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Effects of Impactor and other Geometric Parameters on Impact Behavior of FRP Laminated Composite Plate

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Abstract

In the present study, behaviour of FRP laminated composite plate subjected to impact by a spherical steel bullet has been investigated by numerical analysis using finite element method. The variation of stresses and central transverse deflections with time for different thickness as well as stacking sequences of composite plates, different sizes and velocities of impactors have been presented for different boundary conditions. Nature of failure of FRP composite plate due to low velocity impact has been study in detailed. Effects of stacking sequences and boundary conditions on damage initiation in the FRP laminated composite plates based on Hashin's criterion have been studied. From the numerical analysis it can be concluded that, the angle ply ($45°/-45°/45°$) laminate is more efficient than the cross ply ($0°/90°/0°$) and other angle ply ($30°/-30°/30°$) laminates since it exhibits less damage area and less deflection. Some results obtained from the present FE model are also validated and discussed with those available in the literature.

Key words

FRP composite, finite element method, Impact load, Damage initiation, GFRP

1. Introduction

FRP composites are versatile materials for the structural application due to their virtues of light weight, high stiffness, high strength and ease of erection in any environment. Some composite material like GFRP and Kevlar epoxy are resistive against thermal as well as chemical attack in most of the cases and hence these materials are widely used in retrofitting and marine structures like deck harbor, ship decks etc. Due to light weight and high stiffness of FRP composite, these materials are effectively used in the making of indoor and outdoor swimming pools, external body of racing bikes, roof sheeting and bridge deck etc.

The analysis of FRP laminated composite plate subjected to impact load has received widespread attention. Effect of low energy impact on a FRP laminated composite plate may be quite considerable as internal damage can cause a significant reduction of the strength of material without any observable damage on the impacted surface [1-3]. Due to this reason, it attracts many researchers to predict the nature and extent of damage caused by low energy impact in which penetration of the impactor does no take place and after impact it rebounds.

Despite of many virtues, these structures show highly complex behavior under impact and are very sensitive to non-visual damages that strongly influence their residual load caring capacity. Damage initiation and growth are closely dependent on both impact source properties. During low energy impact, the time of contact between the impactor and target material is relatively long. Theoretically, many works had been carried out with an aim to study the behavior of composite targets under impact load. Chakrabarti et al. [4-5] studied the delamination behaviour in FRP composite plate by using analytical methods. Karakuzu et al. [6] studied about the residual stresses in a composite beam under transverse loading.

Using the composite laminate theory and failure criteria given by Hashin [7], Wang and Yew [8] analyzed the damage in composite plate under transverse impact load. Sun and Liou [9] studied the behaviour of laminated composite plate by using a three-dimensional hybrid stress finite element method in the space domain along with the Newmark direct integration method. Palazotto et al. [10] analyzed Nomex honey comb sandwich core and modeling was done using an elastic plastic foundation. Contact loading is simulated by Hertizian pressure distribution for which contact radius is determined iteratively. Mishra and Nayak [11] proposed an analytical model for woven fabric composite under impact with four edges simply supported. Evci and Gülgeç [12] studied the impact damage and maximum force thresholds in three different types of composites, Unidirectional E-Glass, woven E-Glass and woven Aramid composite samples under impact load. Bilingardi and Vadori [13] experimentally analyzed a composite plate under low energy impact with small dirt. Sabet et al. [14] worked on high velocity impact performance of glass reinforced polyester (*GRP*) resin with different types of reinforcements.

However, very less numbers of works are reported in the literature highlighting the effect of impact in describing the damage area and their propagation for laminated composite plates having different stacking sequence, thickness of plate and boundary conditions. In the present work, ABAQUS (6.12) finite element software is used to investigate the transient response of FRP composite plate under impact with different thickness, stacking sequences of composite plate, different sizes and velocities of impactor to investigate the damage area in addition to other responses. The finite element model is implemented using Hashin's failure model available in ABAQUS to predict damage initiation in FRP composite plate. The present results are validated with the results available in literature before generating new results for future reference.

2. Modeling and Simulation

FRP laminated composite plate is modeled with three dimensional elements i.e. 8 nodded continuum shell (SC8R) to study the dynamic behavior as well as modes of damage under impact. Analysis is carried out with reduced integration and hourglass controlled condition to minimize the computational time. Surface-to-surface contact interaction is used describe the contact between deformable surface and a rigid surface. Therefore, surface to surface contact with zero friction is assigned for the interaction between bullet and composite plate under explicit condition. Damage initiation refers to the onset of degradation at a material point. The damage initiation criteria for fiber reinforced composite plate are based on Hashin's theory. Four different modes of failure initiation criteria given by Hashin (1980) are described as follows:

- Fiber tension initiation criteria (HSNFTCRT)
- Fiber compression initiation criteria (HSNFCCRT)
- Matrix tension initiation criteria (HSNMTCRT) and
- Matrix compression initiation criteria (HSNMCCRT)

Expression of Hashin's initiation criteria as follows

Fiber tension $\left(\sigma_{11} \geq 0\right)$

$$F_{\mathrm{f}}^{\mathrm{t}} = \left(\frac{\sigma_{11}}{X^{\mathrm{T}}}\right)^2 + \left(\frac{\tau_{12}}{S^{\mathrm{L}}}\right)^2 \tag{2.1}$$

Fiber compression $\left(\sigma_{11} < 0\right)$

$$F_{\mathrm{f}}^{\mathrm{C}} = \left(\frac{\sigma_{11}}{X^{\mathrm{C}}}\right)^2 \tag{2.2}$$

Matrix tension $(\sigma_{22} \geq 0)$

$$F_{\mathrm{m}}^{\mathrm{t}} = \left(\frac{\sigma_{22}}{Y^{\mathrm{T}}}\right)^2 + \left(\frac{\tau_{12}}{S^{\mathrm{L}}}\right)^2 \tag{2.3}$$

Matrix compression $(\sigma_{22} < 0)$

$$F_{m}^{C} = \left(\frac{\sigma_{22}}{2S^{\mathrm{T}}}\right)^2 + \left[\left(\frac{Y^{\mathrm{C}}}{2S^{\mathrm{T}}}\right)^2 - 1\right]\left(\frac{\sigma_{22}}{Y^{\mathrm{C}}}\right) + \left(\frac{\tau_{12}}{S^{\mathrm{L}}}\right)^2 \tag{2.4}$$

Where $F_{\mathrm{f}}^{\mathrm{t}}$, $F_{\mathrm{f}}^{\mathrm{C}}$ are failure index for fiber in tension and compression, respectively; $F_{\mathrm{m}}^{\mathrm{t}}, F_{m}^{C}$ are failure index for matrix in tension and compression, respectively; X^{T}, X^{C} are tensile and compressive strength in fiber direction; Y^{C} is compressive strength perpendicular to fiber direction, S^{L}, S^{T} = longitudinal and transverse shear strength. A value of 1.0 or higher for failure indices indicate that the initiation criterion has been met and elements in composite starts to fail.

