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STATIC ANALYSIS COMPARISON of E-GLASS/ POLYMER AND CARBON/EPOXY COMPOSITE PLATES

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ABSTRACT

Fibers or particles embedded in matrix of another material are the best example of modern-day composite materials, which are mostly structural. The advanced qualities of the composites make them used in most of the applications like in Aerospace engineering, constructions etc. The static analysis of plates made of composite materials Carbon/Epoxy and E-Glass/Polyester under concentrated and uniformly distributed loads with clamped boundary conditions are used to predict the deflection and stresses. The deflection and stresses are estimated for the plate with varying number of layers, and thickness of entire composite plate. In each condition the length of the plate is kept constant and the thickness of the plate is varied. In each boundary condition there are two load conditions namely concentrated and uniformly distributed load. A load of 1000 N is applied in the Z direction. Hence there are four different thicknesses in terms of 6 types of l/t ratio in the order of 10,20,40,66.6,100,200. Variation of nodal displacements in Z direction with respect to distance from the center is studied. Influence of l/t ratio on the thickness of the plate and the deflection, stress values are estimated with different load conditions. ANSYS APDL 14.5 is used to carry out the analysis of the plate.

KEY WORDS: ANSYS, Composites, Modeling, Static analysis.

I.INTRODUCTION

People have been making composites for many thousands of years. One early example is mud bricks. Mud can be dried out into a brick shape to give a building material. It is strong to squash it (it has good compressive strength) but it breaks quite easily when tried to bend it (it has poor tensile strength). Straw seems very strong tried to stretch it, but it can be crumpled easily. By mixing mud and straw together it is possible to make bricks that are resistant to both squeezing and tearing and make excellent building blocks. Another ancient composite is concrete. Concrete is a mix of aggregate (small stones or gravel), cement and sand. It has good compressive strength (it resists squashing). In more recent times it has been found that adding metal rods or wires to the concrete can increase its tensile (bending) strength. Concrete containing such rods or wires is called reinforced concrete. Most composites are made of just two materials. One is the matrix or binder. It surrounds and binds together fibres or fragments of the other material, which is called the reinforcement.

The first modern composite material was fibre glass. It is still widely used today for boat hulls, sports equipment, building panels and many car bodies. The matrix is a plastic and the reinforcement is glass that has been made into fine threads and often woven into a sort of cloth. On its own the glass is very strong but brittle and it will break if bent sharply. The plastic matrix holds the glass fibers together and also protects them from damage by sharing out the forces acting on them. Some advanced composites are now made using carbon fibers instead of glass. These materials are lighter and stronger than fibre-glass but more expensive to produce. They are used in aircraft structures and expensive sports equipment such as golf clubs. Carbon nanotubes have also been used successfully to make new composites. These are even lighter and stronger than composites made with ordinary carbon fibres but they are still extremely expensive. They do, however, offer possibilities for making lighter cars and aircraft (which will use less fuel than the heavier vehicles we have now). The new Airbus A380, the world's largest passenger airliner, makes use of modern composites in its design. More than 20 % of the A380 is made of composite materials, mainly plastic reinforced with carbon fibres. The design is the first large-scale use of glass-fibre-reinforced aluminum, a new composite that is 25 % stronger than conventional airframe aluminum but 20 % lighter. The biggest advantage of modern composite materials is that they are light as well as strong. By choosing an appropriate combination of matrix and reinforcement material, a new material can be made that exactly meets the requirements of a particular application. Composites also provide design flexibility because many of them can be moulded into complex shapes. The downside is often the cost. Although the resulting product is more efficient, the raw materials are often expensive.

