

# Interlaminar Shear Stresses in Plate Made of Carbon/Epoxy Composite Material Using ANSYS

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**ABSTRACT:** This work deals with the static analysis of carbon/epoxy woven fabric composite under different boundary and load conditions with varying thickness (l/t ratio). The input variables for optimization are number of layers in the composite plate, boundary conditions, load conditions, thickness of composite plate. Boundary conditions like simple supported and clamped supported are considered. In each boundary condition there are two load conditions namely concentrated and uniformly distributed load. A load of 1000 N is applied in the in Z direction. Hence there are four cases with different thickness in terms of 6 types of l/t ratios in the order of 10,20,40,60,100,200. Inter laminar shear stresses are determined in the plates with respect to boundary, loading condition, variation of l/t ratios are included and compared. ANSYS APDL 14.5 is used to carry out the analysis for the stability of the plate.

**KEYWORDS:** Carbon/Epoxy, square plate, FEA, l/t ratio, Interlaminar shear stresses

## I. INTRODUCTION

Static analysis is a type of structural analysis which determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Marcus Schobig et al [1] investigated on Glass fiber reinforced polypropylene and polybutene-1 materials in a high speed tensile test. The glass fiber content especially the strain rate, influence the material behavior. In this case, the stress strains behavior, the tensile strength and the fracture appearance. Hao Yan et al [2] worked on compression-after-Impact failure in woven fiber reinforced composites. Compression failure of composite structures previously damaged by an impact event is due to the propagation of impact induced damage mechanisms such as interlaminar debonding, constituent, micro cracking, sub laminate buckling as well as the interactions between these mechanisms. Alcock et al [3] worked on the effect of temperature and strain rate on the impact performance of recyclable all-polypropylene composites, the relationship between the impact resistance of all-PP composite laminates based on these highly oriented co-extruded PP tapes, and the temperature and velocity of impact. Koerber et al [4] High strain rate characterization of unidirectional carbon-epoxy IM7-8552 in transverse compression and in-plane shear using digital Image correlation. Cantwell et al [5] worked on to identify the fundamental parameters determining the impact resistance of continuous fibre-reinforced composite materials. The effect of varying the properties of the fibre, matrix and interphase are examined as well as the role of target geometry and loading rate on the dynamic response of these materials.

The work done by Guillaume Seon, Andrew Makeev, Yuri Nikishkov and Edward Lee [6] presents a methodology for accurate assessment of the effects of porosity defects on the interlaminar tensile (ILT) fatigue behavior of carbon/epoxy tape composites that can be used in aircraft fatigue-critical structural designs. A primary failure mechanism for such structures is delamination. YosraTurki, MalekHabak [7] Machining generates damages which affect mechanical properties and have to be taken into account during manufacturing process. Experimentally analyzed the influence of drilling on a carbon/epoxy composite, to investigate the relationships among damages, cutting forces, and mechanical properties of the drilled specimens and crack propagation. Stitching and arrange of spindle speed and feed have been

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tested when drilling with a classic twist drill. Seyed mohammad S. Shams, Rani F.El-Hajjar [8] denotes that composite structures are susceptible to a wide variety of defects both during manufacturing and in service. Julien Berthe, Mathias Brieu [9] says Mechanical loads are covering a wide spectrum of strain rates, from low strain rates during operational flights to high strain rates under various impacts. Thermal loads are mainly due to the decrease of the temperature between the ground, for instance the ambient temperature, and the cruise altitude, where the temperature is around 50°C. Michaël Guy Callens, Larissa Gorbatiikh [9] results show that annealed stainless steel fibres have a potential in designing tough polymer composites for structural applications. According to the studies of R.Wisnom, S.R. Hallett, B. G. Green and W.Jiang [10], large composite structures can give much lower strengths than small coupons, and so a proper understanding of scaling is vital for their safe and efficient use. Reddy P R et al [11-15] studied the carbon/epoxy material with CNTs and they characterized the parameters for finding ILSS and fracture behaviors using FEA.

## II. PROBLEM STATEMENT

A Carbon/epoxy composite orthotropic square plate of 500 mm is taken to analyze. In order to do that the area of the square plate is divided into four parts. The four square plates each plate having the dimension of 250 mm X 250 mm Therefore only this quarter plate is analyzed as the whole plate possesses the same properties. According to the  $l/t$  ratios the total thickness of plate is calculated. As the length 'l' is constant i.e 254mm then the thickness with respect to  $l/t$  ratio are 10, 20 40, 66.6, 100, 200 the thickness is calculated in mm successively as 25.4, 12.7, 6.35, 3.8, 2.54, 1.27. As the thickness of each layer is constant i.e 0.3mm, the number of layers differs such as 85, 42, 21, 13, 8, 4. Two types of boundary conditions are applied like simply supported (SS) and clamped supported (Clamped). In each type of boundary condition two types of load conditions are applied, they are concentrated load (CL) and uniformly distributed load (UDL). A load of 1000N is applied in terms of force in Z direction .

So the boundary and load conditions cases are (i) Simply Supported Plate Under Concentrated Load (SS\_CL),(ii) Simply Supported Plate Under Uniformly Distributed Load (SS\_UDL),(iii) Clamped Plate Under Concentrated Load (Clamped\_CL) and (iv)Clamped Plate Under Uniformed Distributed Load (Clamped\_UDL). The quarter plate is analysed with symmetric boundary conditions and loading.

