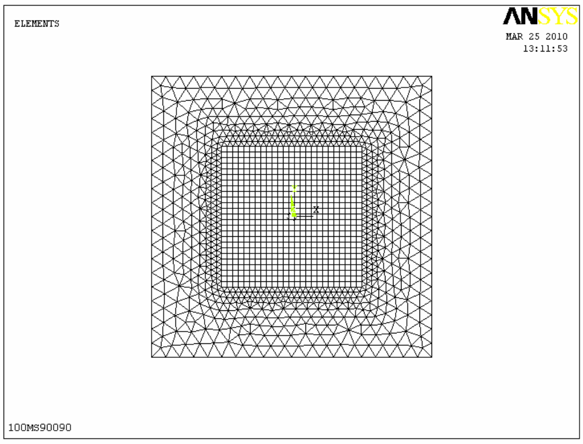


Fig.(3) finite element model for the target panel

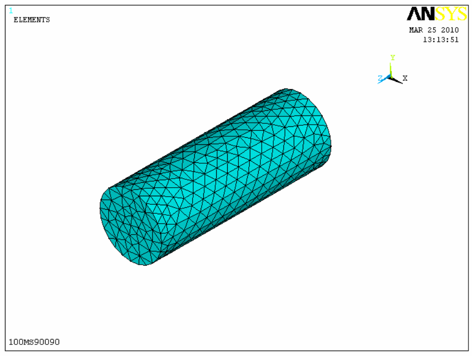


Fig.(4) finite element model for projectile (flat nose)

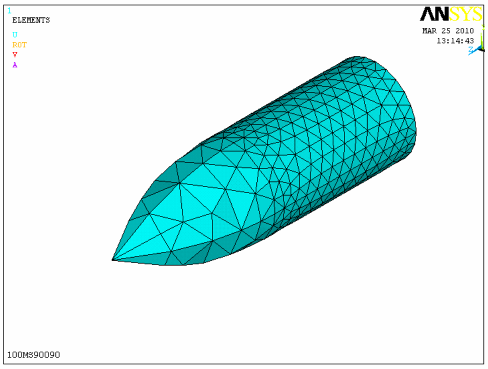


Fig.(5) finite element model for projectile

(ogival nose)

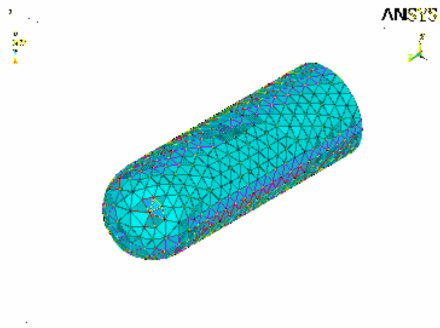


Fig.(6) finite element model for projectile

(semi spherical nose)

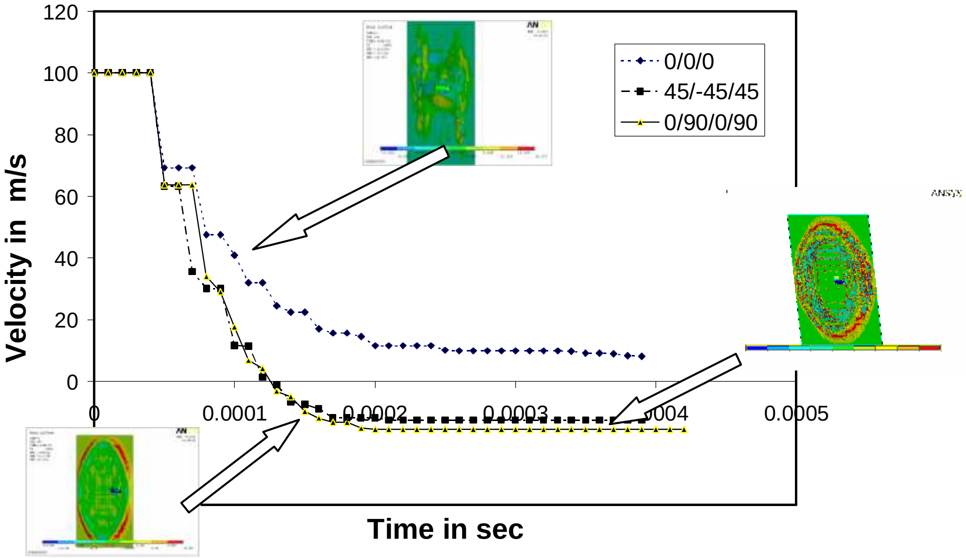


Fig.(7) residual velocities of flat nose projectile (impact velocity is 100m/s)