Polymer matrix composites are predominantly used for the aerospace industry, but the decreasing price of carbon Fibers is widening the applications of these composites to include the automobile, marine, sports, biomedical, construction, and other industries [1]. Carbon Fiber polymer-matrix composites have started to be used in automobiles mainly for saving weight for fuel economy. The so-called graphite car employs carbon Fiber epoxy-matrix composites for body panels, structural members, bumpers, wheels, drive shaft, engine components, and suspension systems. This car is 570kg lighter than an equivalent vehicle made of steel. It weighs only 1250 kg instead of the conventional 1800 kg for the average American car. Thermoplastic composites with PEEK and polycarbonate (PC) matrices are finding use as spring elements for car suspension systems [2]. Issac M Daniel et al. [3] conducted investigation on failure modes and criteria for their occurrence in composite columns and beams. They found that the initiation of the various failure modes depends on the material properties, geometric dimensions and type of loading. They reported that the loading type or condition determines the state of stress throughout the composite structure, which controls the location and mode of failure. The appropriate failure criteria at any point of the structure account for the bi-axiality or tri-axiality of the state of stress. Jeam Marc et al. [4] investigates the modeling of the flexural behavior of all thermo-plastic composite structures with improved aesthetic properties, manufactured by isothermal compression moulding. Topdar et al. [5] investigated on four noded plate element based on a refined higher order shear deformation theory is developed for the analysis of composite plates. This plate theory satisfies the conditions of Inter laminar shear stress continuity and stress free top and bottom surfaces of the plate. Moreover, the number of independent unknowns is the same as that in the first order Shear deformation theory. Banerji and Nirmal [6] reported an increase in flexural strength of unidirectional carbon Fiber/ Poly (methyl methacrylate), composite laminates having polyethylene fibers plies at the lower face. Li and Xian [7] showed that the incorporation of a moderate amount of carbon Fibers into ultra-high-modulus polyethylene (UHMPE) Fibers reinforced composites greatly improved the compressive strength, flexural modulus while the addition of a small amount of UHMPE Fibers into a carbon Fiber reinforced composite remarkably enhanced the ductility with only a small decrease in compressive strength. Rohchoon and Jang[8] studied the effect of stacking sequence on the flexural properties and flexural failure modes of aramid-UHMPE hybrid composites. The flexural strength depends upon the type of fibers at the compressive face and dispersion extent of

the Fibers. Matteson and Crane [9] reported increase in flexural strength by using unidirectional steel wire tapes in glass Fiber composites and carbon Fibers composites. They showed that the increase in flexural strength was due to a change in failure mode from compressive buckling to nearly ductile tensile failure. Bradley and Harris [10] used unidirectional high carbon steel wires to improve the iMPact properties of epoxy resin reinforced with unidirectional carbon Fiber reinforced. Unfortunately, flexural design methodologies rely on their experimental boundary conditions and the particular laminate setup, since a scaling of the results is very difficult matrix tensile fracture, localized compressive failure and Fiber shear failure is strongly dependent of the material configuration. Abot et al. [11] has done investigations on the in-plane mechanical properties of satin weave Carbon/Epoxy fabric composite, determined under quasi-static loading condition and these measured properties were also correlated with the corresponding ones for the unidirectional composites made of same fibre and matrix. The authors explored that both the elastic modulus and the strength in tension and compression of woven fabric composites are approximately one half of their corresponding values in the fibre direction of the unidirectional composite. Huang Gu [12] measured and coMPared the tensile strength of composite laminates with various layers of glass fabric. It was shown that the strength of the multilayer laminates fabricated using woven fabrics was proportional to the increased number of layers. Hosur et al. [13] investigated on High strain rate compression of Carbon/Epoxy laminate composites. The response of Carbon/Epoxy laminated composites under high strain rate compression loading is considered using a modified Split Hopkinson Pressure Bar (SHPB) T. Kant [14] made analytical and static analysis of laminated composite and sandwich plates based on a higher order refined theory which incorporates laminate deformations which account for the effects of transverse shear deformation, transverse normal strain/stress and a nonlinear variation of in-plane displacements with respect to the thickness coordinate.

