COMPARATIVE ANALYSIS OF SIMULATION OF COMPOSITES MATERIAL WITH ANSYS

Pankaj Lahariya[1], Dushyant Dwivedi[2]

[1] Pankaj Lahariya, Mechanical Engineering Department, Vikrant Institute of Technology and Management Gwalior, Madhyapradesh, India
[2] Dushyant Dwivedi, Mechanical Engineering Department, Vikrant Institute of Technology and Management Gwalior, Madhyapradesh, India

ABSTRACT

A laminated composite material consists of several layers of a composite mixture consisting of matrix and fibers. Each layer may have similar or dissimilar material properties with different fiber orientations under varying stacking sequence. There are many open issues relating to design of these laminated composites. Design engineer must consider several alternatives such as best stacking sequence, optimum fiber angles in each layer as well as number of layers itself based on criteria such as achieving highest natural frequency or largest buckling loads of such structure. Analysis of such composite materials starts with estimation of resultant material properties. In this study, a three layered composite shell consisting of middle layer of High Strength Steel-4340 and outside layers of Aluminium Alloy 7075-76 is designed and analysed for complex aerodynamic loading. The analysis results are found for both elemental & nodal solution. The minimum & maximum elastic strain intensities are 0.172e-04 and 0.00855 respectively for elemental solution while the minimum & maximum values of stress Intensity are 0.140e+07 & 0.594e+09 respectively in case of Nodal Solution, which indicates the variation in the stress intensities in different materials corresponding to their moduli of elasticity. The analysis results directly relate to the stress-strain characteristics of each material and need to be carefully considered keeping in view the variation in stress-strain characteristics of different grades of steel and numerous alloys of Aluminium. The behaviour of each material subject to axial & biaxial tensile as well as compressive loading up to elastic limit is taken into account in the analysis of composites for point loads.

Keyword: - *Al Alloy, ANSYS, Composite Material, Elastic Limit, Strain, Stress.*

---

1. INTRODUCTION AND TERMINOLOGY

Structural materials can be divided into 4 basic categories:

- Metals
- Polymers
- Ceramics
- Composites

Composites, which consist of two or more separate materials combined in a macroscopic structural unit, are made from various combinations of the other three materials.

The relative importance of the four basic materials in a historical context has been presented by Ashby (Technology of the 1990s: Advanced Materials and Predictive Design, M.F. Ashby, *Philosophical Transactions of the Royal Society of London*, A322, 393-407, 1987) and is shown schematically below (figure taken from Gibson):

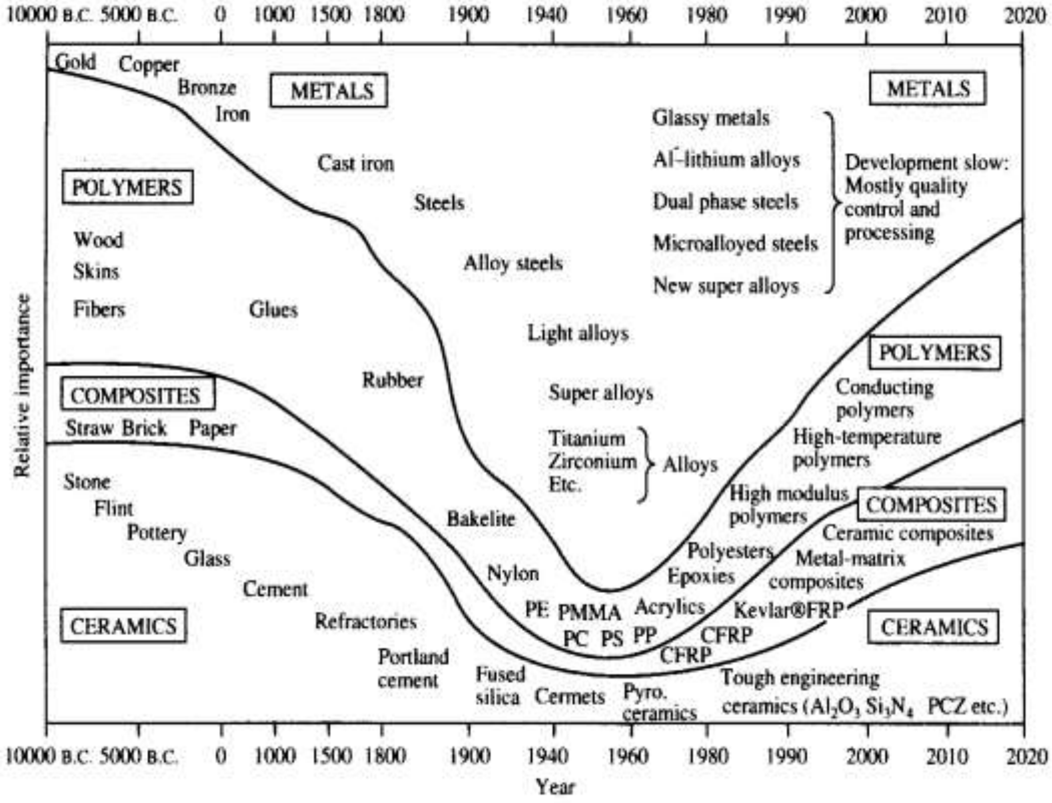


FIGURE 1.1

The relative importance of metals, polymers, composites, and ceramics as a function of time. The diagram is schematic and describes neither tonnage nor value. The time scale is nonlinear. (*From Ashby* [1.1].)

MATRIX AND FILLER MATERIALS

Polymers, metals and ceramics are all used as matrix materials in composites. The matrix

- holds the fibers together in a structural unit,
- protects them from external damage,
- transfers and distributes the applied loads to the fibers, and
- In many cases, contributes some needed property such as ductility, toughness, or electrical insulation.