## III. FINITE ELEMENT MODELING OF THE PLATE

The laminate orientations of all the laminae are  $0^{\circ}$  as the composite is woven-Fabric. Material properties of orthotropic Carbon/epoxy are  $E_x = 70.03$  MPa;  $E_y = 70.03$  MPa;  $E_z = 12.65$  MPa;  $\nu_{xy} = 0.04$ ;  $\nu_{yz} = 0.31$ ;  $\nu_{xz} = 0.31$ ;  $G_{xy} = 3.81$  MPa;  $G_{yz} = 4.19$  MPa;  $G_{xz} = 4.19$  MPa. The mesh refinement is made based on the convergence studies.

## IV. RESULTS AND DISCUSSIONS

**A.Comparison of interlaminar shear stresses with respective layers in different boundary and load conditions:**The figures 1 to 8 are plotted between the interlaminar shear stresses(ILSS) in particular plane and layer number of different  $l/t$  ratios successively 40, 66.6, 100, 200 in all the four cases of load and boundary conditions, the variation look alike in all the cases for a particular plane. The graph indicating the variation of inter laminar shear stresses in XY plane( $S_{xy}$ ) for simply supported plate under concentrated load at  $l/t=66.6$ ;  $l/t=100$ ;  $l/t= 200$ . The  $l/t=40$  plate has 21 layers,  $l/t=66.6$  plate has 13 layers,  $l/t=100$  plate has 8 layers,  $l/t=200$  plate has 4 layers. The plate with less thickness which has four layers has the maximum inter laminar shear stress at the 3<sup>rd</sup> and 4<sup>th</sup> layer. Initially at 1<sup>st</sup> and 2<sup>nd</sup> layers the stresses are same equivalent to the remaining plates of  $l/t$  ratio of 40, 66.6, 100, 200. As the  $l/t$  ratio increasing from 40 to 200, the interlaminar shear stresses are decreasing. Interlaminar shear stresses are inversely proportional to the thickness of the plate. The above discussed concept is shown in the Fig. 1 to Fig. 8 the inter laminar shear stresses are in YZ and XZ planes are same. They follow the symmetrical pattern with respect to their mid layers. Therefore irrespective of  $l/t$  ratios, the curves of these take the shape of concave parabola as the stresses increase up to a certain level at the middle layer and fall, attains the initial stresses value at the bottom layer. Here also the plate with fewer layers has the maximum inter laminar shear stresses.

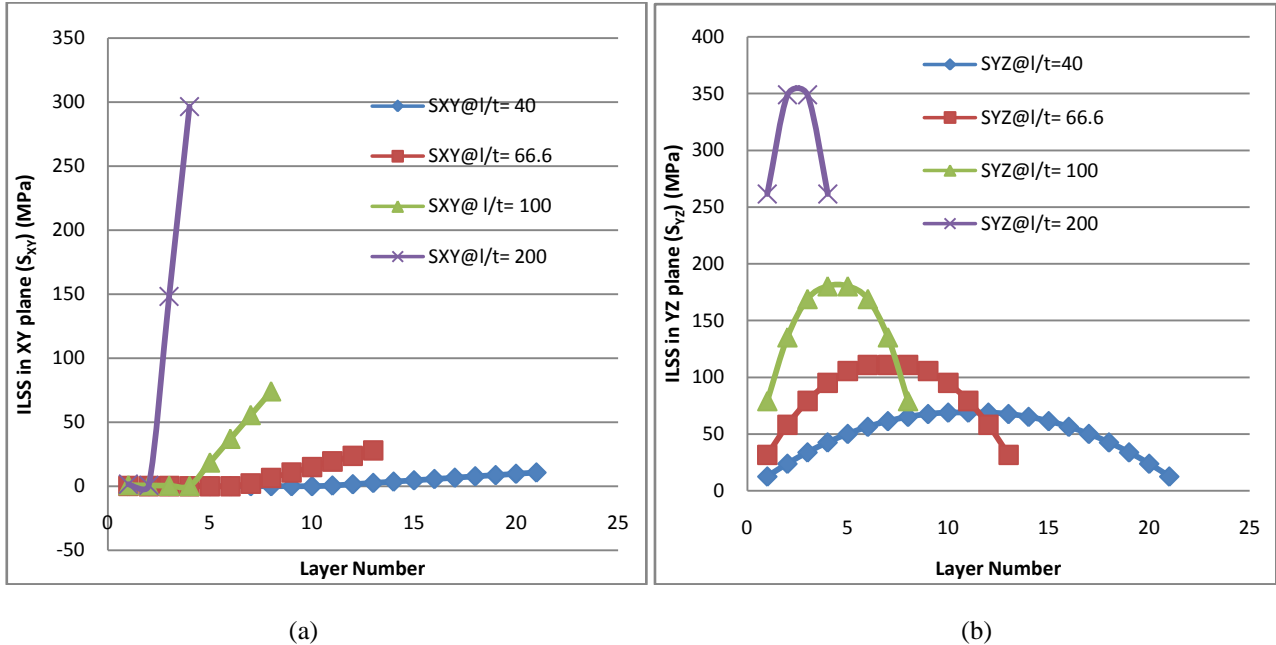


Figure 1: Variation of Interlaminar shear stresses for simply supported concentrated load at  $l/t = 40, 66.6, 100, 200$  in (a) XY plane; (b) YZ plane