II.MODELING AND ANLYSIS

Finite element modeling of laminated composite

Finite element model of composite laminated structure discretizes the entire thickness along the linear direction into number of elements. Often 2D-modeling is sufficient for getting accurate results. The shell elements are the famous 2D discretization elements. A shell element has nodes with each node having 6 DOFs. SHELL181 is suitable for analyzing thin to moderately-thick shell structures. It is a four-noded element with six degrees of freedom at each node: translations in the x, y, and z directions, and rotations about the x, y, and z axes. The degenerate triangular option should only be used as filler elements in mesh generation. SHELL181 is wellsuited for linear, large rotation, and/or large strain nonlinear applications. Change in shell thickness is accounted for in nonlinear analyses. In the element domain, both full and reduced integration schemes are supported. SHELL181 accounts for follower effects of distributed pressures. The figure 3.1 represents the element type SHELL 181 in ANSYS and the parameters are 4 noded element with I, j, k, l as nodes, sometimes the it can be a triangular element with two nodes coinciding and mostly quadrilateral element. The corner numbers that is from number 1 to 8 at the corners represent the thermal loads and the circled numbers from ①to ⑥indicate the body loads or the pressures on the surfaces, the coordinates x, y, z indicates the local coordinate system and the x0, y0, z0 are the global coordinates, sometimes both may be coincided.

Static Analysis of Composite Materials

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. Both linear and nonlinear static analyses. Nonlinearities can include

plasticity, stress stiffening, large deflection, large strain, hyper elasticity, contact surfaces, and creep. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time. The types of loading that can be applied in a static analysis include:

- Externally applied forces and pressures
- Steady-state inertial forces (such as gravity or rotational velocity)
- Imposed (nonzero) displacements
- Temperatures (for thermal strain)
- Fluencies (for nuclear swelling)

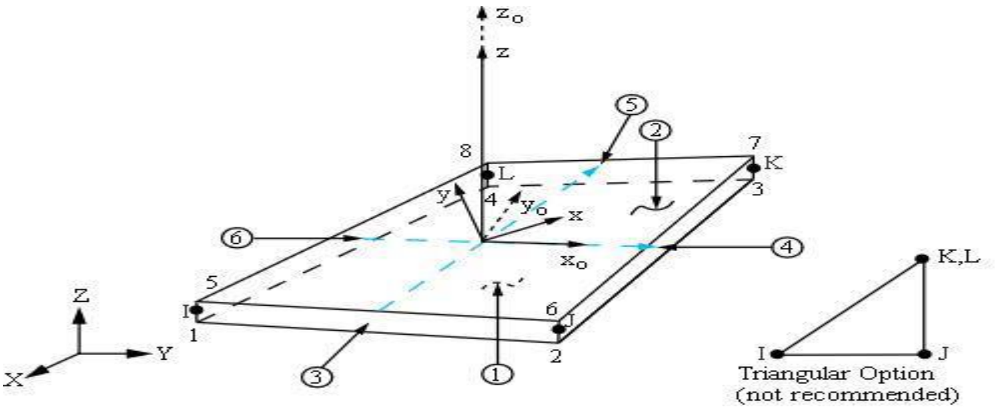

Figure 1: Element type SHELL181.

Statics is the mechanics of things that don’t move. But everything does move, at least a little. Hence statics doesn't exactly apply to anything. The statics equations are, however, a very good approximation of the more general dynamics equations for many practical problems. The statics equations are also easier to manage than the dynamics equations. That's why with little loss of accuracy, sometimes very little loss, and a great saving of effort, sometimes a very great saving, many calculations can be performed using a statics model instead of a more general dynamics model. Thus it is not surprising that typical engineers perform many more statics calculations than dynamics calculations. Statics is the core of structural and strength analysis. And even for a moving system, say an accelerating car, statics calculations are appropriate for many of the parts. The two mains to be taken care in static analysis are

- The sum of all the external forces are zero.
- The sum of the moments is zero.

A system is in static equilibrium if the applied forces and moments add to zero. The statement is also said like The forces on a system in static equilibrium, considered as a system, are equivalent to a zero force and a zero couple.

Von-Mises Stress

This criterion is based on the determination of the distortion energy in a given material, i.e., of the energy associated with changes in the shape in that material as opposed to the energy associated with the changes in volume in the same material. According to this criterion, named after German-American applied mathematician Richard Von Mises (1883-1953), a given structural material is safe as long as the maximum value of the distortion energy per unit volume in that material remains smaller than the distortion energy per unit volume required to cause yield in a tensile-test specified of the same material.