Because the matrix must transfer load to the fibers, a strong interface bond between the fiber and matrix is extremely important; either through a mechanical or chemical bond between fibers and matrix. Fibers and matrix must obviously be chemically compatible to prevent undesirable reactions at the interface; this is especially important at high temperature where chemical reactions can be accelerated.[4]

Service temperature is quite often a controlling factor in consideration of a matrix material. Listed in order of increasing temperature capability, we have:

Polymers are the most widely used matrix materials. They may be either thermosets (e.g., epoxy, polyester, phenolics) or thermoplastics (e.g., polyimide (PI), polyetheretherketone (PEEK), polyphenylene sulfide (PPS)). Upon curing, thermosets form a highly cross-linked, three-dimensional molecular network which does not melt at high temperature. Thermoplastics, however, are based on polymer chains that do not cross-link. As a result, thermoplastics will soften and melt at high temperature, then harden again upon cooling.

Epoxies and polyesters are also widely used. High grade epoxies are typically cured at about 350F and are generally not used at temperatures about 300°F. The advanced thermoplastics (PEEK, PI and PPS) have melting temperatures in the range of 600-700°F. For higher temperatures, metal, ceramic or carbon matrix materials are required.

Lightweight metals such as aluminum, titanium and magnesium and their alloys such titanium aluminide and nickel aluminide may be used as matrix materials. For some of these, operating temperature can be extended to about 2,250°F. Advantages of metal matrices include higher strength, stiffness and ductility (compared to polymers) but at the expense of higher density. [5]

Ceramic matrix materials such as silicon carbide and silicon nitride can be use at temperatures up to 3,000°F. Hoever, ceramics have poor tensile strength are are quite brittle.

Carbon fiber/carbon matrix composites can be used at temperatures approaching 5,000°F, but the cost is such that they are only used in a few critical aerospace applications.

Filler materials are often used as a third component of a composite, and are typically mixed with the matrix material during fabrication. Fillers do not typically enhance mechanical properties but are used to alter or improve some other characteristic of the composite. Examples include: hollow glass microspheres are used to reduce weight, clay or mica particles are used to reduce cost, carbon black particles are used for protection against ultraviolet radiation, and alumina trihydrate is used for flame and smoke suppression.

2. LITERATURE SURVEY

Anil kumar et al [10] investigated the mechanical properties of fly ash reinforced aluminum alloy (Al 6061) composites fabricated by stir casting. Three sets of composites with fly ash particle sizes of 75-100, 45-50 and 4-25 μm were used. Each set had three types of composite samples with the reinforcement weight fractions of 10%, 15% and 20%. The mechanical properties studied were compressive strength, tensile strength, ductility and hardness.

Unreinforced Al6061 samples were also tested for determining the mechanical properties. It was found that the compressive strength, tensile strength and hardness of the aluminum alloy composites decreased with the increase in particle size of reinforced fly ash. With an increase in the weight fractions of the fly ash particles, the ultimate tensile strength, compressive strength, hardness and the ductility of the composite decreases. The SEM of the samples indicated uniform distribution of the fly ash particles in the matrix without any voids.

AzamTafreshi et al [1] analyzed that the composite cylindrical shells and panels are widely used in aerospace structures. These are often subjected to defects and damage from both in-service and manufacturing events. Delamination is the most important of these defects. This paper deals with the computational modelling of delamination in isotropic and laminated composite cylindrical shells. The use of three-dimensional finite elements for predicting the delamination buckling of these structures is computationally expensive. Here combined double-layer and single-layer of shell elements are employed to study the effect of delamination on the global load-carrying capacity of such systems under axial compressive load. It is shown that through-the-thickness delamination can be modelled and analysed effectively without requiring a great deal of computing time and memory. A parametric study is carried out to study the influence of the delamination size, orientation and through-the-width position of a series of laminated cylinders. The effect of material properties is also investigated. Some of the results are compared with the corresponding analytical results. It is shown that ignoring the contact between the delaminated layers can result in wrong estimations of the critical buckling loads in cylindrical shells under compressive load.

AzamTafreshi and Tobias Oswald [2] investigated that the finite element models were developed to study global, local and mixed mode buckling behaviour of composite plates with embedded delaminations under compression. The global modelling results were compared with corresponding experimental results. It is shown that the numerical results for embedded delaminations agree very well with the experimental results, whereas the difference between the results was high for delaminations located at the edge of the plates. It is also shown that at lower loading levels the interaction of global and local buckling is negligible. At higher loading levels the strain energy release rate distribution and the delamination growth potential at the delamination front strongly depend on the shape of the debonded region and the local buckling mode. It was observed that the local buckling mode was highly influenced by the laminate stacking sequence. In the course of global buckling a parametric study was carried out to investigate the influence of the delamination size, shape and alignment of a series of composite plates.

C.Roos et al [3] studied that the Flexible matrix composites (FMCs) consist of low modulus elastomers such as polyurethanes which are reinforced with high-stiffness continuous fibers such as carbon. This fiber–resin system is more compliant compared to typical rigid matrix composites and hence allows for higher design flexibility. Continuous, single-piece FMC driveshafts can be used for helicopter applications. In the present investigation, an optimization tool using a genetic algorithm approach is developed to determine the best combination of stacking sequence, number of plies and number of in-span bearings for a minimum-weight, spinning, misaligned FMC helicopter driveshaft. In order to gain more insight into designing driveshafts, various loading scenarios are analyzed and the effect of misalignment of the shaft is investigated. This is the first time that a self-heating analysis of a driveshaft with frequency- and temperature-dependent material properties is incorporated within a design optimization model.The analysis assures that the material does not overheat and that allowables are not exceeded. The challenge is that the analysis needs to address several physical processes such as self-heating in the presence of material damping, conduction and surface convection, ply-level stresses and strains, buckling and dynamic stability. Quasi-static and dynamic temperature- and frequency-dependent material properties for a carbon-polyurethane composite are embedded within the model. For two different helicopter drivelines, weight savings of about 20% are shown to be possible by replacing existing multi-segmented metallic drivelines with FMC drivelines.