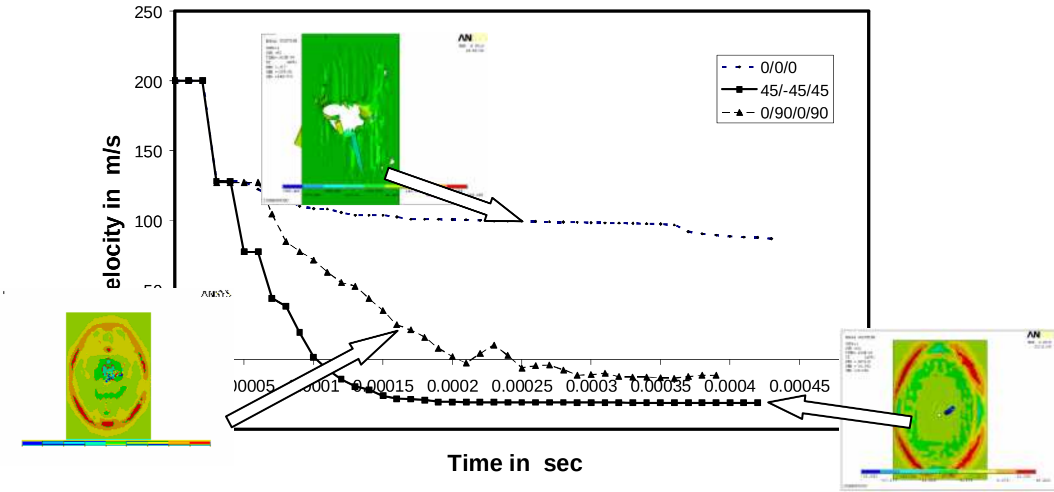


Fig.(8) residual velocities of flat nose projectile (impact velocity is200m/s)

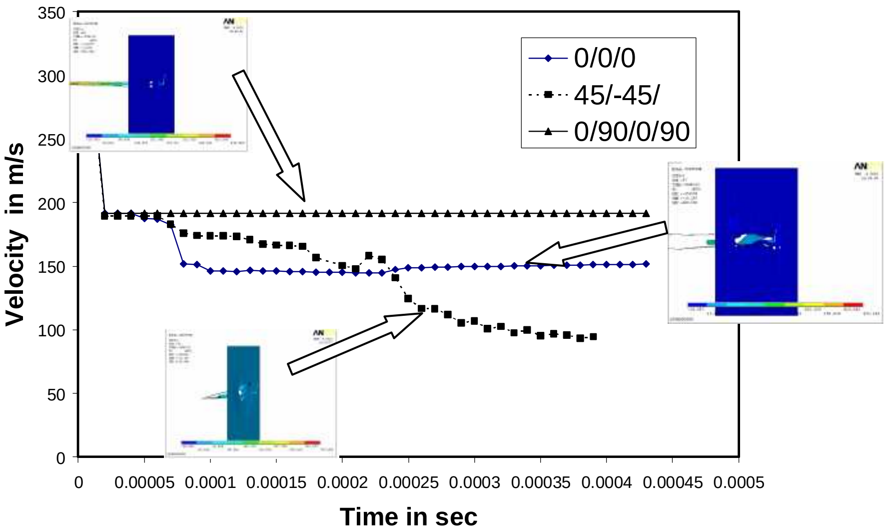


Fig.(9) residual velocities of flat nose projectile (impact velocity is300m/s)