3. Results and Discussions

3.1. Convergence verification

Mesh convergence study of numerical model is required to identify the optimum mesh division which meets more accurate and mesh independent results. In the present work, mesh division of 72 x 72 along *x-y* plane has been taken which shows convergence in the result as in Fig. 1. Square plate of dimension 140 mm × 140 mm with three layers of equal thickness and impactor as a rigid body of diameter 10 mm and mass 0.014175 kg are considered in this work as shown in Fig. 2. The material properties of composite plate made of graphite-epoxy AS-3501-6 are: E_{11}= 142.73 GPa, E_{22} = 13.79 GPa, G_{12}= G_{13}= 4.64 GPa, G_{23} = 4.14 GPa, $\nu_{12} = \nu_{13} = 0.3$, $\nu_{23} = 0.28$

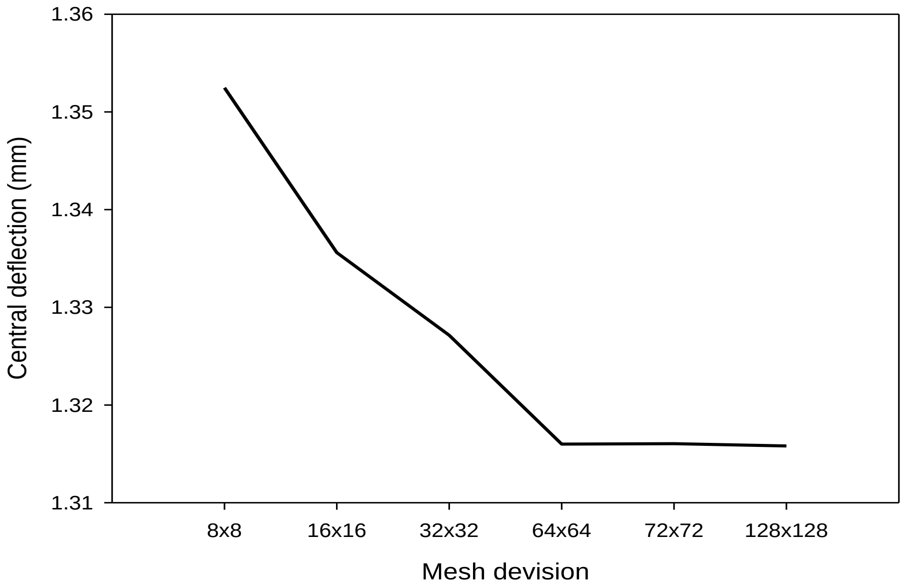


Fig. 1. Variation of central deflection with mesh division

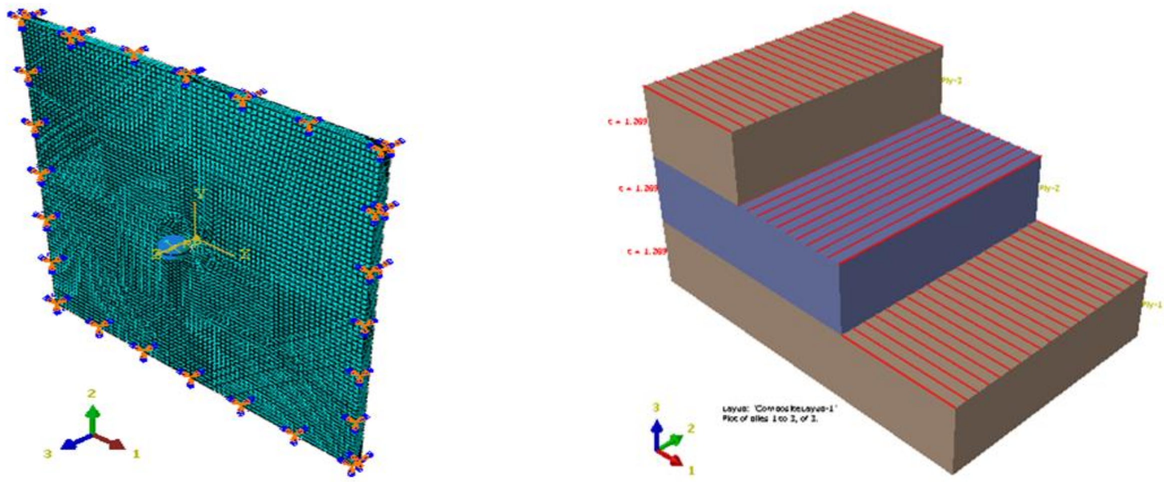


Fig. 2. Composite plate coordinate system and ply stacking of cross ply ($0° / 90° / 0°$) laminate

3.2. Numerical results and discussions

This section presents the response of FRP composite plate under impact with different sizes of impactors (radius: 5 mm and 7.5 mm) and initial velocities of impactors on different thickness and stacking sequences of composite plate under different boundary conditions. Deflection of cross ply ($0°/90°/0°$) laminated plate at contact point due to impact by 0.014175 kg impactor with incidence velocity 22.6 m/s has been shown in Fig. 3 and compared with available literature as mentioned there. Time of separation of impactor from the plate is approximately 210 μs in present case that is comparable to 195 μs as in case of Chun et al. [15]. However, the deflection during contact and before separation is differing; this may be due to different approaches used in defining the contact between impactor and composite plate. Due to orthotropic nature of composite plate, different types of stresses are developed in composite plate under impact that causes failure in composite plate by action of individual or in combinations. Therefore, different modes of stresses such as normal stresses (σ_{11}) at 100 μs and inter laminar stresses (τ_{13} and τ_{23}) at 80 μs and transverse central deflection (u_3) in two different composite plate i.e. cross ply ($0°/90°/0°$) and angle ply ($30°/-30°/30°$) are studied under two different boundary conditions. Numerical results of stresses and deflections in composite plate under impact by spherical impactor of two different incidence velocities (V_0 = 22.6 m/s and 40 m/s) have been presented in Table 1-2. In this section, particular time (100 μs, 80 μs) and locations of the target plate have been chosen to compare the results with those obtained by Sun and Liou [9] in which these times are stated as the critical time corresponding to maximum stresses. For cross ply laminate, some results are compared with the results of Sun and Liou [9] which show good agreement in most of the cases.