C.s.ramesh et al [4] studied the Al6061 matrix composite reinforced with nickel coated silicon nitride particles were manufactured by liquid metallurgy route. Microstructure and tribological properties of both matrix alloy and developed composites have been evaluated. Dry sliding friction and wear tests were carried out using pin on disk type machine over a load range of 20–100 N and sliding velocities of range 0.31–1.57 m/s. Results revealed that, nickel coated silicon nitride particles are uniformly distributed throughout the matrix alloy. Al6061–Ni–P–Si_3N_4 composite exhibited lower coefficient of friction and wear rate compared to matrix alloy. The coefficient of friction of both matrix alloy and developed composite decreased with increase in load up to 80 N. Beyond this, with further increase in the load, the coefficient of friction increased slightly. However, with increase in sliding velocity coefficient of friction of both matrix alloy and developed composite increases continuously. Wear rates of both matrix alloy and developed composites increased with increase in both load and sliding velocity. Worn surfaces and wear debris was examined using scanning electron microscopy (SEM) for possible wear mechanisms. Energy dispersive spectroscope (EDS), X-ray diffraction (XRD) and X-ray photoelectron spectroscope (XPS) techniques were used to identify the oxides formed on the worn surfaces and wear debris.

BalasivanandhaPrabu et al [29] investigated that the better stir process and stir time. The high silicon content aluminum alloy –silicon carbide MMC material, with 10% Si-C by using a variance of stirring speeds and stirring times. The microstructure of the produced composite was examined by optical microscope and scanning electron microscope. The results with respect to that stirring speed and stirring time influenced the microstructure and the hardness of composite also. They investigated that at lower stirring speed with lower stirring time, the particle group was more.

Increase in stirring time and speed resulted in better distribution of particles. The mechanical test results also revealed that stirring speed and stirring time have their effect on the hardness of the composite. The uniform hardness valued was achieved at 600 rpm with 10min stirring but above this stir speed, the properties degraded again. This study established the trend between processing parameters such as stirring speed and stirring time with microstructure and hardness of composite.

Bienias et al [12] studied the microstructure characteristics of aluminium matrix Ak12 composites containing of fly ash particles, obtained by gravity and squeeze costing techniques followed by the study of pitting corrosion behaviour and corrosion kinetics. It was found that in comparison to squeeze casting, gravity casting technology is advantageous for obtaining higher structural homogeneity with minimum possible porosity levels, good interfacial bonding and quite a uniform distribution of reinforcement. The fly ash particles lead to an enhanced potting corrosion of the Ak12/9%flyash (75-100 μm fraction) composite in comparison with unreinforced matrix (Ak12 alloy), and further the presence of nobler second phase of fly ash particles, cast defects like pores, and higher silicon content formed as a result of reaction between aluminum and silica in Ak12 alloy and aluminum fly ash composite determining the pitting corrosion behaviour and the properties of oxide film forming on the corroding surface.

G.Sharifishourabi et al [9] Studied the composition of the beam varies gradually from ceramic to metal along both the thickness and width directions. Continuous gradations according to both the power law and exponential law variations are considered. In the presence of a thermal gradient and transverse distributed loads an analytical solution based on the Euler-Bernoulli beam theory is presented. Numerical sample where material gradations vary along both the thickness and width directions is carried out. It is found that the gradation of materials affects the neutral axis position.

Karunamoorthy et al [28] analyzed that the 2D microstructure-based FEA models and these were then developed to study the mechanical behavior of MMC. The model has taken into account the randomness and clustering effects. The particle clustering effects on stress-strain response and the failure behavior were studied from the model. The optimization of properties was carried out from analysis of microstructure of MMC, since the properties depend on particles arrangement in microstructure. In order to model the microstructure for finite element analysis (FEA), the micro-structures image converted into vector form from the raster was further facilitated by its conversion push to IGES step and mesh in FEA model in ANSYS 7. The failure such as particle interface de-cohesion and fracture predicted for particle clustered and non-clustered micro structures. They analyzed that failure mechanisms and effects of particles arrangement as well.

Li Li et al [15] studied the various methods for the calculation of the sensitivity of element modal strain energy (MSE) are surveyed and classified as the finite difference method, the indirect method and the direct algebraic method. Also, based on the variation principle, a method is presented to accurately calculate the sensitivity of element MSE for undamped systems with distinct eigen values. The method computes the sensitivity by constructing a Lagrange function. Once the Lagrange multipliers are evaluated, the sensitivity can be determined directly. Note the Lagrange multipliers are independent of the number of design variables. More importantly, the proposed method is robust since the linear system is independent of the derivatives of system matrices and some weight constants are introduced in the coefficient matrices of the linear system to reduce the condition number. An operational flop count to compare the relative computational cost of the indirect method, Yan and Ren's method and the proposed method is evaluated as a function of system matrix size, the number of mode shape of interest, the number of design variables and the number of individual element stiffness matrices. The storage capacity and robustness are also considered. General guidelines are established to choose the computational method for a given problem. Finally, three examples are used to show the effectiveness of the results. It is shown that the proposed method is more robust than the indirect method and the direct algebraic method.

Mahendra et al [21] concluded that development of hybrid metal matrix composites has become an important area of research interest in materials science. In view of this, this study was aimed at evaluating the physical properties of Al-2024 in the presence of fly ash, silicon carbide and its combinations. Consequently Al-MMC combination resulted in the strength of the reinforcement with the toughness of the matrix to achieve a combination of desirable properties not available in any single conventional material. Stir casting method was used for the fabrication of Al-MMC. Structural characterization was carried out on MMC by x-ray diffraction studies and optical microscopy was used for the micro structural studies. The mechanical behaviors of MMC like density, elongation, hardness, yield strength and tensile test were ascertained by performing carefully designed laboratory experiments that replicate as nearly as possible the service conditions. In the presence of fly ash and silicon carbide [sic (5%) + fly ash (10%) and fly ash (10%) +sic (10%)] with Al, the result show that the decrease in density with increasing hardness and tensile strength was also observed but elongation of the hybrid MMC in comparison with unreinforced aluminium decreased. The hybrid metal matrix composites significantly differed in all of the properties measured.