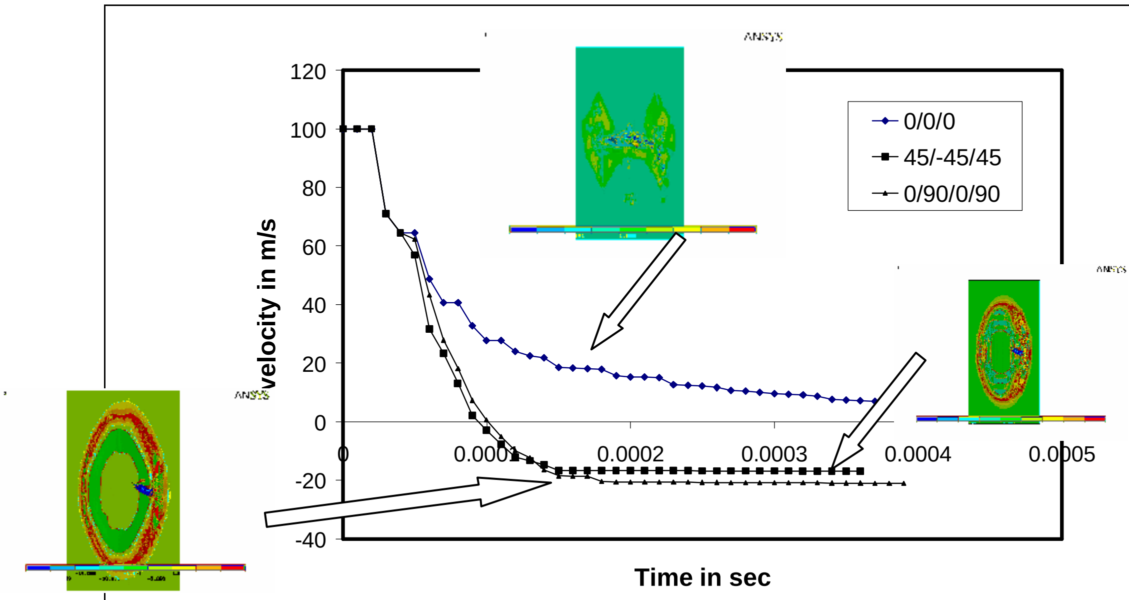


Fig.(10) residual velocities of ogival nose projectile (impact velocity is 100m/s)

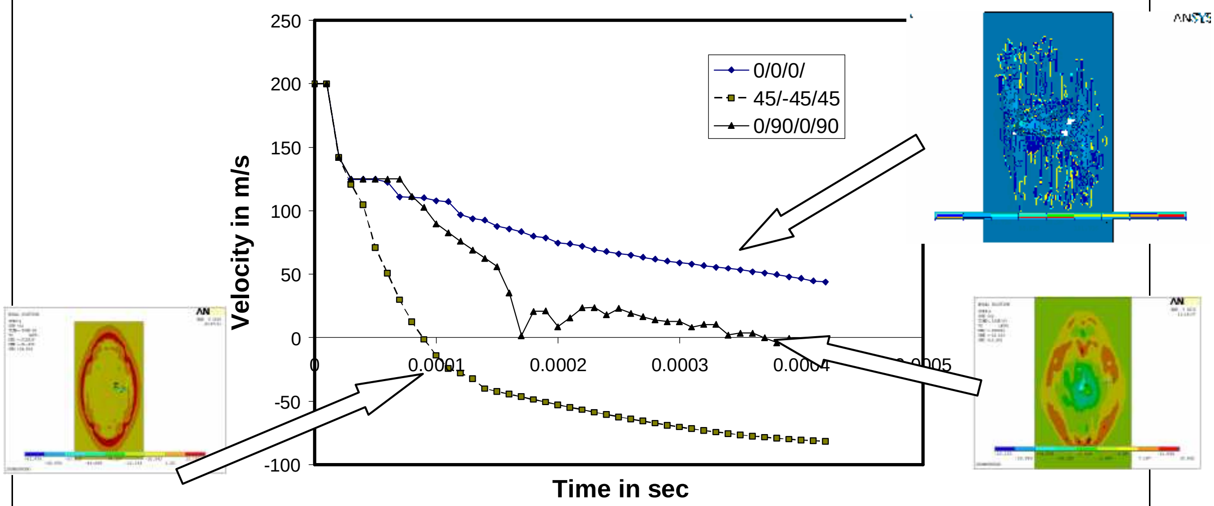


Fig.(11) residual velocities of ogival nose projectile (impact velocity is 200m/s)