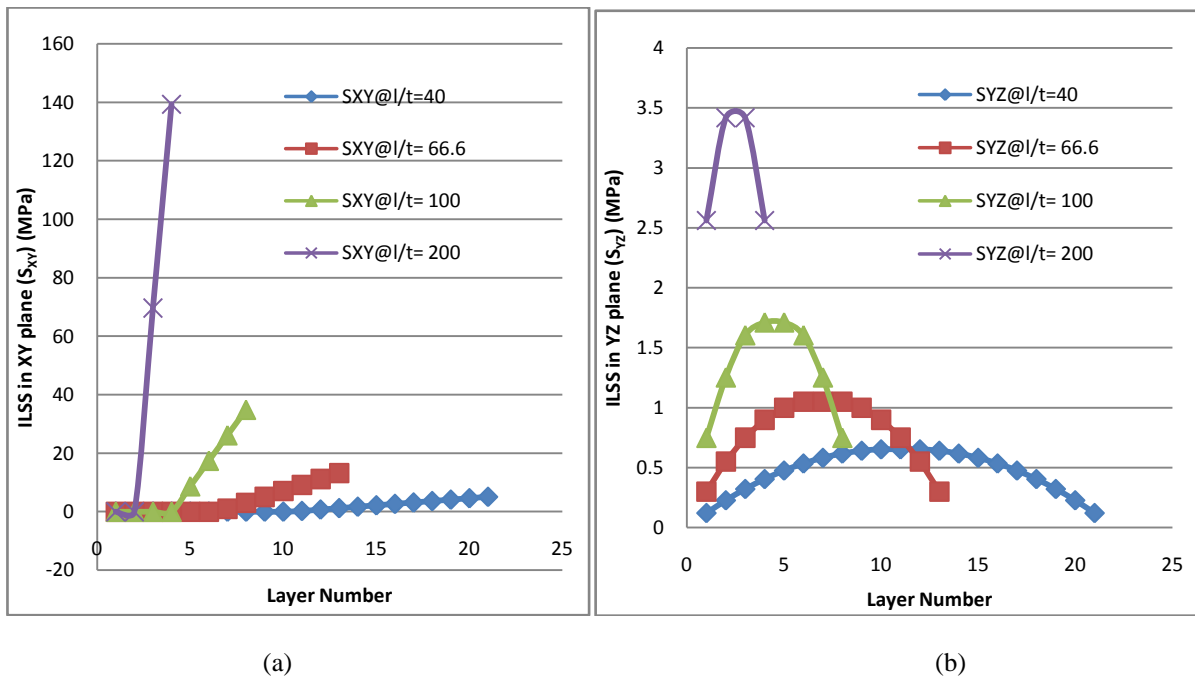
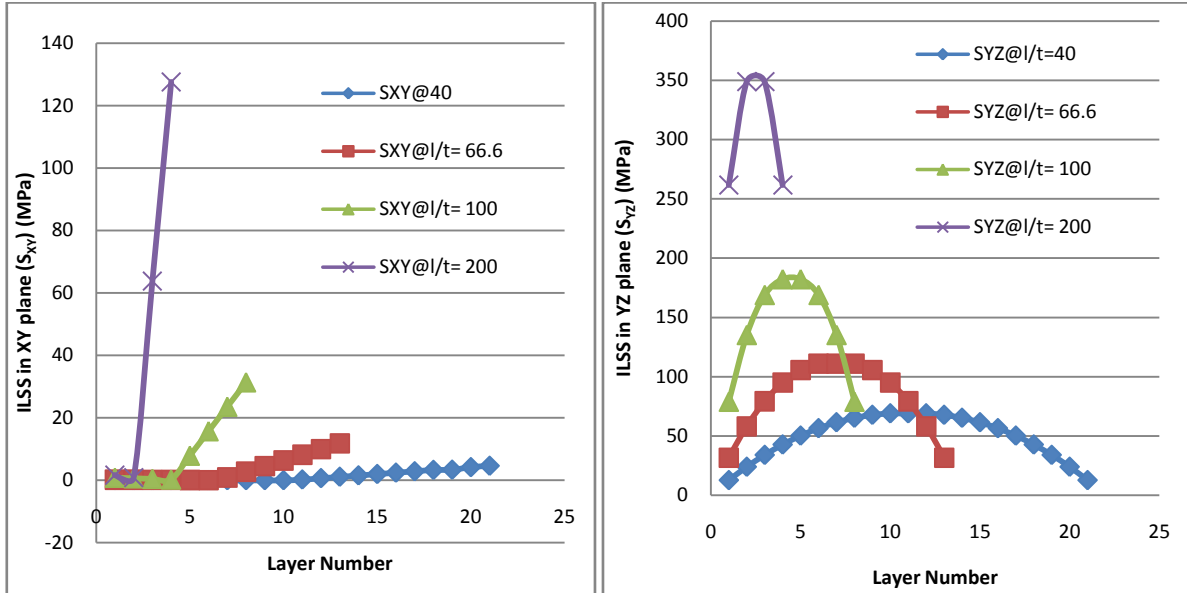