Rama Rao et al [30] examined that aluminum alloy-boron carbide composites were fabricated by liquid metallurgy techniques with different particulate weight fraction (2.5, 5 and 7.5%). Phase identification was carried out on boron carbide by x-ray diffraction studies microstructure analysis was done with SEM a composites were characterized by hardness and compression tests. The result shows that with an increase in the amount of the boron carbide, the density of the composites decreased whereas the hardness is increased. Whereas the compressive strength of the composites was increased with increase in the weight percentage of the boron carbide in the composites.

Rohatgi et al [23] analysed the A356-fly ash composites which can be synthesized using gas pressure infiltration technique over a wide range of reinforcement volume fraction from 20 to 65%. The densities of Al356-fly ash composites, made under various experimental conditions, are in the range of 1250-2180 kg/m3 corresponding to the volume fraction of cenosphere in the range 20-65%. The density of composites increased for the same cenosphere volume fraction with increasing size of particles, applied pressure and melt temperature. This appears to be related to a decrease in voids present near particles and enhancement of the melt flow in a bed of cenosphere. The compressive strength Plateau stress and modulus of the composites increased with the composite density.

Siva Prasad et al [6], this investigation, studied the dry sliding wear behavior of aluminum (Al) matrix hybrid composites reinforced with rice husk ash (RHA) and silicon carbide (SiC) particulates up to 8% (in equal proportions) fabricated by vortex method. Pin-on disk wear test was carried out for both unreinforced alloy and hybrid composites. Scanning electron microscopy is used to study the wear characteristics of the unreinforced Al alloy and the hybrid composites. The results showed that the hybrid composites exhibits higher wear resistance than the unreinforced alloy. The wear mechanisms in the unreinforced alloy and the hybrid composites are analyzed and presented.

3. RESEARCH OBJECTIVE

The following are the objectives of the present work:
1. To predict the overall elastic properties of multilayer composite material of given number of layers, stacking sequence and elastic constants of each layer.
2. Validate the elastic data with finite element modeling.
3. Analyse the program in a graphic user interface.
4. using equivalent modulus beam theory, estimate the strain properties, Stresses and load of beams.
5. Comparison and effect of material properties, material behavior of composite material Al-Steel-Al and its characteristics with the uses of analytical tool: ANSYS

3.1 LAMINATED COMPOSITE STRUCTURES

A laminate is constructed by stacking a number of laminas in the thickness (z) direction. Each layer is thin and may have different fiber orientation. The fiber orientation, stacking arrangements and material properties influence the response from the laminate. The theory of lamination is same whether the composite structure may be a plate, a beam or a shell. Figure 3.1 shows a laminated plate or panel considered in most of the analysis.

The following assumptions are made in formulations: (i) the middle plane of the plate is taken as the reference plane. (ii) The laminated plate consists of arbitrary number of homogeneous, linearly elastic orthotropic layers perfectly bonded to each other. (iii) The analysis follows linear constitutive relations i.e. obeys generalized Hooke's law for the material. (iv) The lateral displacements are small compared to plate thickness. (v) Normal strain in z-direction is neglected.

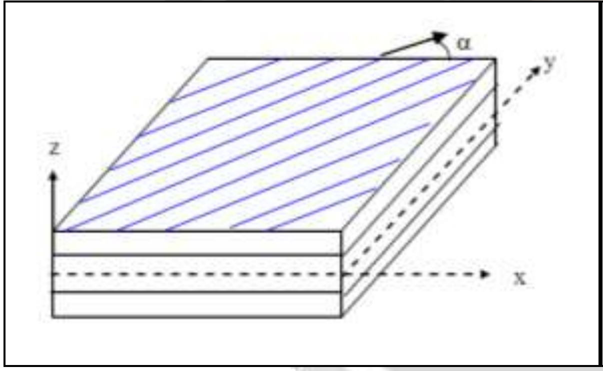


Figure 3.1 Plate

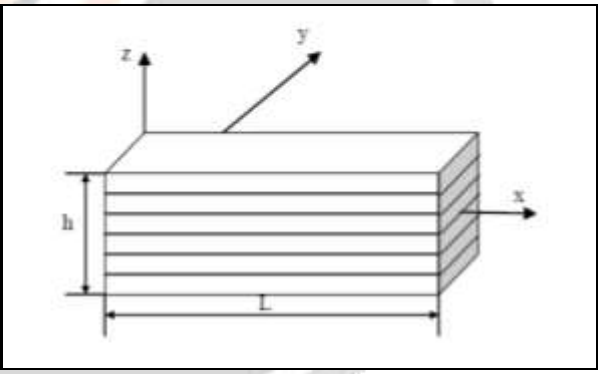


Figure 3.2 Beams

As shown in Figure 3.1, laminated beams are made-up of many plies of orthotropic materials and the principal material axes of a ply may be oriented at an arbitrary angle with respect to the x-axis. In the right-handed Cartesian coordinate system, the x-axis coincides with the beam axis and its origin is on the mid-plane of the beam. The length, breadth and thickness of the beam are represented by L, b and h, respectively.

In practical engineering applications, laminated shells of revolution may have different geometries based mainly on their curvature characteristics such as cylindrical shells, spherical shells and conical shells. The composite shell of revolution is composed of orthotropic layers of uniform thickness as shown in Figure 3.3 a differential element of a laminated shell shown with orthogonal curvilinear coordinate system located on the middle surface of the shell. The total thickness of the shell is h.