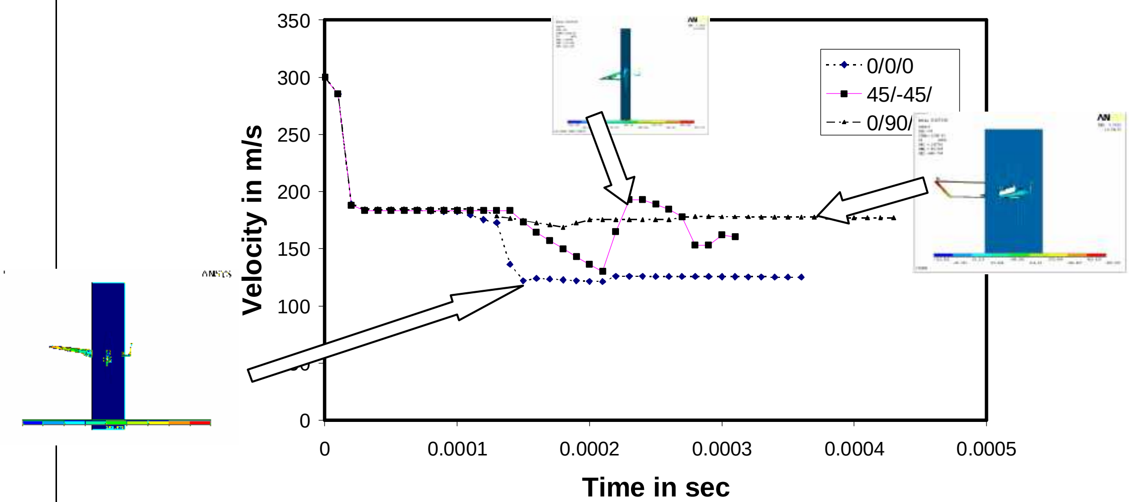


Fig.(12) residual velocities of ogival nose projectile (impact velocity is 300m/s)

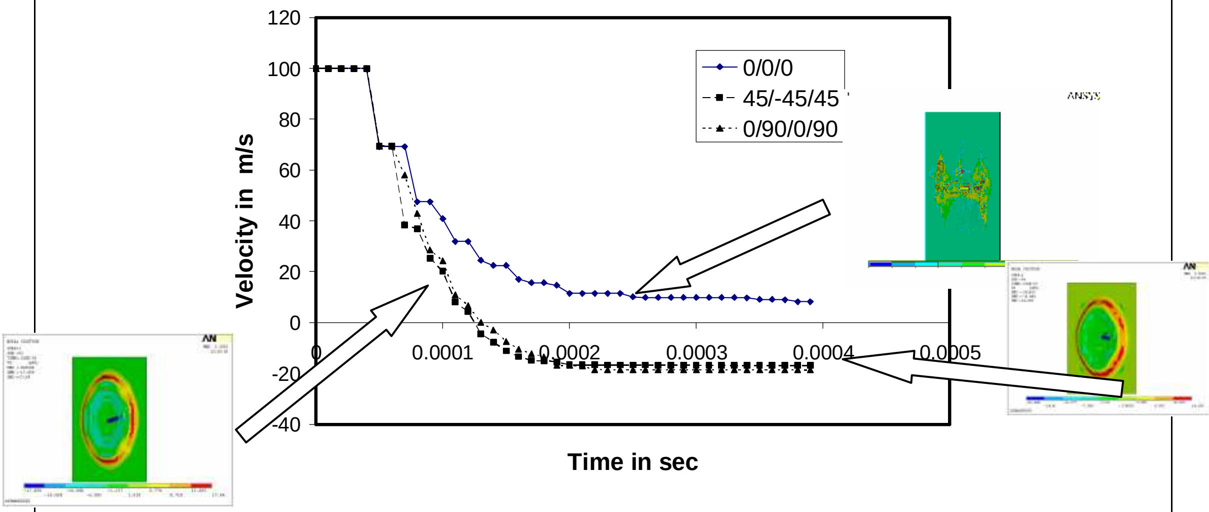


Fig.(13) residual velocities of semi spherical nose projectile
(impact velocity is 100m/s)