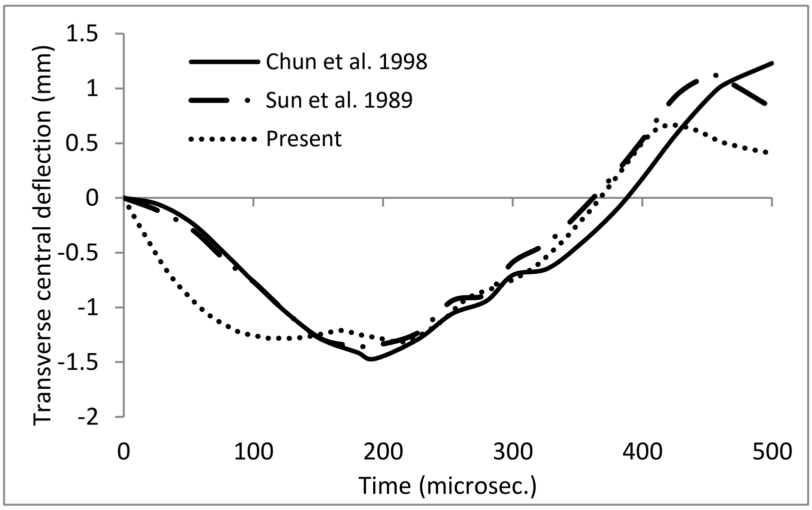


Fig. 3. Comparison of central deflection of cross ply laminated plate ($0°/90°/0°$) impacted at V_i = 22.6 m/s

Some differences are observed which are inevitable among results based on different approaches used in defining the contact.

Table 1 Maximum Stresses and deflections of FRP composite plates for impactor radius=5mm

V_0 (m/s)	h	Boundary conditions	References	σ_{11} (MPa) (0,0,h)	τ_{13} (MPa) (4,0,h/2)	τ_{23} (MPa) (0,4,h/2)	u_3 (mm) (0,0,h)
				$0°/90°/0°$			

22.6	3.81	CCCC	Present	565.232	37.796	29.918	1.32
		CCCC	Sun and Liou [9]	570	38	36	1.38
		SSSS	Present	888.813	38.284	30.072	2.261
	5.715	CCCC	Present	388.751	29.300	20.845	0.840
		SSSS	Present	407.414	29.968	21.136	1.168
	7.62	CCCC	Present	173.61	19.658	13.964	0.735
		SSSS	Present	330.045	20.314	13.718	0.756
40.0	3.81	CCCC	Present	765.468	54.771	44.087	2.227
		SSSS	Present	932.156	70.760	51.530	3.791
	5.715	CCCC	Present	584.613	38.708	25.019	1.413
		SSSS	Present	749.411	37.338	23.539	2.011
	7.62	CCCC	Present	290.343	20.607	16.976	1.162
		SSSS	Present	369.415	18.860	16.879	1.293
			$30° / -30° / 30°$				
22.6	3.81	CCCC	Present	784.165	30.859	35.949	1.341
		SSSS	Present	874.449	28.536	36.343	1.593
	5.715	CCCC	Present	471.455	20.639	30.114	0.837
		SSSS	Present	516.336	21.449	28.393	0.874
	7.62	CCCC	Present	147.455	13.241	20.404	0.739
		SSSS	Present	171.000	12.768	19.069	0.749
40.0	3.81	CCCC	Present	881.837	34.463	39.501	2.426
		SSSS	Present	940.145	33.881	38.325	2.702
	5.715	CCCC	Present	788.127	24.722	41.419	1.465
		SSSS	Present	822.486	22.878	38.514	1.503
	7.62	CCCC	Present	227.528	11.603	17.137	1.00
		SSSS	Present	299.417	12.095	17.105	1.161

Table 2 Maximum Stresses and deflections of FRP composite plates for impactor radius =7.5 mm

V_0 (m/s)	h	Boundary conditions	Reference	σ_{11} (MPa) $(0,0,h)$	τ_{13} (MPa) $(4,0,h/2)$	τ_{23} (MPa) $(0,4,h/2)$	u_3 (mm) $(0,0,h)$
			$0° / 90° / 0°$				
	3.81	CCCC	Present	815.62	34.330	33.840	1.297
		SSSS	Present	826.947	36.394	34.243	2.262

	5.715	CCCC	Present	271.980	21.404	14.716	0.767
22.6		SSSS	Present	291.338	21.256	9.609	1.148
	7.62	CCCC	Present	53.111	12.007	5.858	0.678
		SSSS	Present	74.083	12.218	8.263	0.739
	3.81	CCCC	Present	1230.49	60.848	62.6927	2.137
		SSSS	Present	1340.44	60.160	61.371	3.805
	5.715	CCCC	Present	450.811	27.4432	19.810	1.280
40.0		SSSS	Present	481.561	28.100	20.400	1.970
	7.62	CCCC	Present	45.496	9.628	6.422	1.061
		SSSS	Present	65.112	9.676	6.729	1.274
				$30° / -30° / 30°$			
	3.81	CCCC	Present	845.910	23.974	34.844	1.174
		SSSS	Present	860.632	25.334	32.450	1.539
	5.715	CCCC	Present	317.767	14.581	20.908	0.788
22.6		SSSS	Present	324.561	15.309	20.678	0.861
	7.62	CCCC	Present	57.489	7.846	11.952	0.670
		SSSS	Present	87.187	7.912	11.729	0.672
	3.81	CCCC	Present	1220.11	30.7139	54.939	2.204
		SSSS	Present	1248.21	30.353	55.179	2.623
	5.715	CCCC	Present	346.005	16.356	23.133	1.268
40.0		SSSS	Present	368.079	16.551	23.927	1.274
	7.62	CCCC	Present	88.766	6.281	8.890	1.060
		SSSS	Present	94.963	7.738	9.609	1.069

3.2.1. Deflection

Maximum central transverse deflections of 140 mm × 140 mm square composite plate due to impact by spherical impactor of different sizes and incidence velocities under different thickness, stacking sequences and boundary conditions have been presented in Table 1-2. It is observed that the deflection is more in the case of simply supported plate than the plate having fully clamped condition for both cross ply and angle ply laminates. Deflection in composite plate decreases as the size of impactor increases for different incidence velocities and thicknesses under both boundary conditions. For fully clamped cross ply laminate deflection decreases by 2.11% for impactor size increases by 1.5 times with incidence velocity of 22.6 m/s and plate thickness h = 3.81 mm.

To study the effect of ply thickness on the behavior of composite plate, a cross ply laminate with 3, 4 and 5 plies is impacted by a spherical bullet with incidence velocity of 22.6 m/s.

Transverse central deflection at impact point has been plotted for all the three laminate as shown in Fig. 4. Central transverse deflection is showing little bit difference in their peak values but the same trend of variation is observed. However, 4 layered cross ply laminate shows more deflection as compared to others and possibility of this difference is due to its unsymmetrical nature. For symmetric laminates, central deflection and the nature of vibration are more in the case of 5 layered laminate than 3 layered laminate.