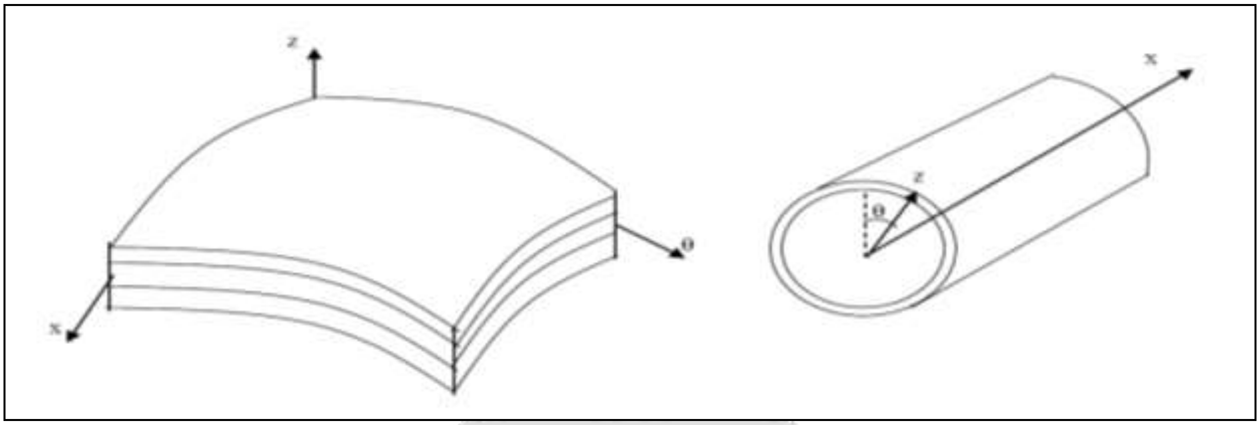
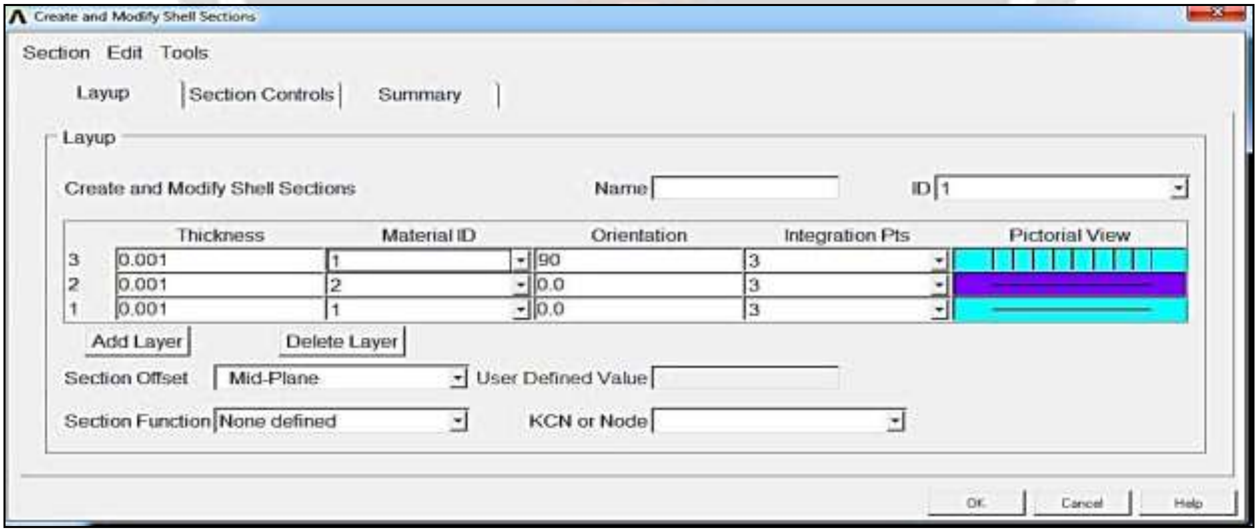


Figure 3.3 Shell (cylindrical)

3.2 MODELLING OF THE Al-Steel-Al COMPOSITE

The Modelling of three layered composite has been done using ANSYS 14.5. The layers are modeled as SHELL181. It is suitable for analyzing thin to moderately-thick shell structures. It is a four-node 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. (If the membrane option is used, the element has translational degrees of freedom only). The degenerate triangular option should only be used as filler elements in mesh generation. SHELL181 is well-suited 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 (load stiffness) effects of distributed pressures. SHELL181 can be used for layered applications for modeling composite shells or sandwich construction. The accuracy in modeling composite shells is governed by the first-order shear-deformation theory (usually referred to as Mindlin-Reissner shell theory). The element formulation is based on logarithmic strain and true stress measures. The element kinematics allow for finite membrane strains (stretching). However, the curvature changes within a time increment are assumed to be small.

The Material model used in this study is Linear Isotropic Structural Static model. Further, the properties of the layered shells are given in Figure 3.4.



Layup

Create and Modify Shell Sections

Name

ID 1

	Thickness	Material ID	Orientation	Integration Pts	Pictorial View
3	0.001	1	90	3	
2	0.001	2	0.0	3	
1	0.001	1	0.0	3	

