ANALYSIS OF A NON GASKETED COMPOSITE FLANGE FOR PRELOAD AND OPERATING CONDITIONS

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Abstract

Flanges are basically used to connect the pipe joints and they are widely used in chemical, power plants, petro chemical industries. Flanges are classified according to class of working range and are designed according to ASME standards. In industries fluid is pressurized and due to this the pipe joints are affected internally as well as externally. We are concentrating on these critical areas by adopting a composite flange. Since composite materials are most promising now days so, use of composite flanges can make difference to the existing components. In the present paper metallic flange for radial stress(x-direction) and axial stresses (y-direction) for preload condition are compared with a carbon epoxy composite flange. Analytical solutions are obtained using laminate theory. The analytical results are validated with finite element solution using different fiber orientations. The stress obtained for different orientations are compared with each other and they are compared with analytical results. From results it can be said that [0/45] and [0/60] orientation will give better results. Finally it is said that metallic flanges can be replaced by composite flanges in some industrial applications as the radial and axial stress developed is less when compared to metallic flanges.

Keywords: *Metallic Flange, Composite Materials, Composite Flange, Fiber Orientation, Finite Element Analysis*

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1. INTRODUCTION

Flange is a component used to connect tubular members in piping systems, a flange is a disc, collar or ring that attaches to pipe with the purpose of providing increased support for strength, blocking off a pipeline or implementing the attachment of more items. These flanges are widely used in chemical industries, hydraulic systems etc. Pipe flanges are usually welded or screwed to the pipe end and are connected with bolts. Flanges are affected by the varying forces, pressure, temperature and an environmental effect because of which leakages occurs in the connection. So sealing of a connection must analyzed. [1].

The most used flange types acc. to ASME B16.5 are: Welding Neck, Slip On, Socket Weld, Lap Joint, Stub end, Threaded and Blind flange [2].

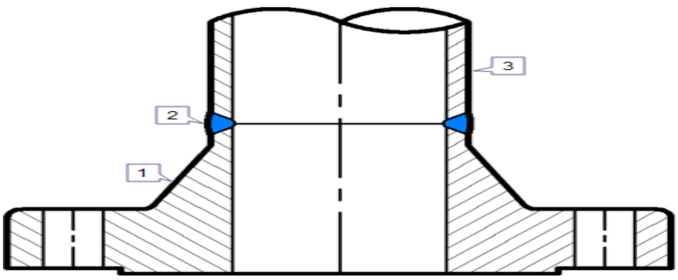


Fig-1.1: Details of Welding Neck flange

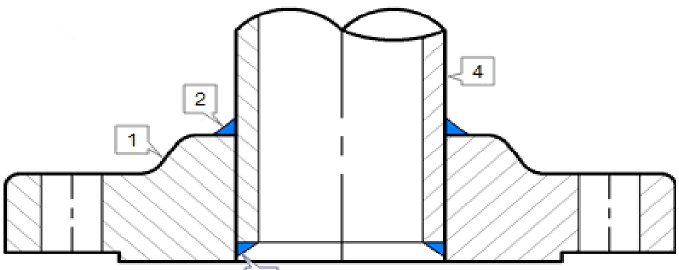


Fig-1.2: Details of Slip On flange

A composite is a structural material that consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called the reinforcing phase and the one in which it is embedded is called the matrix .The reinforcing phase material may be in the form of fibers, particles, or flakes. The matrix phase materials are generally continuous. Examples of composite systems include concrete reinforced with steel and epoxy reinforced with graphite fibers, etc. [3]. Our area of interest are Laminated composite structures consisting of several layers of different fiber reinforced laminate bonded together to obtain desired structural properties (e.g. stiffness, strength, wear resistance, damping, etc.). Varying the lamina thickness, lamina material properties, and stacking sequence the desired structural properties can be achieved. Composite materials exhibit high strength-to weight and stiffness-to-weight ratios, which make them ideally suited for use in weight sensitive structures.