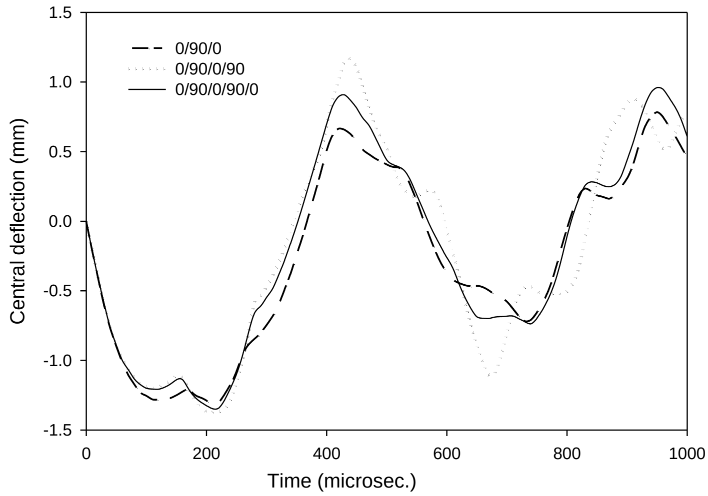


Fig. 4. Central transverse deflections for 3, 4 and 5 layered cross ply laminate

Furthermore, the numerical analysis with the present FE model has been extended to investigate the suitability of ply orientations for the FRP laminate. Three different laminated composite plate made up with different ply orientations have been chosen for study the effect of impact by spherical impactor of incidence velocity 22.6 m/s. Variation of central deflection of three different composite plate such as ($0°/90°/0°$), ($45°/-45°/45°$) and ($30°/-30°/30°$) have been analyzed as shown in Fig. 5. It is observed that the composite plate with lamina scheme ($45°/-45°/45°$) is stiffer than the other laminate as considered because of the central deflection is less as compared to other laminates i.e. ($0°/90°/0°$) and ($30°/-30°/30°$).

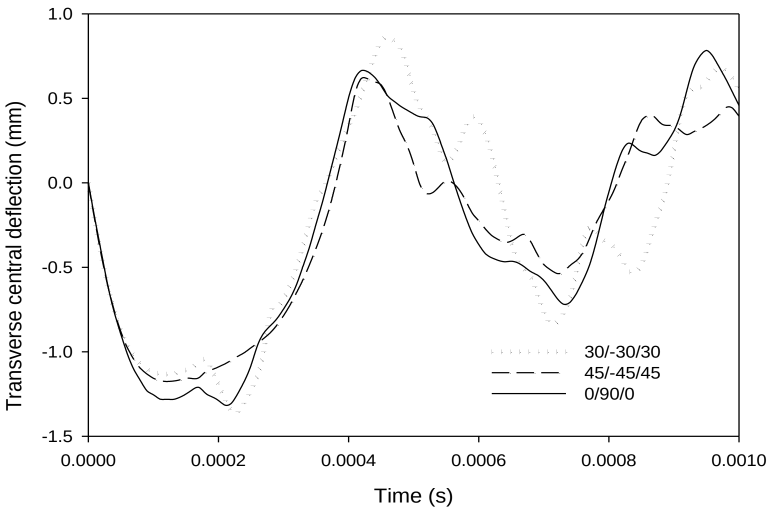


Fig. 5. Central transverse deflections for angle ply and cross ply laminate

3.2.2. Stresses

To study the variation of stresses in FRP composite plate due to impact load, a plate of size 140 mm × 140 mm has been impacted with spherical bullet of different sizes at different incidence velocity under different boundary conditions. Different modes of stresses arises due to impact on the composite plate that cause of damages in FRP composite as stated by Hashin [7]. Therefore, the variations of stresses in FRP composite plate due to impact with different parametric changes in the bullet as well as composite plate are studied. The numerical values of normal stresses and inter laminar stresses are presented in Table 1-2. It is observed from Table 1-2 that, the stresses are more in case of simply supported composite plate as compared to fully clamped plate. Numerical value of stresses decreases as thickness of the composite plate increases.

Considering the impactor size and their effect on stress and deflection, it is observed that the value of normal stress is increased but the deflection decreases when size of impactor increases as shown in Table 1-2. This may be due to more contact surface area of impactor that causes more tension in fiber.

Also, to investigate the nature and variation of normal stress with time under low velocity impact on FRP composite plate, a target plate of thickness 3.81 mm is impacted with incidence velocity of 10 m/s under fully clamped boundary condition. Size of impactor is 5 mm in radius for this analysis. Time interval of 0 to 1000 microseconds is taken for the analysis of impact. From Fig. 6, it is observed that the numerical values of normal stress increases up to maximum limit as the bullet passes and after that it decreases as the bullet rebounds back. After rebound of impactor, composite plate vibrates for long time and hence the nature of stress variation is showing up and down.

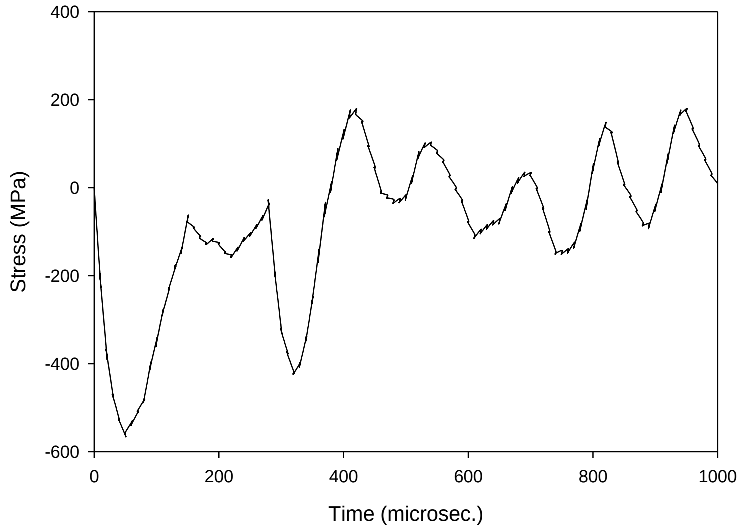


Fig. 6. Variation of normal stress σ_{11} with time

Main concern of damages in composite plate due to impact load is delamination of constituting ply and the main cause of this delamination is inter laminar stresses. Matrix failure in tension occurs due to inter laminar stresses. The variations of inter laminar stresses in composite plate due to impact by spherical bullet with incidence velocity 10 m/s are also studied. Inter laminar stresses τ_{13} and τ_{23} have been plotted at points (4, 0, *h*/2) and (0, 4, *h*/2) which located on mid depth of plate and theses points are the critical point suggested by Sun and Liou [9]. It is observed that the variation in inter laminar stresses are similar but opposite in nature as shown in Fig. 7 (a-b). Both τ_{13} and τ_{23} have their maximum values at same time (40 μs) and being approximately constant after 400 μs. Variations of stresses are showing periodic nature and this may be due to vibration of the plate due to impact.