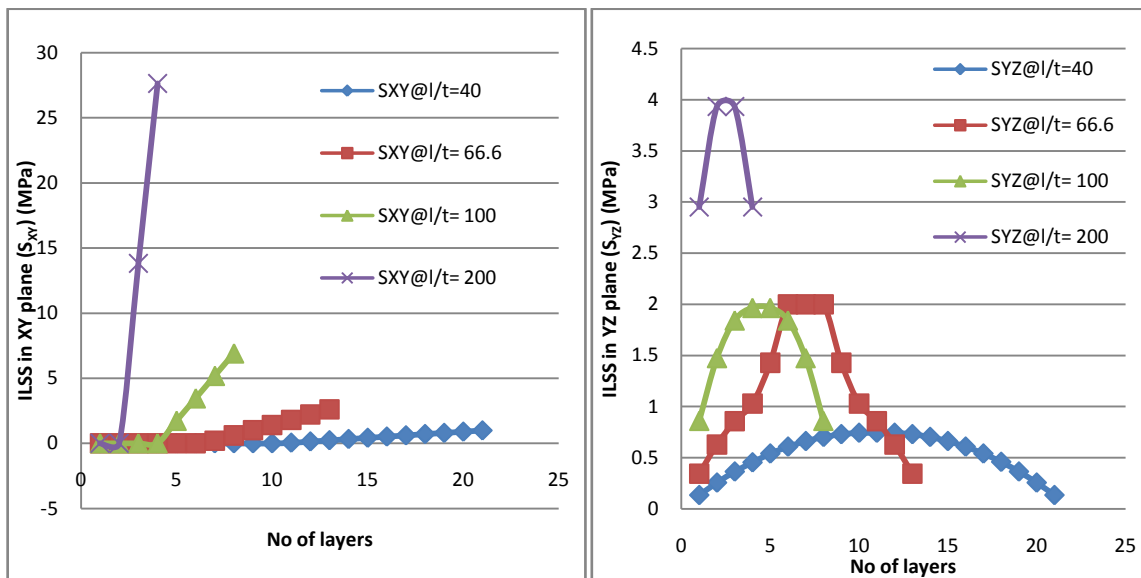
Figure 2: Variation of Interlaminar shear stresses for simply supported uniformly distributed load at  $l/t=40, 66.6, 100, 200$  in (a) XY plane; (b) YZ plane



(a)

(b)

Figure 3: Variation of Interlaminar shear stresses for clamped supported concentrated load at  $l/t=40, 66.6, 100, 200$  in (a) XY plane; (b) YZ plane

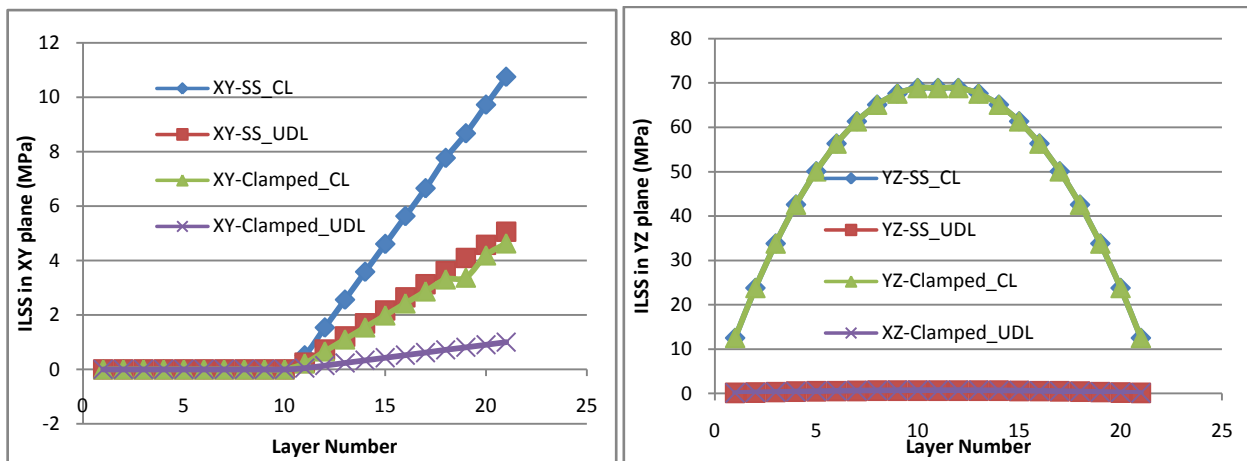


(a)

(b)

Figure 4: Variation of Interlaminar shear stresses for clamped supported uniformly distributed load at  $l/t=40, 66.6, 100, 200$  in (a) XY plane; (b) YZ plane