Table 1.Mechanical properties of composite materials

S.No	Property	Carbon/Epoxy Composite	E-Glass/Polymer
1.	(EX) Youngs modulus in X direction	70.03 MPa	44.84 MPa
2.	(EY)Youngs modulus in Y direction	70.03 MPa	44.84 MPa
3.	(EZ) Youngs modulus in Z direction	12.65 MPa	8.15 MPa
4.	(PRXY) Poissons Ratio in XY plane	0.04	0.024
5.	(PRYZ) Poissons Ratio in YZ plane	0.31	0.057
6.	(PRZX) Poissons Ratio in XZ plane	0.31	0.057
7.	(GXY) Shear modulus in XY plane	3.81 MPa	2.99 MPa
8.	(GYZ) Shear modulus in YZ plane	4.19 MPa	2.99 MPa
9.	(GZX) Shear modulus in ZX plane	4.19 MPa	2.99 MPa

A model of two dimensional rectangular sheet is prepared using ANSYS and analysis is also done.

Analysis of Carbon and Glass composite plates

The main observation is on the deflection of the plates in the Z direction and stress distribution that is along the application of the load. The analysis is done on the Carbon/Epoxy and glass polymer laminates in two load conditions likely uniformly distributed load and concentrated load at the center taking the boundary condition of clamping at the two sides of the plate and the load in the Z direction (-ve) towards the plate. The analysis is done according to the l/t ratio of 10, 20, 40, 66.6, 100, 200 by keeping the length unchanged and changing the thickness of plates and load condition. By taking the thickness of each layer as 0.3mm the number of layers for the l/t ratios mentioned earlier will be 84, 42, 21, 13, 8, 4 respectively with total thickness of 25.4, 12.7, 6.35, 3.8, 2.54, 1.27 mm respectively.

III.RESULTS AND DISCUSSIONS

The composite plates are made of Carbon/Epoxy and E-Glass/Polyemer are considered for testing with clamped ends at two sides and the load conditions are uniformly distributed load (UDL) and concentrated load (CL) with a magnitude of 1000N. The length of the plates are kept constant and thickness is varied according to length to thickness ratios (l/t) 10, 20, 40, 66.6, 10, 200. Each layer is 0.3mm thick. After modeling and analyzing the results are presented from Table 2 to Table 6 . As the load is applied in the (-ve) Z direction the deflections are considered in the Z direction for efficient analysis and testing the model.

Table 2: Deflection results of uniformly distributed load.

S.No	Length to thickness (l/t) ratio	Length in mm	Total thickness in mm	No. of layers	Single layer thickness in mm	Max deflection in Z direction	
						Carbon/Epoxy	E-Glass/Polymer
1.	10	250	25.2	84	0.3	1.97E-07	2.93E-07
2.	20	250	12.6	42	0.3	1.04E-06	1.59E-06
3.	40	250	6.3	21	0.3	7.27E-06	1.12E-05
4.	66.6	250	3.9	13	0.3	2.97E-05	4.6E-05
5.	100	250	2.4	8	0.3	1.26E-04	1.95E-04
6.	200	250	1.2	4	0.3	1.002E-03	1.552-03

Table. 2 and Table 3 show the deflection in the Z direction because the loads are given in negative direction of Z axis. In the table only maximum deflection is shown because the minimum deflection is zero at the sides and the maximum at the center. From the results it is observed that deflection increases with increase in *l/t* ratio for both UDL and CL for Carbon/Epoxy and E-Glass/Polymer plates. From Table 4 higher deflection is observed for E-Glass/Polymer compared to Carbon/Epoxy plate. From Table 5. It is observed that Von Misses Maximum Von Misses stress is same for Carbon/Epoxy and E-Glass/Polymer at any l/t ratio whereas minimum Von Misses stress values are higher for Carbon/Epoxy compared to E-Glass/Polymer at any l/t ratio. From Table 6. Maximum stresses are higher for Carbon/Epoxy compared to E-Glass/Polymer where as opposite trend is observed for minimum stress when concentrated loads are applied.

Table 3: Deflection results of concentrated load at center of the Plate.