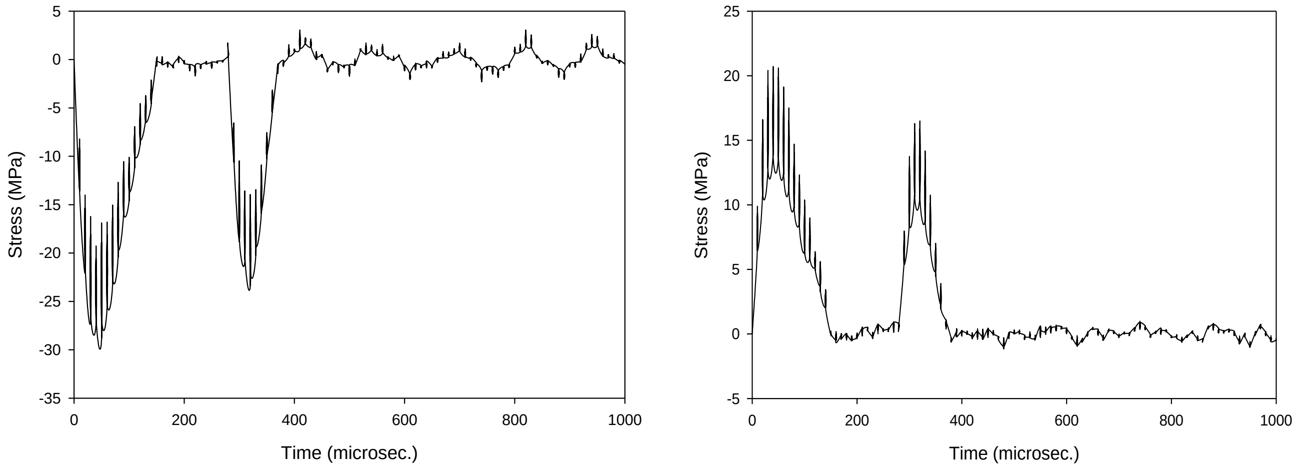
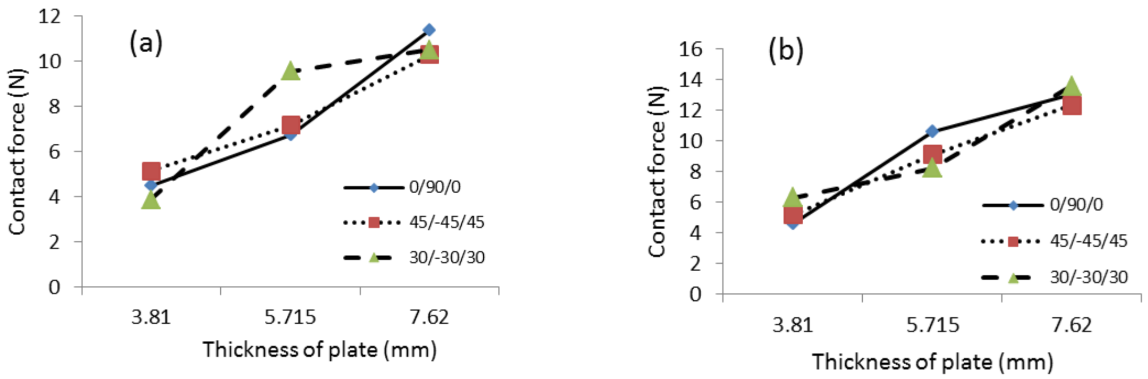


Fig. 7 Variation of inter laminar stress with time, (a) for σ_{13}, (b) for σ_{23}

3.2.3. Contact Force

Contact force in the composite plate due to impact is the measure of momentum change of impactor and resistance applied by composite plate to retain their originality. To study the variation of contact force in FRP composite plate under impact, a plate of size 140 mm × 140 mm is impacted under different incidence velocities and boundary conditions. Effect of composite plate thickness and stacking sequence of lamina on the variation of contact force are also studied. Impactor of mass 0.014175 gm with incidence velocities of 22.6, 50, 75 m/s have been considered. From Figs. 8-10, it may be observed that the contact force increases as the thickness of composite plate as well as velocities of impactor increases.

Influence of boundary conditions of the composite plate on the variation of contact force is also dominant for the cross ply laminate. However the values of contact force shows the increasing trend as the boundary condition releases from clamped to simply supported boundary condition (*CCCC*, *CFCF* and *SSSS*).



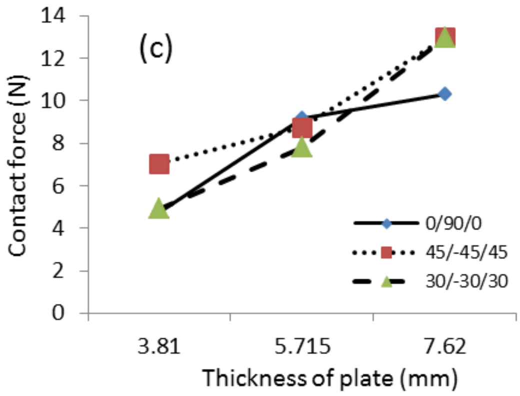


Fig. 8. Variation of contact forces with thickness of at V_0=22.6 m/s, (a) *CCCC* (b) *CFCF* (c) *SSSS*