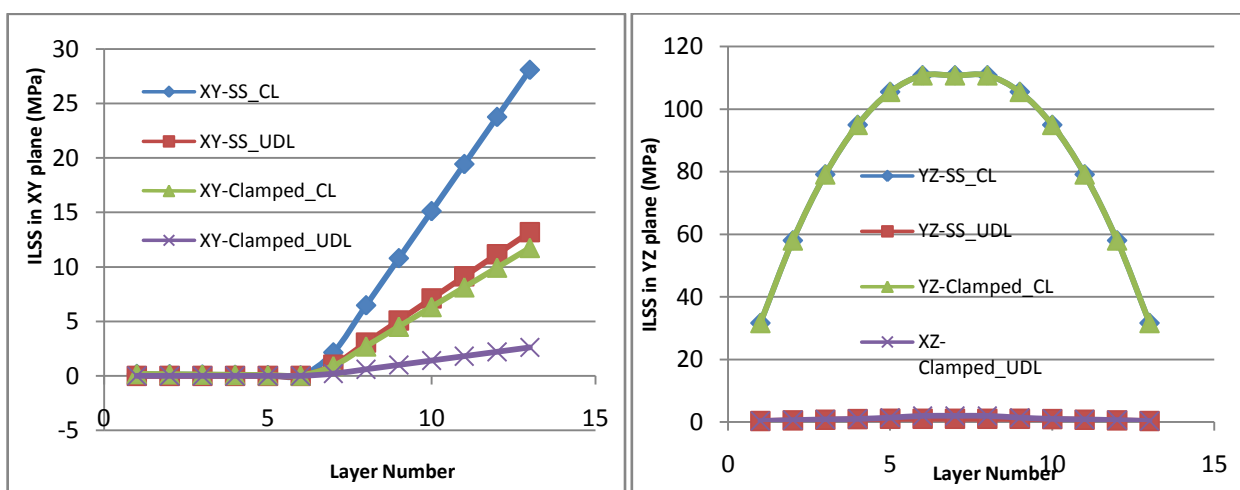
**B. Comparison of interlaminar shear stresses in specified direction with respect to different boundary and load condition at different l/t ratios:** When compared here irrespective of all l/t ratios the interlaminar shear stresses from fig. 9 to 16 in XY plane are almost follow similar pattern in all boundary and load conditions. They almost have the same values of ILSS from top layer to middle layer, but after the mid layer they differ. Simply supported concentrated load (SS\_CL) holds the maximum ILSS values compared to others. The order followed by simply supported uniformly distributed load (SS\_UDL), clamped concentrated load (Clamped\_CL) and clamped uniformly distributed load (Clamped\_UDL). Simply supported uniformly distributed load (SS\_UDL), clamped concentrated load (Clamped\_CL) gives almost nearer values of ILSS in XY direction. In YZ direction the set of ILSS are same in Simply supported concentrated load (SS\_CL) and clamped concentrated load (Clamped\_CL) are same. Another set of simply supported uniformly distributed load (SS\_UDL) and clamped uniformly distributed load (Clamped\_UDL) are almost same.



(a)

(b)

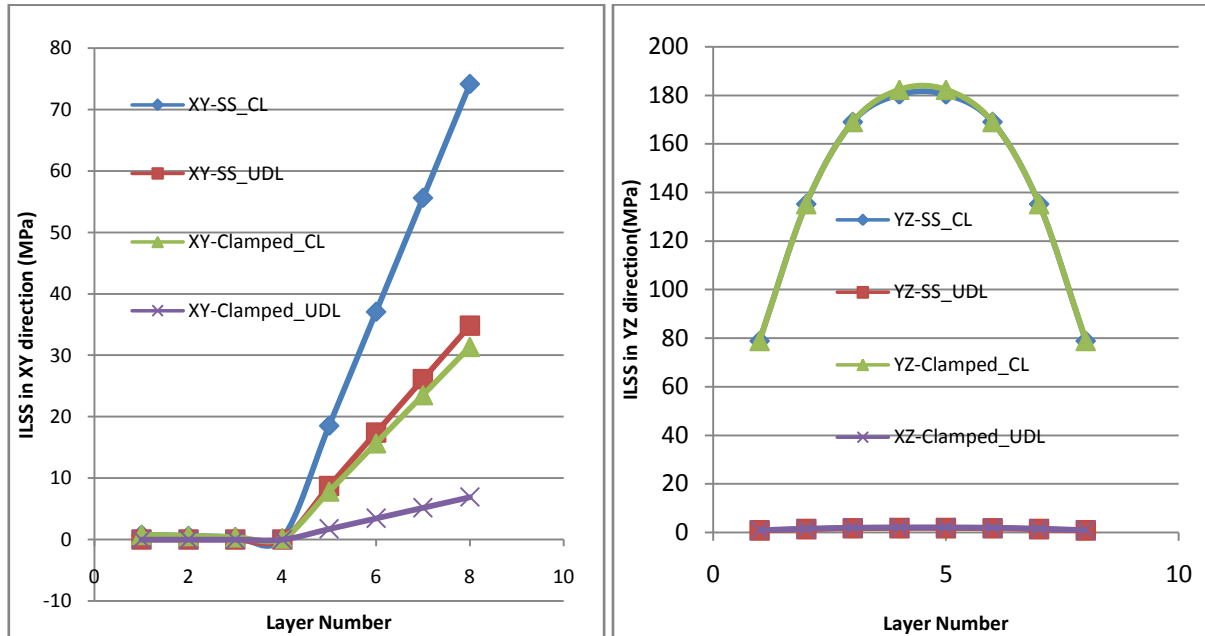
Figure 5: Variation of interlaminar shear stresses with respect to l/t ratio l/t= 40 at different boundary and load conditions in (a) XY plane (b) YZ plane



(a)

(b)