Section Offset: Mid-Plane

User Defined Value

Section Function: None defined

KCN or Node

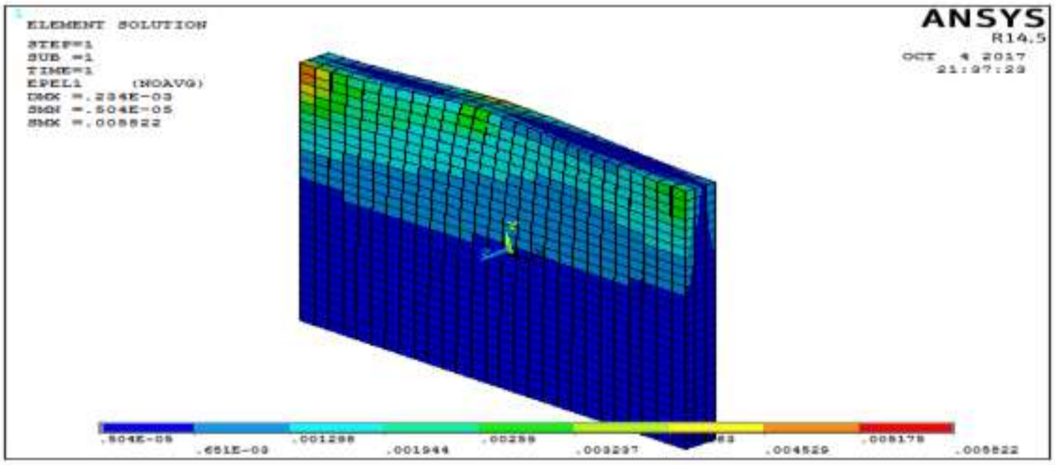
The Material properties of Steel & Aluminium alloy used in this study are given in Table 3.1.

Material	**Young's Modulus, E**	**Modulus of Rigidity, G**	**Density**	**Poisson's Ratio**	**Co-eff. of Thermal Expansion**
High Strength Steel 4340	210GPa	76Gpa	$7.8 Mg/m^3$	0.26	$14*10^6$
Aluminium Alloy 7075-76	70GPa	28Gpa	$2.7 Mg/m^3$	0.34	$33*10^6$

Table 3.1.

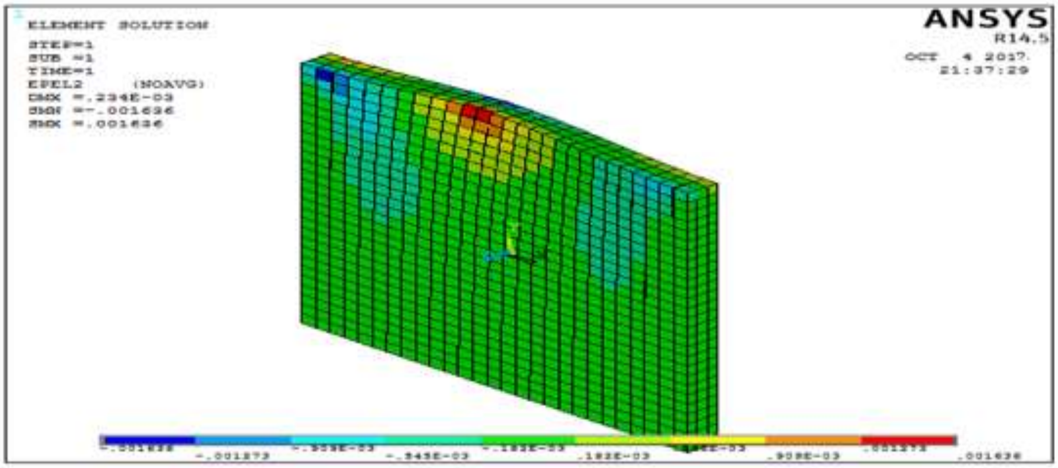
4. RESULTS

4.1.1 1st Principal Elastic Strain



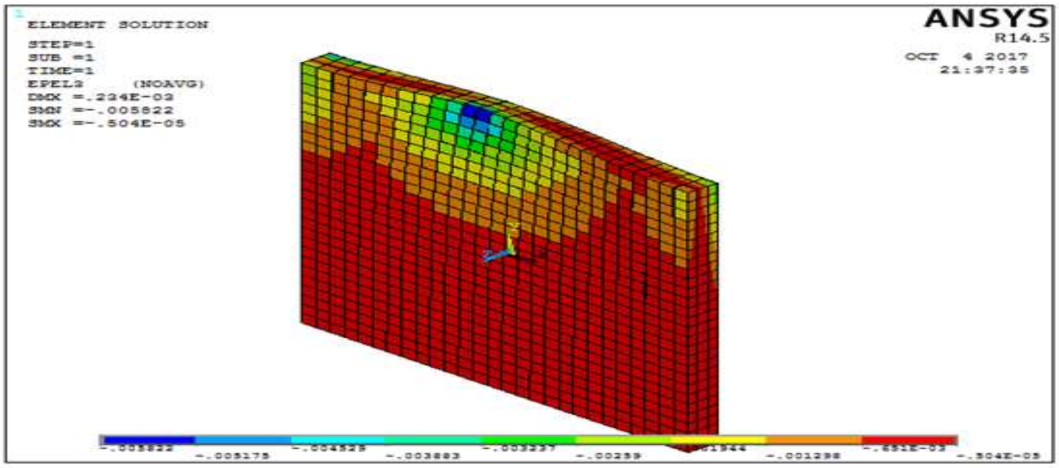
The maximum 1st principal elastic strain is 0.005822 and the minimum is 0.50e-05.