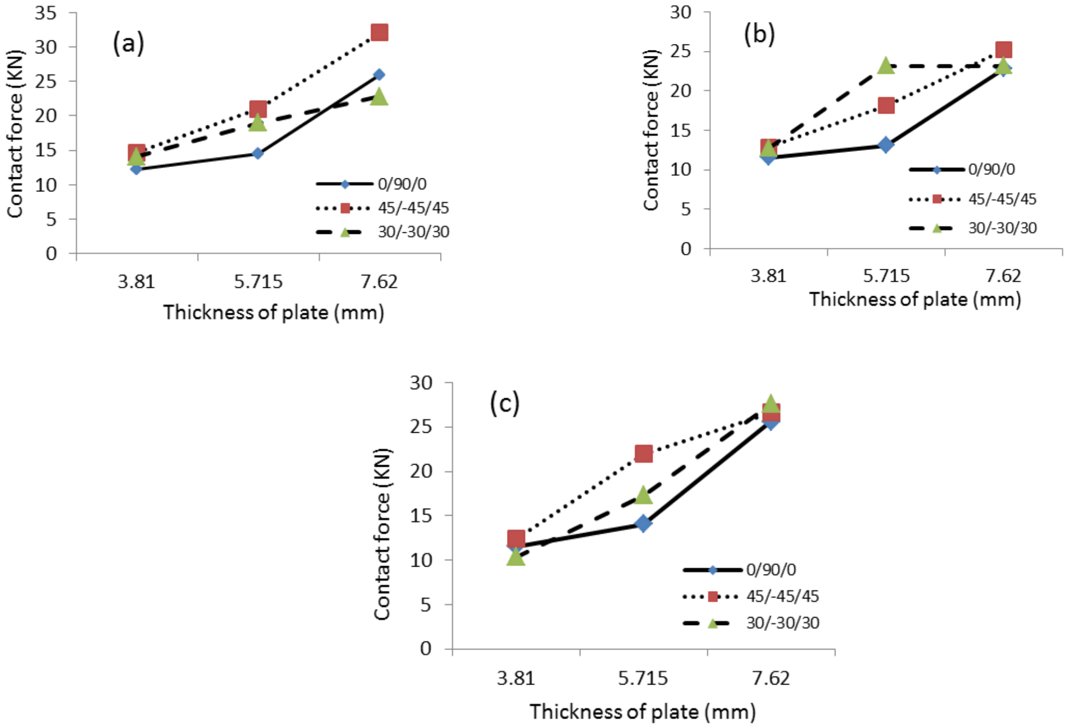


Fig. 9. Variation of contact forces with thickness at V_0=50.0 m/s, (a) *CCCC* (b) *CFCF* (c) *SSSS*

Considering the stacking sequences in laminated composite plate, contact force is slightly more in case of angle ply laminate ($45°/-45°/45°$) than the other two cases as considered for all the thickness under clamped boundary condition.

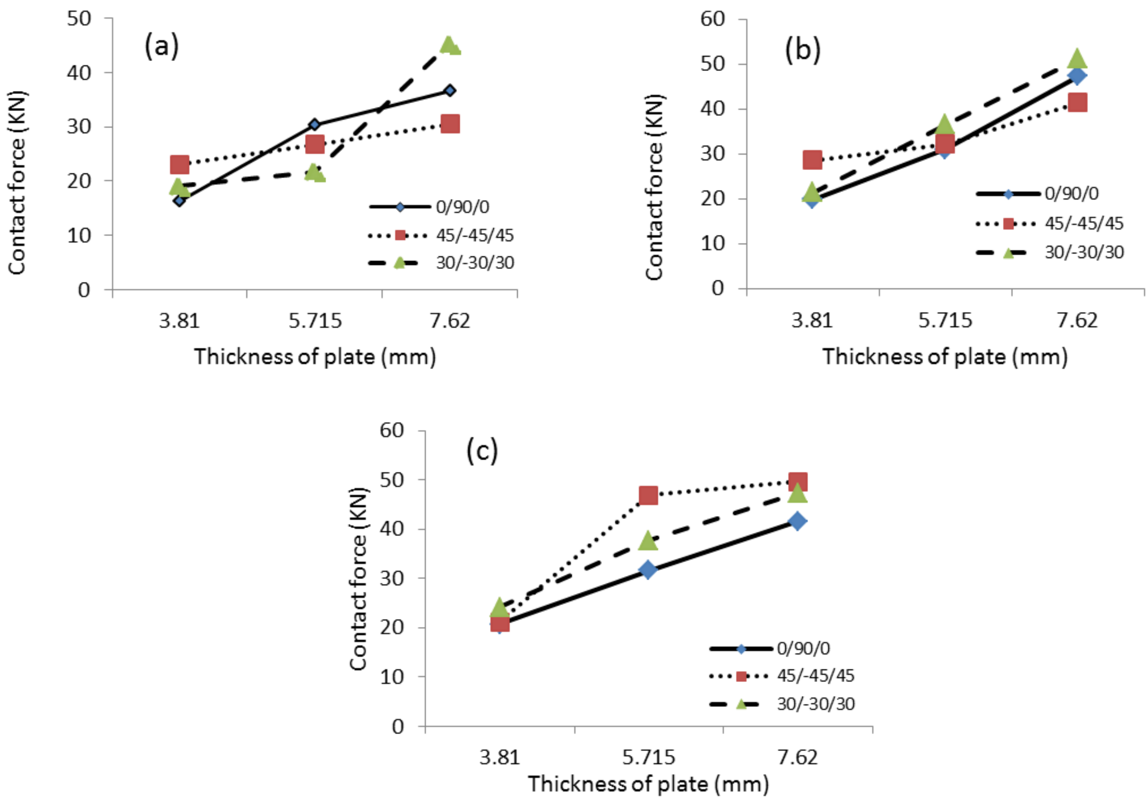


Fig. 10 Variation of contact forces with thickness of plate at V_0=75.0 m/s, (a) *CCCC* (b) *CFCF* (c) *SSSS*

3.3. Damage initiation

FRP composite plate of size 140 mm × 140 mm × 3.81 mm with material properties given in Table 3 and spherical bullet of diameter 10 mm and mass 0.014175 kg have been modeled to study the damage initiation in composite plate due to impact. In this analysis, Hashin's criteria is incorporated in material model to remove the elements those meet the criteria of failure. Element in the composite plate that meet the criteria of damage initiation then it assumed that the contribution of that element in the stiffness matrix calculation is zero. Indeed there is no complete penetration of the FRP composite plate by impactor.

Table 3: Material properties of graphite-epoxy AS-3501-6

Young modulus at fibre direction, E_{11}	142.73 GPa
Young modulus at normal to the fibre, E_{22}	13.79 GPa
Poisson's ratio, υ_{12}	0.3
Shear modulus, G_{12}	4.64 GPa
Shear modulus, G_{13}	4.64 GPa

Shear modulus, G_{23}	3.03 GPa
Density, ρ	1.61 X 10^3 kg / m^3
Tensile strength in the fibre direction, X^T	1447 MPa
Compressive strength in the fibre direction, X^C	1447 MPa
Tensile strength in the direction perpendicular to the fibres, Y^T	51.7 MPa
Compressive strength in the direction perpendicular to the fibre, Y^C	206 MPa
Longitudinal shear strength, S^L	93 MPa
Transverse shear strength, S^T	103 MPa
Volume fraction	0.66

FRP composite plate is impacted with rigid mass spherical bullet with incidence velocity of 22.6 m/s. Different modes of damage initiation as stated in Eq. (2.1-2.4) are studied for all the mentioned stacking sequences under different boundary conditions. Furthermore, to study the amount of failed element under different modes of damage initiation criterion, a cross ply laminate with fully clamped condition is taken into consideration. Fig. 11 (a, b) show the impacted composite plate in which Hashin's criteria of fiber failure in compression and tension are applied as stated in Eq. (2.1-2.2). It is observed that there is no failure in fiber either due to tension or compression.

Hashin's matrix failure criteria under compression (i.e. HSNMCCRT) and tension (i.e. HSNMTCRT) are implemented in impacted composite plate as shown in Fig 11 (c, d) as respectively stated in Eq. 2.3-2.4. There is no damage appeared in the impacted region in case of matrix failure under compression (Fig. 11 c). However, there is damage in composite plate near impacted region in case of fiber failure under tension criteria as observed in Fig. 11 (d). This matrix failure in tension is termed as delamination.