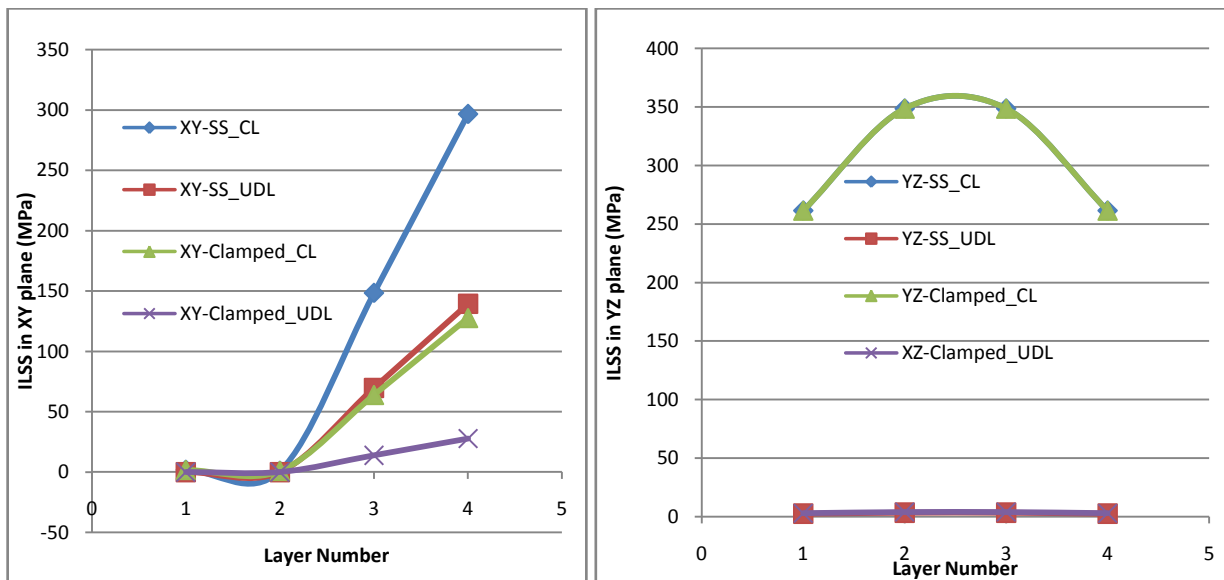
Figure 6: Variation of interlaminar shear stresses with respect to l/t ratio l/t= 66.6 at different boundary and load conditions in (a) XY plane (b) YZ plane



(a)

(b)

Figure 7: Variation of interlaminar shear stresses with respect to  $l/t$  ratio  $l/t= 100$  at different boundary and load conditions in (a) XY plane (b) YZ plane



(a)

(b)

Figure 8: Variation of interlaminar shear stresses with respect to  $l/t$  ratio  $l/t= 100$  at different boundary and load conditions in (a) XY plane (b) YZ plane

**C. Interlaminar shear stresses of each layer with respect to boundary conditions with their respective  $l/t$  ratios:**  
The interlaminar shear stresses are zero for  $l/t$  ratio 10 and 20. In all the cases irrespective of boundary and load conditions the shear stresses in XY direction increases from top layer to bottom layer. In case of YZ and XZ directions

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it increases from top layer to middle layer and then decreases to the last layer symmetrically. In the load condition of irrespective of boundary conditions, in concentrated load the stresses in XZ and YZ planes are greater than the stresses in XY direction. In the load condition of uniformly distributed load the stresses in XY are greater than YZ and XZ. The stresses are higher for concentrated load than the UDL.

Table1: Interlaminar shear stresses for a simply supported plate under concentrated and uniformly distributed load at  $l/40$

Layer No.	Interlaminar shear stresses, MPa					
	$S_{xy}$ in MPa		$S_{yz}$ in MPa		$S_{xz}$ in MPa	
	CL	UDL	CL	UDL	CL	UDL
1	0	0	12.521	0.1184	12.521	0.1184
2	0	0	23.789	0.225	23.789	0.225
3	0	0	33.806	0.3197	33.806	0.3197
4	0	0	42.5921	0.4026	42.592	0.4026
5	0	0	50.084	0.4737	50.084	0.4737
6	0	0	56.344	0.5329	56.344	0.5329
7	0	0	61.352	0.5803	61.352	0.5803
8	0	0	65.109	0.6158	65.109	0.6158
9	0	0	67.613	0.6395	67.613	0.6395
10	0	0	68.865	0.6513	68.865	0.6513
11	0.5117	0.2410	68.865	0.6513	68.865	0.6513
12	1.5351	0.7231	68.865	0.6513	68.865	0.6513
13	2.558	1.2051	67.613	0.6395	67.613	0.6395
14	3.582	1.6872	65.109	0.6158	65.109	0.6158
15	4.6055	2.1693	61.352	0.5803	61.352	0.5803
16	5.629	2.651	56.344	0.5329	56.344	0.5329
17	6.652	3.1334	50.084	0.4737	50.084	0.4737
18	7.765	3.6155	42.5714	0.4026	42.571	0.4026
19	8.669	4.0976	33.806	0.3197	33.806	0.3197
20	9.722	4.5797	23.789	0.2250	23.789	0.2250
21	10.746	5.061	12.521	0.1184	12.521	0.1184

Table2 shows the variation of the interlaminar shear stresses in the plate in all 21 layers. From the table it is observed that the maximum stresses are induced in the plate due to concentrated load than the application of uniformly distributed load. The shear stresses in xy plane are higher than the other planes. The variation of shear stresses in xy plane is linear where as the variation of transverse shear stresses are parabolic maximum at the middle and minimum at the end layers. Table3 shows the variation of the interlaminar shear stresses in the plate in all 13 layers. From the table it is observed that the maximum stresses are induced in the plate due to concentrated load than the application of uniformly distributed load. The shear stresses in xy plane are higher than the other planes. The variation of shear stresses in xy plane is linear where as the variation of transverse shear stresses are parabolic maximum at the middle and minimum at the end layers.