S.No	Length to thickness (l/t) ratio	Length in mm	Total thickness in mm	No. of layers	Single layer thickness in mm	Max deflection in Z direction	
						Carbon/Epoxy	E-Glass/Polymer
1.	10	250	25.2	84	0.3	1.46E-05	2.21E-05
2.	20	250	12.6	42	0.3	6.63E-05	1.01E-04
3.	40	250	6.3	21	0.3	4.3E-04	6.62E-04

4.	66.6	250	3.9	13	0.3	1.723E-03	2.667E-03
5.	100	250	2.4	8	0.3	7.246E-03	1.123E-02
6.	200	250	1.2	4	0.3	5.743E-02	8.914E-02

Table 4. Deflection values for different l/t ratios for two load conditions on composite plates.

S.No	Material	Case	Central Deflection Uz in mm					
			Length to Thickness (*l/t*) ratio					
			10	20	40	66.6	100	200
1	Carbon/Epoxy	UDL	0.00019	0.0010	0.0072	0.0297	0.126	1.002
2		CL	0.00146	0.00663	0.43	1.723	7.246	57.435
3	E-Glass/Polymer	UDL	0.00293	0.00519	0.0112	0.046	0.195	1.55
4		CL	0.0021	0.0101	0.662	2.667	11.238	89.143

Table 5: VON-MISSES stresses by UDL.

S.No	Length to thickness (l/t) ratio	Length in mm	Total thickness in mm	No. of layers	Maximum Stress		Minimum Stress	
					Carbon/ Epoxy	E-Glass / Polymer	Carbon/Epoxy	E-Glass/Polymer
1.	10	250	25.2	84	37505.2	37500	11.2806	6.73892
2.	20	250	12.6	42	150085	150063	25.0194	14.4825
3.	40	250	6.3	21	599036	599630	8830.1	9632.37
4.	66.6	250	3.9	13	1.56E+06	1.56+E06	22456	24805.3
5.	100	250	2.4	8	4.12E+06	4.13E+06	51.2328	44.9869
6.	200	250	1.2	4	1.65E+07	1.65E+07	62.2912	73.6739

Table 6: VON-MISSES stresses by CL

S.No	Length to thickness (l/t) ratio	Length in mm	Total thickness in mm	No. of layers	Maximum Stress		Minimum Stress	
					Carbon/ Epoxy	E-Glass/Polymer	Carbon/Epoxy	E-Glass/Polymer
1.	10	250	25.2	84	2.15E+07	2.08E+06	1352.84	2014.67
2.	20	250	12.6	42	8.38E+07	8.12E+06	965.119	5860.27
3.	40	250	6.3	21	3.28E+08	3.21E+07	81761.2	95606
4.	66.6	250	3.9	13	8.52E+08	8.34E+07	336801	398655
5.	100	250	2.4	8	2.24E+09	2.20E+08	29395.1	20511
6.	200	250	1.2	4	9.04E+09	8.79E+08	56753.4	73270.8

IV. CONCLUSIONS

The following are the conclusions considered from the results.

The minimum deflections for uniformly distributed load condition occur at the l/t ratio 10 with magnitude of 0.00019 mm for the Carbon/Epoxy material plate where as for the concentrated load condition occurs at the l/t ratio 10 with magnitude of 0.00146 mm . The deflections in both the materials increases with the increase in the length to thickness ratio. The maximum deflections for each length to thickness ratios are less for Carbon/Epoxy when compared to that of E-Glass/Polyester composite plates. The stresses for the uniformly distributed load are least for the l/t ratio 10 and are almost same for the both Carbon/Epoxy and E-Glass/Polyester material. In the uniformly distributed load condition the stresses for each slenderness ratio are almost equal. The maximum stresses formed for the concentrated load condition are minimum for E-Glass/Polyester composite plate for length to thickness ratio 10 with a magnitude of 2.06E+06. The maximum stress values in both Carbon/Epoxy and Glass/Fiber for uniformly distributed and concentrated load are increasing with the increase in slenderness ratio because the strength of the plate decreases with the increase in slenderness ratio. If we consider the cost criteria, then E-Glass/polymer costs way less than the Carbon/Epoxy composites.

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