2. OBJECTIVES

- To analyze metallic flange for radial stress(x-direction) and axial stresses (y-direction) for preload condition.
- To analyze a carbon epoxy composite flange for preload condition at various orientations.
- To calculate radial stress (x-direction) and axial stresses (y-direction) of carbon epoxy composite flange for preload condition by analytical method using laminate plate theory.
- To analyze radial stress (x-direction) and axial stresses (y-direction) of composite flange for preload condition by using finite element software ANSYS.
- To compare the radial stress and axial stress of composite flange and metallic flange.

3. STRESS ANALYSIS OF METALLIC FLANGE BY FINITE ELEMENT ANALYSIS

Finite element analysis involves solution of engineering problems using problems. Engineering strictures that have complex geometry and loads, are either very difficult to analyze or have no theoretical solution. However in finite element analysis a structure of this type can be easily analyzed. Commercial finite element analysis programs, written so that a user can solve a complex engineering problems without knowing the governing equations or the mathematics; the user is required only to know the geometry of the structure and its boundary conditions. Finite element analysis software provides a complete solution including deflections, stresses, reactions, etc.

3.1 Dimensions of the Flange

In this analysis we are considering a non gasketed flange. The following parameters are considered and the flange is analyzed.

The design pressure(P)	= 15.32 Mpa
The flange material	= ASTM A105
The bolt material	= ASTM SA193 B7
The inside diameter(B)	= 406.4 mm
The outside diameter (A)	= 558.8 mm
The bolt circle (C)	= 514.36 mm
The flange thickness	= 44.4 mm
The hub length (h)	= 133.6 mm
The hub thickness (g_0=g_1)	= 19 mm
Number of bolts	= 16
Bolt diameter	= 25mm

3.2 Material Properties

Table-3.1: Material properties of flange and bolt

Component	Young's Modulus(E) Mpa	Poisson's Ratio	Allowable Stress (Mpa)	Material
Flange	173058 Mpa	0.3	248.2 Mpa	ASTM A105
Bolt	168922 Mpa	0.3	723.9 Mpa	ASTM SA193 B7

3.3 3dimensional and Finite Element Analysis Model of Flange

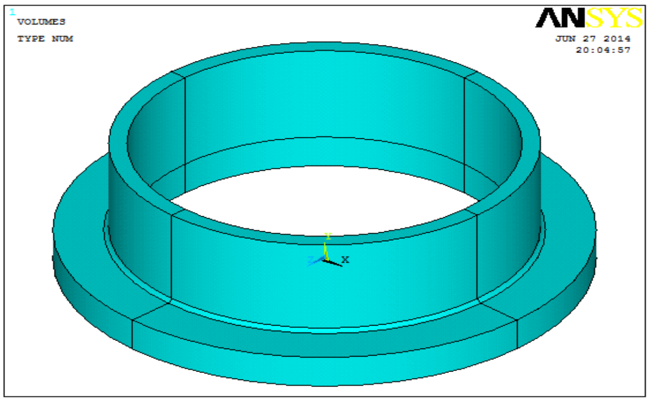


Fig-3.1: 3Dimensional model of flange

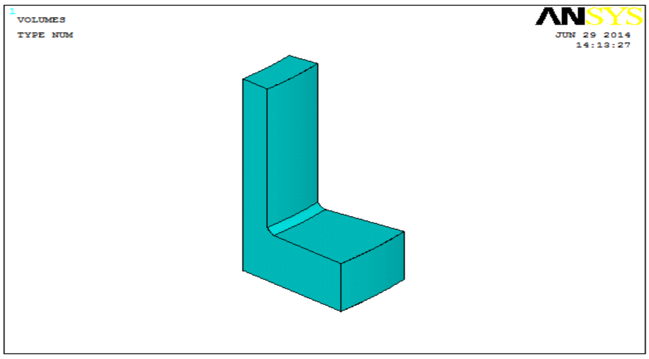


Fig-3.2:1/16th Part of metallic flange of 44.mm thickness

A 3D model of flange analysis requires more space and time to solve the problem; hence 1/16th part of the model is used to study the entire behavior of the component as shown in Figure-3.2

3.4 Finite Element Formulation and Boundary Conditions

In finite element analysis model domain is discretized into number of small regions called elements, these are selected based on geometric and analysis type. SOLID187 element is a higher order 3D, 10 node element. SOLID187 has a quadratic displacement behavior and is well suited to create elements in irregular model shapes. Element is defined by 10 nodes having three degrees of freedom at each node. The figure 3.3shows the finite element meshes of the flange.