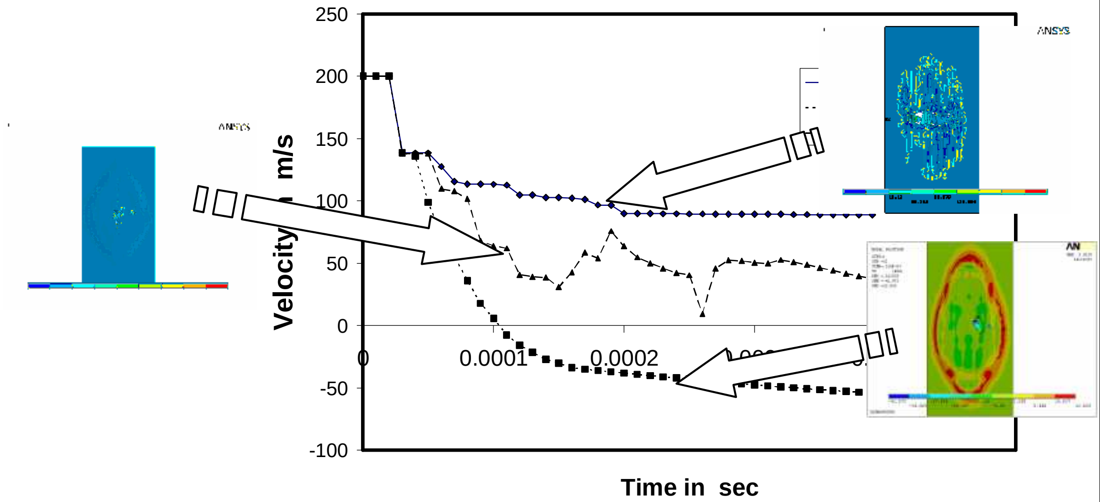


Fig.(14 residual velocities of semi spherical nose projectile
(impact velocity is 200m/s)

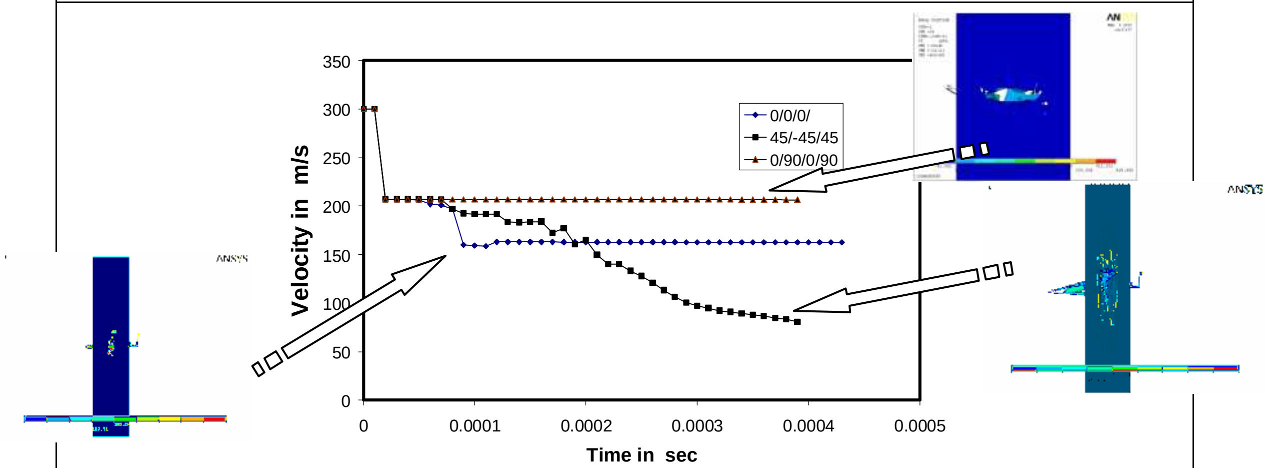


Fig.(15) residual velocities of semi spherical nose projectile
(impact velocity is 300m/s)

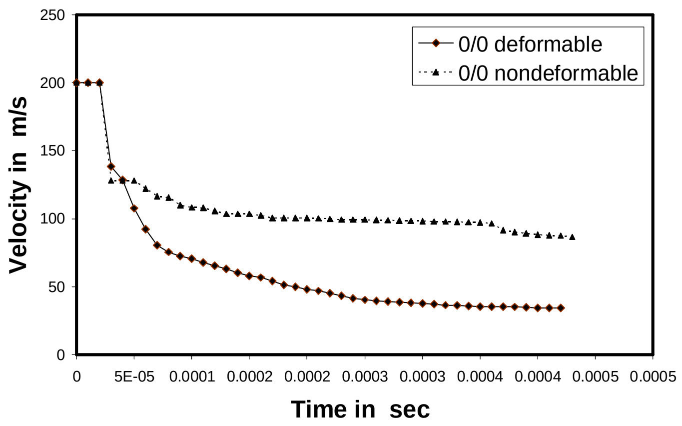


Fig.(16) residual velocities of flat nose projectile (impact velocity is200m/s) with 0/0…0/0 plies stacking sequence