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Table2: Interlaminar shear stresses for clamped plate under concentrated and uniformly distributed load at  $l/t= 40$ .

Layer No.	Interlaminar shear stresses, MPa					
	$S_{XY}$ in MPa		$S_{YZ}$ in MPa		$S_{XZ}$ in MPa	
	CL	UDL	CL	UDL	CL	UDL
1	0.00117	0	12.521	0.1351	12.521	0.1351
2	0.00106	0	23.789	0.2567	23.789	0.2567
3	0.000951	0	33.806	0.3647	33.806	0.3647
4	0.000839	0	42.572	0.4543	42.572	0.4543
5	0.000727	0	50.084	0.5404	50.084	0.5404
6	0.000615	0	56.344	0.6079	56.344	0.6079
7	0.000503	0	61.352	0.662	61.352	0.662
8	0.000392	0	65.109	0.7025	65.109	0.7025
9	0.00028	0	67.613	0.7295	67.613	0.7295
10	0.000168	0	68.865	0.74309	68.865	0.74309
11	0.2205	0.0474	68.865	0.74308	68.865	0.74308
12	0.6617	0.1424	68.865	0.74308	68.865	0.74308
13	1.102	0.2374	67.613	0.7295	67.613	0.7295
14	1.544	0.3323	65.109	0.70255	65.109	0.70255
15	1.985	0.4273	61.352	0.662	61.352	0.662
16	2.426	0.5222	56.344	0.6079	56.344	0.6079
17	2.867	0.6172	50.084	0.5404	50.084	0.5404
18	3.308	0.7172	42.571	0.4593	42.571	0.4593
19	3.374	0.8071	33.806	0.3647	33.806	0.3647
20	4.191	0.9021	23.789	0.2567	23.789	0.2567
21	4.632	0.9971	12.521	0.1351	12.521	0.1351

Table3: Interlaminar shear stresses for simply supported plate under concentrated and uniformly distributed load at  $l/t= 66.6$ .

Layer No.	Interlaminar shear stresses, MPa					
	$S_{XY}$ in MPa		$S_{YZ}$ in MPa		$S_{XZ}$ in MPa	
	CL	UDL	CL	UDL	CL	UDL
1	0.1785	0.0000095	31.659	0.2992	31.659	0.2992
2	0.151	0.0000080	58.042	0.5485	58.042	0.5485
3	0.1236	0.0000066	79.148	0.748	79.148	0.748
4	0.0961	0.0000051	94.978	0.8976	94.978	0.8976
5	0.0686	0.0000036	105.532	0.9974	105.532	0.9974
6	0.0412	0.0000022	110.808	1.0472	110.808	1.0472
7	2.158	1.0151	110.808	1.0472	110.808	1.0472
8	6.476	3.0452	110.808	1.0472	110.808	1.0472
9	10.794	5.0753	105.532	0.9974	105.532	0.9974
10	15.112	7.1055	94.978	0.8976	94.978	0.8976
11	19.43	9.1356	79.148	0.748	79.148	0.748
12	23.7486	11.1758	58.042	0.5485	58.042	0.5485
13	28.0666	13.1959	31.659	0.2992	31.659	0.2992

Table4 shows the variation of the interlaminar shear stresses in the plate in all 13 layers. From the table it is observed that the maximum stresses are induced in the plate due to concentrated load than the application of uniformly distributed load. The shear stresses in xy plane are higher than the other planes. The variation of shear stresses in xy



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plane is linear where as the variation of transverse shear stresses are parabolic maximum at the middle and minimum at the end layers.

Table4: Interlaminar shear stresses for clamped plate under concentrated and uniformly distributed load at  $l/t= 66.6$ .

Layer No.	Interlaminar shear stresses, MPa					
	$S_{XY}$ in MPa		$S_{YZ}$ in MPa		$S_{XZ}$ in MPa	
	CL	UDL	CL	UDL	CL	UDL
1	0.1785	$8*10^{-6}$	31.659	0.3428	31.659	0.3428
2	0.151	$6*10^{-6}$	58.042	0.6285	58.042	0.6285
3	0.1235	$3*10^{-6}$	79.148	0.8571	79.148	0.8571
4	0.0961	$4*10^{-6}$	94.978	1.0285	94.978	1.0285
5	0.0686	$3*10^{-6}$	106	1.428	106	1.428
6	0.0411	$1*10^{-6}$	110.80	1.999	110.80	1.999
7	0.9041	0.2008	110.80	1.999	110.80	1.999
8	2.712	0.6026	110.80	1.999	110.80	1.999
9	4.5206	1.0043	105.53	1.428	105.53	1.428
10	6.328	1.4061	94.978	1.0285	94.978	1.0285
11	8.137	1.8078	79.148	0.8571	79.148	0.8571
12	9.945	2.2096	58.042	0.6285	58.042	0.6285
13	11.753	2.6114	31.659	0.3428	31.659	0.3428

Table5: Interlaminar shear stresses for simply supported plate under concentrated and uniformly distributed load at  $l/t= 100$ .