Effect of ply orientation and boundary conditions on the damage behaviour of FRP composite due to matrix failure in tension is studied as shown in Fig. 12. It is observed that the damage is localized near the impact region for all the three laminates of different ply orientation and boundary conditions. However the damaged area in composite plate is more in case of simply supported boundary condition (*SSSS*) than the other two boundary conditions for all the three laminates.

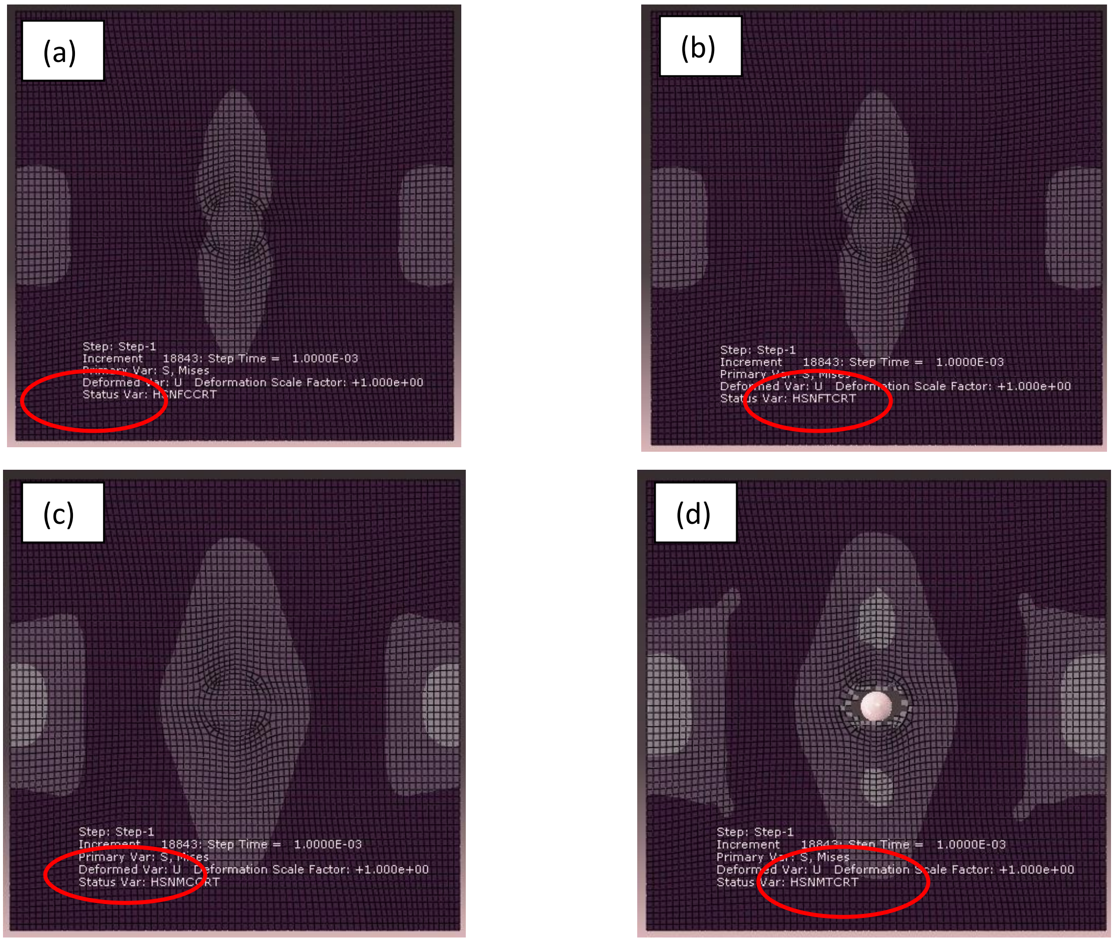


Fig. 11. Failure of elements due to different failure initiation criteria; (a) failure of fibre under compression, (b) failure of fibre under tension, (c) failure of matrix under compression, (d) failure of matrix under compression

Effect of boundary conditions on the damage area in composite plate is more in case cross ply laminate as observed from Fig. 12 (c). Damaged area in composite plate having simply supported condition is more as compared *CCCC* and *CFCF* boundary conditions for all the laminate as considered. In spite of major damage near impact region, there is crack propagation in plate having *SSSS* boundary condition. Damage starts from impact point termed as major damage and propagated along the fiber direction as observed from Fig. 12 (a-i).

In the extension of this study, the amount of damaged area in FRP composite plate of different thickness, stacking sequences and boundary conditions have been studied under impact.