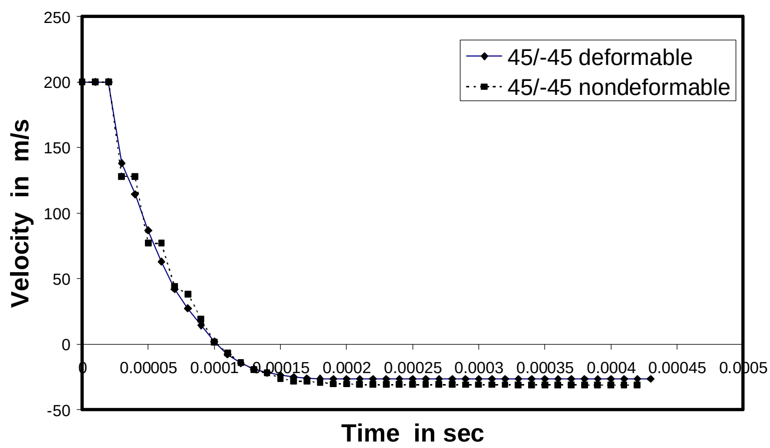


Fig.(17)) residual velocities of flat nose projectile (impact velocity is200m/s) with 45/-45…-45/45 plies stacking sequence

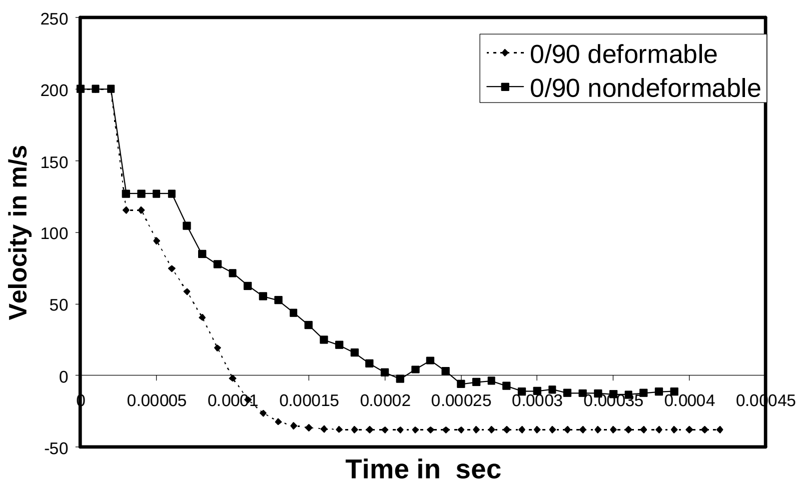


Fig.(18)) residual velocities of flat nose projectile (impact velocity is200m/s) with 0/90…90/0 plies stacking sequence

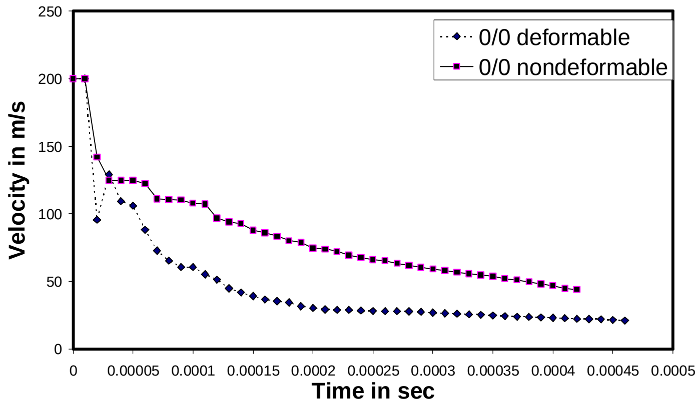


Fig.(19) residual velocities of ogival nose projectile (impact velocity is200m/s) with 0/0…0/0 plies stacking sequence

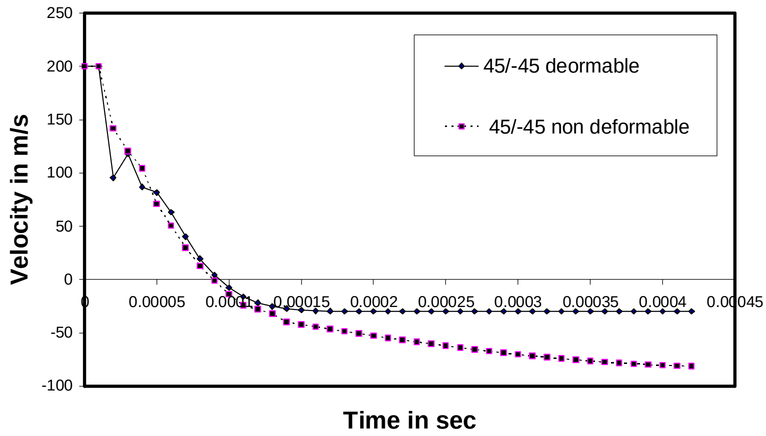


Fig.(20) residual velocities of ogival nose projectile (impact velocity is200m/s) with 45/-45…-45/45 plies stacking sequence