4.1.2 2nd Principal Elastic Strain



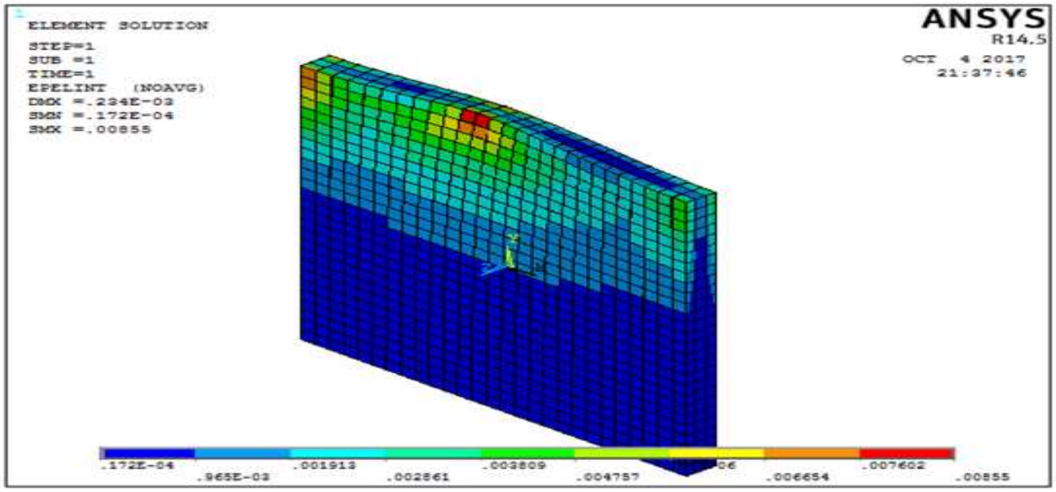
The maximum & minimum 2nd principal elastic strains are 0.001636& -0.001636.

4.1.3 3rd Principal Elastic Strain



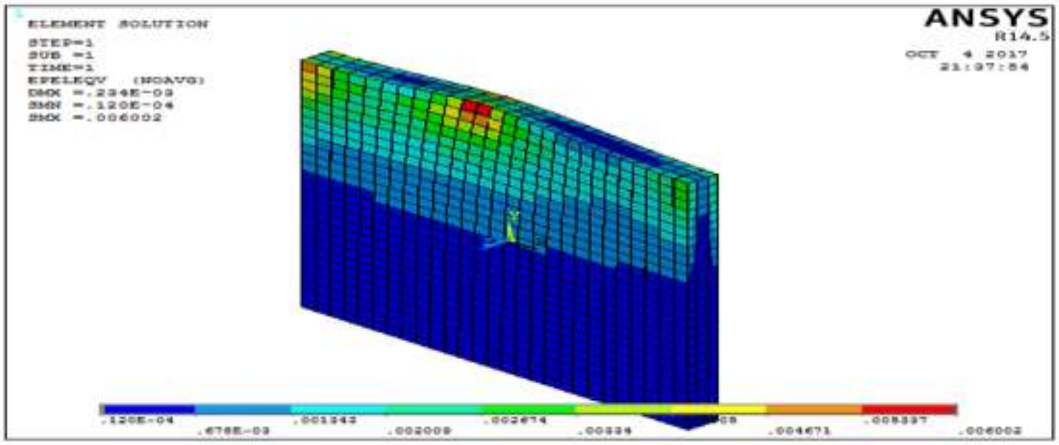
The maximum & minimum 2nd principal elastic strains are 0.50e-05& -0.005022 respectively.

4.1.4 Elastic Strain Intensity



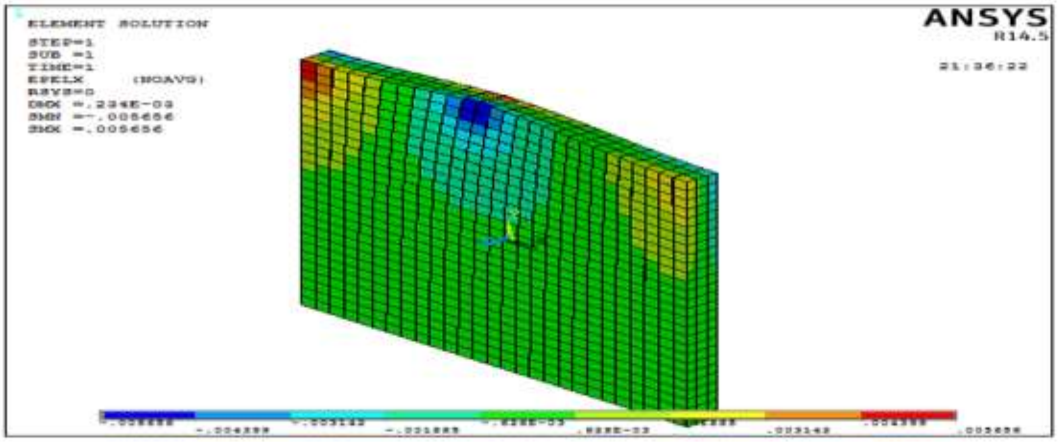
The minimum & maximum elastic strain intensities are 0.172e-04 and .00855 respectively.

4.1.5 Von Mises Elastic Strain



The minimum & maximum Von-Mises Elastic strains are 0.12e-04 & 0.006002 resp.

4.1.6 X- Component of Elastic Strain



The minimum & maximum values of X-Component of Elastic strain are -0.005656 & 0.005656 respectively.

5. CONCLUSIONS

From the analysis of the three layered Al-Steel-Al composites, following conclusions can be drawn:

1. The minimum & maximum elastic strain intensities are 0.172e-04 and 0.00855 respectively for elemental solution while the minimum & maximum values of stress Intensity are 0.140e+07 & 0.594e+09 respectively in case of Nodal Solution, which indicates the variation in the stress intensities in different materials corresponding to their moduli of elasticity.

2. The non-linear behaviour is considered concerning only material & geometric nonlinearities while the structural non-linearity is not considered.