Layer No.	Interlaminar shear stresses, MPa					
	$S_{XY}$ in MPa		$S_{YZ}$ in MPa		$S_{XZ}$ in MPa	
	CL	UDL	CL	UDL	CL	UDL
1	0.7866	0.000065	78.868	0.7483	78.868	0.7483
2	0.59002	0.0000488	135.204	1.252	135.204	1.252
3	0.3933	0.0000325	169.005	1.6035	169.005	1.6035
4	0.1966	0.0000163	180.271	1.7104	180.271	1.7104
5	18.534	8.707	180.271	1.7104	180.271	1.7104
6	37.069	17.415	169.005	1.6035	169.005	1.6035
7	55.6041	26.123	135.204	1.252	135.204	1.252
8	74.138	34.831	78.868	0.7483	78.868	0.7483

Table6: Interlaminar shear stresses for clamped plate under concentrated and uniformly distributed load at  $l/t= 100$ .

Layer No.	Interlaminar shear stresses, MPa					
	$S_{XY}$ in MPa		$S_{YZ}$ in MPa		$S_{XZ}$ in MPa	
	CL	UDL	CL	UDL	CL	UDL
1	0.7866	0.000041	78.868	0.8594	78.868	0.8594
2	0.5899	0.000031	135.204	1.4742	135.204	1.4742
3	0.3933	0.000020	169.004	1.8428	169.004	1.8428
4	0.1966	0.000110	182.271	1.9656	182.271	1.9656
5	7.84	1.7263	182.271	1.9656	182.271	1.9656
6	15.6813	3.4527	169.004	1.8428	169.004	1.8428
7	23.522	5.1791	135.204	1.4742	135.204	1.4742
8	31.3626	6.9055	78.868	0.8594	78.868	0.8594

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Table5 and 6 shows the variation of the interlaminar shear stresses in the plate in all 8 layers. From the table it is observed that the maximum stresses are induced in the plate due to concentrated load than the application of uniformly distributed load. The shear stresses in xy plane are higher than the other planes. The variation of shear stresses in xy plane is linear where as the variation of transverse shear stresses are parabolic maximum at the middle and minimum at the end layers. Table7 and 8 shows the variation of the interlaminar shear stresses in the plate in all 4 layers. From the table it is observed that the maximum stresses are induced in the plate due to concentrated load than the application of uniformly distributed load. The shear stresses in xy plane are higher than the other planes. The variation of shear stresses in xy plane is linear where as the variation of transverse shear stresses are parabolic maximum at the middle and minimum at the end layers.

Table7: Interlaminar shear stresses for simply supported plate under concentrated and uniformly distributed load at  $l/t=200$ .

Layer No.	Interlaminar shear stresses, MPa					
	$S_{XY}$ in MPa		$S_{YZ}$ in MPa		$S_{XZ}$ in MPa	
	CL	UDL	CL	UDL	CL	UDL
1	1.653	0.0000711	261.532	2.562	261.532	2.562
2	0.8266	0.0000355	348.71	3.417	348.71	3.417
3	148.301	69.649	348.71	3.417	348.71	3.417
4	296.602	139.299	261.532	2.562	261.532	2.562

Table8: Interlaminar shear stresses for simply supported plate under concentrated and uniformly distributed load at  $l/t=200$ .

Layer No.	Interlaminar shear stresses, MPa					
	$S_{XY}$ in MPa		$S_{YZ}$ in MPa		$S_{XZ}$ in MPa	
	CL	UDL	CL	UDL	CL	UDL
1	1.653	0	261.532	2.9505	261.532	2.9505
2	0.8265	0	348.709	3.934	348.709	3.934
3	63.786	13.8201	348.709	3.934	348.709	3.934
4	127.572	27.6402	261.532	2.9505	261.532	2.9505

## V. CONCLUSIONS

Interlaminar shear stresses (ILSS) in any plane irrespective of boundary and load conditions, the plate with less number of layers i.e the  $l/t = 200$  holds the maximum value of ILSS. At any  $l/t$  ratio the ILSS values in XY plane are same upto the middle layer irrespective of the boundary and load conditions. From the mid layers to bottom layer the condition of SS\_CL holds the maximum ILSS in that plane. At any particular  $l/t$  ratio the ILSS value in YZ plane are same and alike for the conditions of SS\_CL and Clamped\_CL. At the same  $l/t$  ratio the other two load conditions like SS\_UDL and Clamped\_UDL, the values are almost same. The ILSS values follow the property of symmetry with layers of the plate. Therefore the variation follows a curve shape of concave parabola. The SS\_CL and Clamped\_CL values of ILSS are very high compared to the remaining two cases of SS\_UDL and Clamped\_UDL. At any  $l/t$  ratio the central deflection for square plate is maximum in SS\_CL condition and the minimum value occurs in Clamped\_UDL condition. SS\_CL is succeeded by SS\_UDL and Clamped\_UDL is preceded by Clamped\_CL.

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