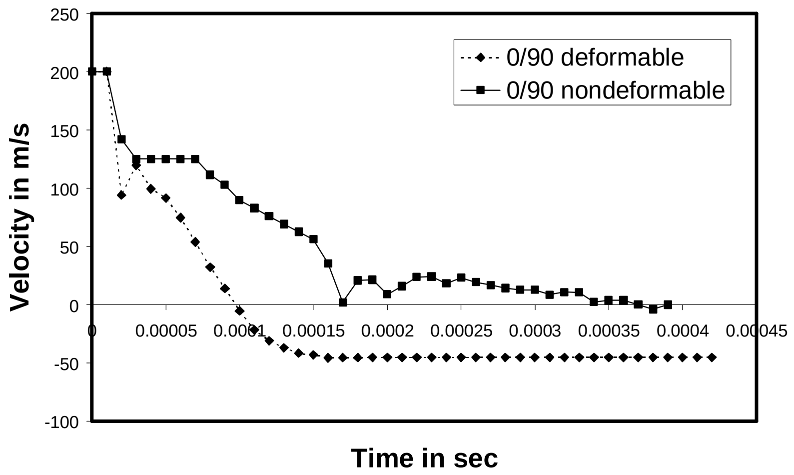


Fig.(21)) residual velocities of ogival nose projectile (impact velocity is200m/s) with 0/90…90/0 plies stacking sequence