6. REFERENCES

[1] AzamTafreshi, 2004, Efficient modelling of delamination buckling in composite cylindrical shells under axial compression, Composite Structures, 64, 511-520.
[2] AzamTafreshi, Tobias Oswald, 2003, Global buckling behaviour and local damage propagation in composite plates with embedded delaminations, International Journal of Pressure Vessels and Piping, 80, 9-20.
[3] C.Roos and C.E.Bakis, „Multi-physics design and optimization of flexible matrix composite driveshafts‟, Composite Structures, Vol. 93, Issue 9, Pp 2231–2240,2011.
[4] C.s.ramesh, r. Keshavamurthy, b.h. channabasappa, s. Pramod, Friction and wear behaviour of Ni-P coated Si3N4 reinforced Al6061composites, tribology international 43(2010)623-634
[5] D.J. Smith, G. Zheng, P.R. Hurrell , C.M. Gill, B.M.E. Pellereau , K. Ayres D. Goudar c, E. Kingston, Measured and predicted residual stresses in thick section electron beam welded steels, International Journal of Pressure Vessels and Piping 120-121 (2014) 66-79
[6] Dora siva Prasad, chintadashoba, nalluramanainah, Investigations on mechanical properties of aluminium hybrid composite, mater res technol. 3(2014) 79-85.
[7] E.J.Barbero, „Finite element analysis of Composite Materials using ANSYS‟, CRC Press, 2008
[8] G.g. sozhamannan. S. Balasivanandhaprabu, r. Paskaramoorthy. Failures analysis of particle reinforced metal matrix composites by microstructure based models, materials and design, 31(2010) 3785-3790
[9] G.Sharifishourabi, Reza Alebrahim, SH.Sharifi Teshnizi, Farid Nasir Ani, Effects of Material Gradation on Thermo-Mechanical Stresses in Functionally Graded Beams, APCBEE Procedia 3 (2012) 194 – 199
[10] H.c. anilkumar, h.s. hebbar and k.s. ravishankar, Mechanical properties of fly ash reinforced aluminium alloy (Al6061) composites, international journal of mechanical and materials engineering 6(2011) 41-45
[11] I.B.C.M. Rocha , E. Parente and A.M.C. Melo, „A hybrid shared/distributed memory parallel genetic algorithm for optimization of laminate composites‟, Composite Structures, Vol. 107, Pages 288–297, 2014.
[12] J. Bienias, m. Walczak, b. Surowska,j.Sobczak,Microstructure and corrosion behaviour of aluminium fly ash composites, journal of optoelectronics and advanced materials, 5(2003), 493-502

[13] J. Lindemann, W. Becker, 2002, The tendency for free-edge delamination in laminates and its minimization, Composites Science and Technology, 62, 233-242.
[14] K Alnefaie, „Finite Element Modeling of composite plates with internal delamination‟, Composite Structures, Vol. 90, pp 21-27, 2009.
[15] Li Li, YujinHun, XuelinWang, Numerical methods for evaluating the sensitivity of element modal strain energy, Finite Elements in Analysis and Design 64 (2013) 13–23
[16] M. H. Sadr and H. G.Bargh, „Optimization of laminated composite plates for maximum fundamental frequency using Elitist-Genetic algorithm and finite strip method‟, Springer Science+ Business Media, 2011
[17] M. H.Rarani,S .S. K.Sharifi and M.M. Shokrieh, „Effect of ply stacking sequence on buckling behavior of E-glass/epoxy laminated composites‟, Computational Material Science, vol.89, pp.89-96, 2014.
[18] M. Hajianmaleki and M. S. Qatu, 'Vibrations of straight and curved composite beams: A review‟, Composite Structures, Vol. 100, pp 218-232, 2013.
[19] M. M.Abadi and A.R Daneshmehr, „An investigation of modified couple stress theory in buckling analysis of micro composite laminated Euler-Bernouli and Timoshinko beams‟, International Journal of Engineering Science‟, vol. 75,pp 40-53, 2014.
[20] M.K.Apalak, M.Yildirim and R.Ekici, „Layer optimization for maximum fundamental frequency of laminated composite plates for different edge conditions‟, Composite science and Technology, vol.68, pp.537-550, 2008.
[21] Mahendra boopathi, k.p. arulshri N. Iyandurai, Evaluation of mechanical properties of aluminium alloy 2024 reinforced with silicon carbide and fly ash metal matrix composites, American journal of applied sciences, 10(2013),219-229
[22] N.Radhia, r. Subramanian, s. venkatprasat, Tribologicalbehaviour of aluminium/alumina/graphite hybrid metal matrix composite using taguchi's techniques, journal of minerals and materials characterization and engineering 10(2011) 427-443
[23] P.k. rohatgi ,j.k. kim, N.gupta, simonalaraj, A.Daoud Compressive characteristics of A356/fly ash cenospehere composites synthesized by pressure infiltration technique, science direct 37(2006) 430-437
[24] R. Khandan, S.Noroozi, P.Sewell, J.Vinney and M.Koohgilani, Optimum design of fibre orientation in composite laminate plates for out-plane stresses, Advances in Material Science and Engineering, Article ID 232847, 2012.
[25] R. Sino a, T.N. Baranger, „Dynamic analysis of a rotating composite shaft‟, Composites Science and Technology, Vol. 68 337–345, 2008.
[26] R.Kayikci and F.O.Sonmez, „Design of composite laminates for optimum frequency response‟, Journal of Sound and Vibration, Vol. 331, Pages 1759–1776, 2012.
[27] R.Sahoo and B.N. Singh, „A new trigonometric zigzag theory for static analysis of laminated composite and sandwich plates‟, Aerospace science and technology, vol.35, pp.15-28, 2014.
[28] S. Balasivanandhaprabu, Karunamoorthy Microstructure- based finite element analysis of failure prediction in particle-reinforced metal-matrix composite, journal of materials processing technology 207(2008)53-62
[29] S.balasivanandhaprabu,Karunamoorthy, s. Kathiresan, b. Mohan, Influence of stirring speed and stirring time on distribution of particles in cast metal matrix composite. Journal of materials processing technology 171(2006) 268-273
[30] S.Ramarao. G. Padmanabhan, Fabrication and mechanical properties of aluminium-boron carbide composites, international journal of materials and biomaterials applications 2(2012) 15-18
[31] T.E Tay, F. Shen, K.H. Lee, A. Scaglione, M. Di Sciuva,1999, Mesh design in finite element analysis of post-buckled delamination in composite laminates, Composite Structures, 47, 603-611.