CCCC	*CFCF*	*SSSS*
	0° / 90° / 0°	

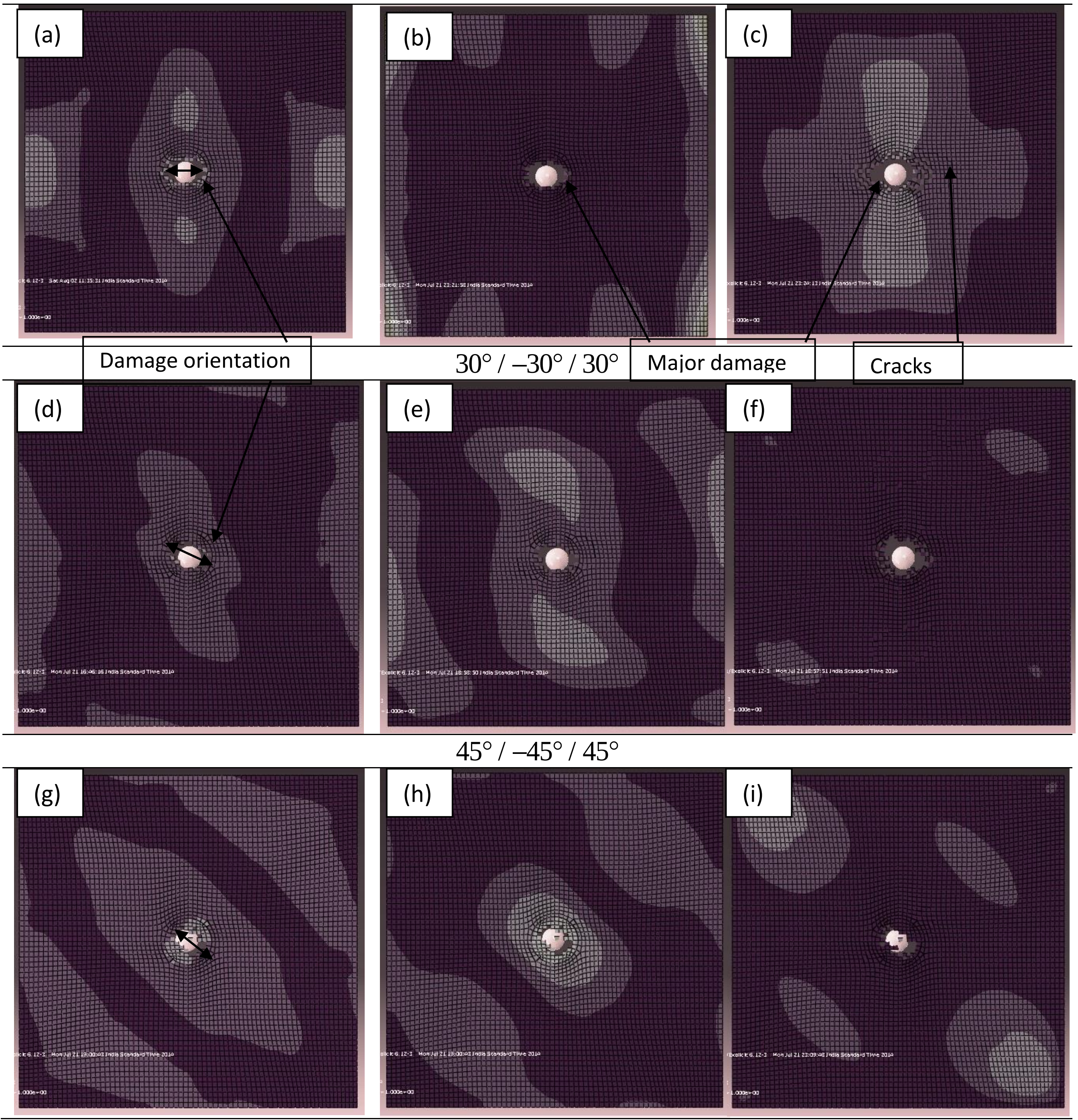


Fig. 12. Damage evolution due to delamination (i.e. HSNMTCRT failure modes)

It is observed that the amount of damaged area in case of angle ply laminate ($45°/-45°/45°$) is less as compared to cross ply ($0°/90°/0°$) and other angle ply ($30°/-30°/30°$) laminates in all the three different boundary conditions as shown in Fig. 13. It may also be observed that the damaged area is less in case of fully clamped composite plate as compared to simply supported one for all the three different laminates as considered.

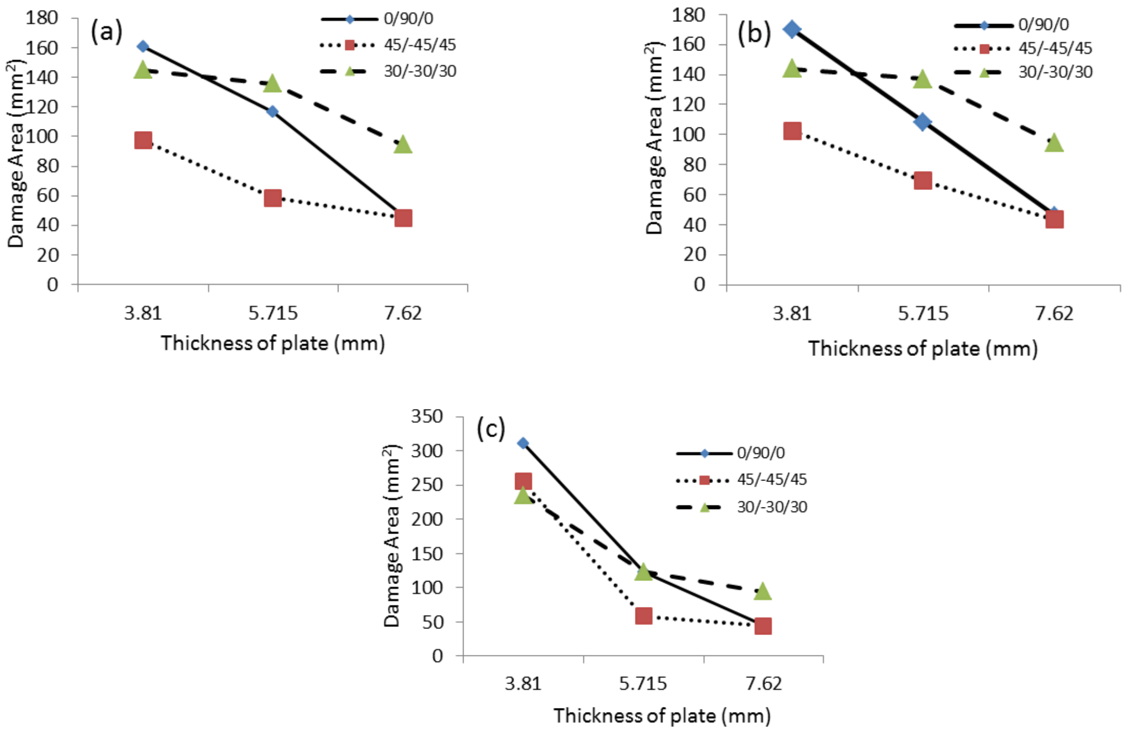


Fig. 13. Variation of damaged area with thickness of plate at V_0=22.6 m/s, (a) *CCCC* (b) *CFCF* (c)

Nomenclature

The following nomenclature is used throughout the paper, otherwise stated locally in the text.

CCCC	–	all four edges clamped
CFCF	–	two edges clamped and two edges free
SSSS	–	all edges simply supported
h	–	thickness of plate
h/a	–	ratio of thickness to side of plate
$\sigma_{11}, \tau_{13}, \tau_{23}$	–	stresses in plate in respective directions
u_3	–	transverse deflection perpendicular to the plate
V_0	–	initial velocity of impactor

4. Conclusions

Laminated FRP composite plate subjected to transverse impact load has been analyzed with finite element model under different parametric variation of impactor as well as composite plate. The damaged areas, central deflections, normal stress and inter laminar stresses in FRP composite with different thickness, stacking sequences of lamina, different sizes and velocities of impactor under different boundary conditions are presented. Nature of failure and its behavior in FRP composite plate have been discussed for different types of laminates and boundary conditions.

On the basis of this analysis some important observations are stated below;

- It may be concluded that the damage initiation and propagation in the composite plate with fully clamped boundary condition is lesser as compared to lesser restrained plate.
- Damage in the composite plate due to low velocity impact is mainly due to matrix cracking in tension or delamination.
- Among the three laminate scheme as considered, angle ply laminate ($45^\circ/-45^\circ/45^\circ$) is stiffer against the deflection and damage than the cross ply ($0^\circ/90^\circ/0^\circ$) and other angle ply ($30^\circ/-30^\circ/30^\circ$) laminates.
- In some cases present results are compared with published results which show close agreement.

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