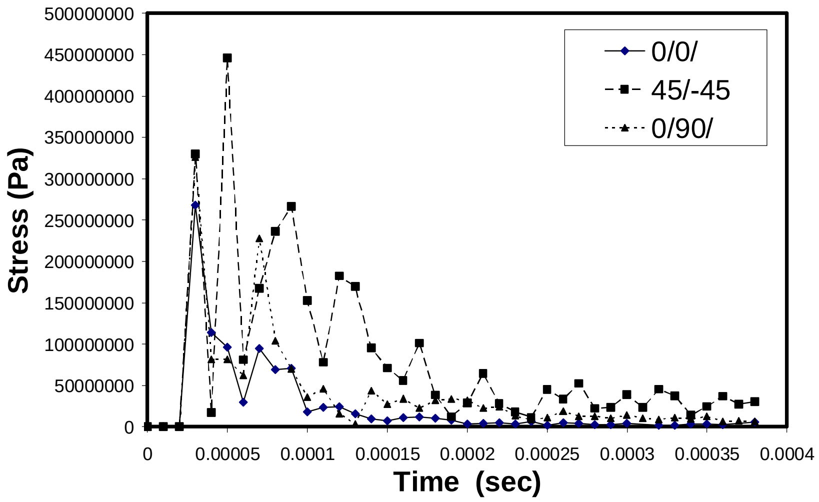


Fig.(22) stress in target impacted with flat nose projectile

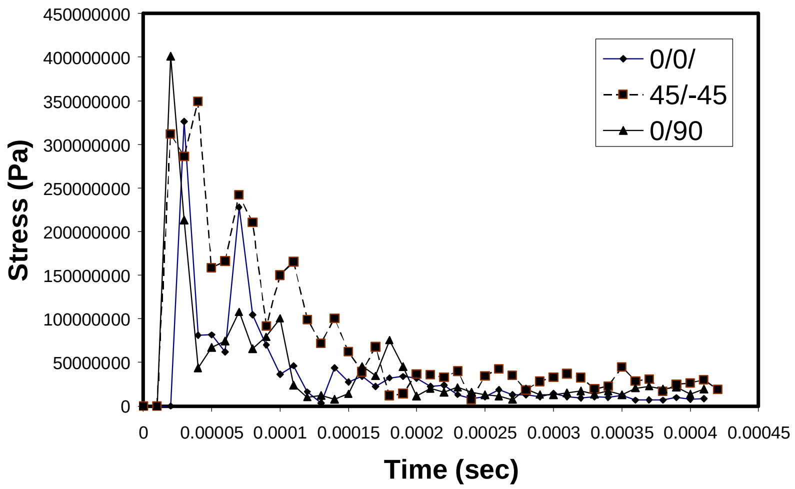


Fig.(23) stress in target impacted with ogival nose projectile

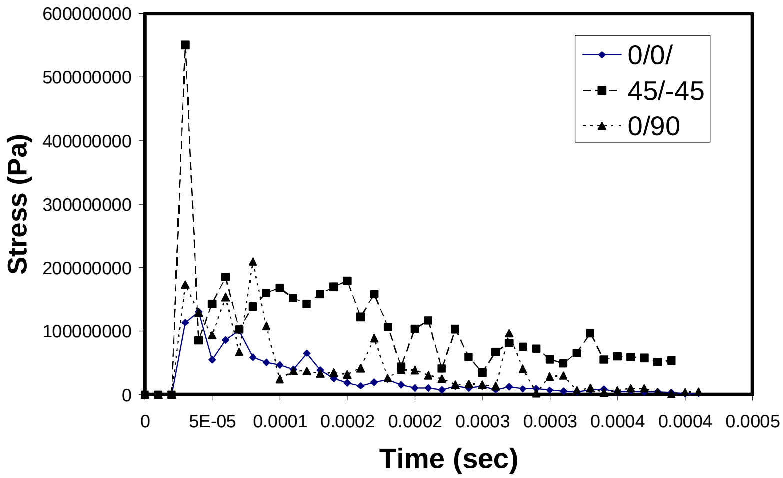
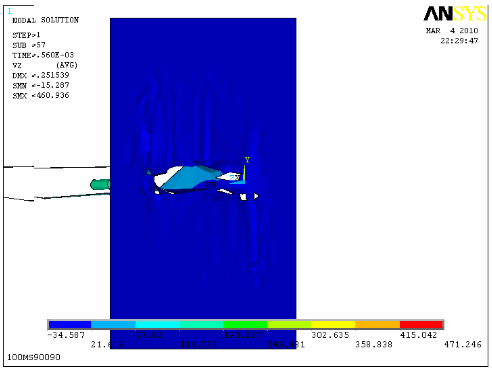
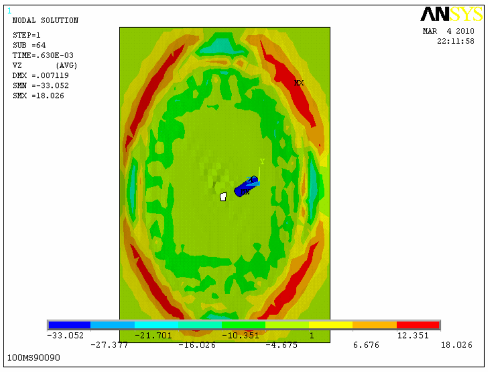


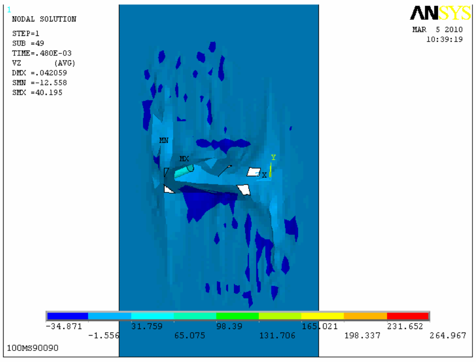
Fig.(24) stress in target impacted with semi spherical nose projectile



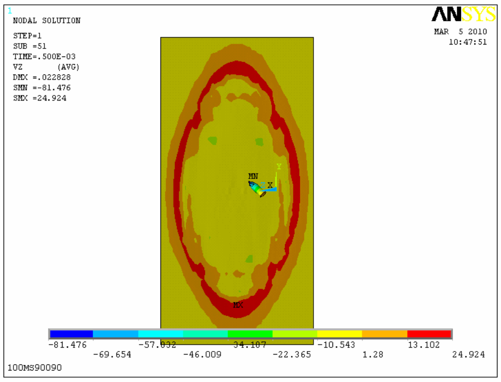
(a)



(b)



(c)



(d)

Fig.(25) F.E analysis for specific cases ,a)flat nose projectile with 300m/s impact with o/o---0/0 panel,b) flat nose projectile with 200m/s impact with 45/-45…..-45/045 panel,c) ogival nose projectile with 200m/s impact with 0/0….0/0 panel,d) ogival nose projectile with 200m/s impact with 45/-45….-45/45 panel.