The following boundary conditions are used to perform finite element analysis using ANSYS software

- The flanges are free to move either in radial (X) or tangential (Z) direction, this provides flange rotation and the exact behavior of stress in flange.
- Bottom of flange is constrained in axial (Y) direction as shown in figure3.4 below.
- Symmetry conditions are applied on both sides of flange.

- The preload applied on the top of flange (Y-direction) is the yield strength of the bolt. We are considering the maximum yield strength of bolt for analysis.
- Internal pressure of 15.32 Mpa is applied on inner surface of the flange.

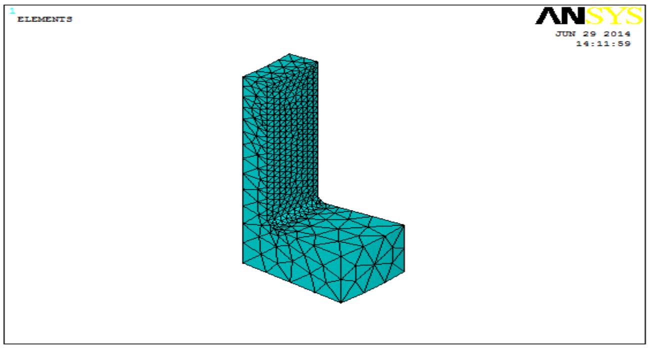


Fig-3.3: Finite element mesh of metallic flange

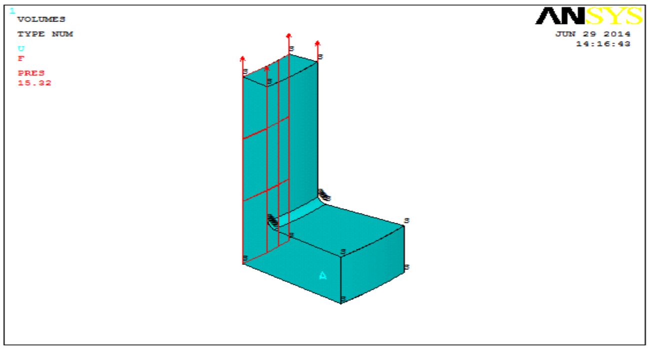


Fig-3.4: Boundary conditions of metallic flange

3.5 Reviewing the Results

The effect of preload on flange in radial direction (X-direction) and axial direction (Y-direction) are shown in the below figures.

The radial stress(X-direction) and axial stresses (Y-direction) are

- The Radial stress (X-direction): σ_X =3983 Mpa
- The Axial Stress (Y-direction): σ_Y =11080 Mpa

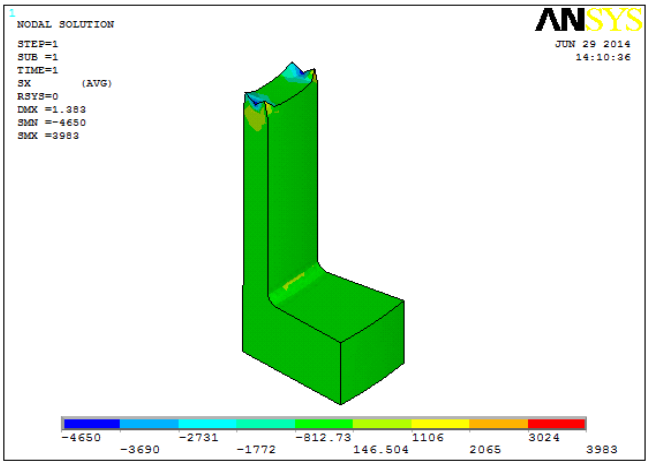


Fig-3.5: Radial stress (X-direction) of metallic flange

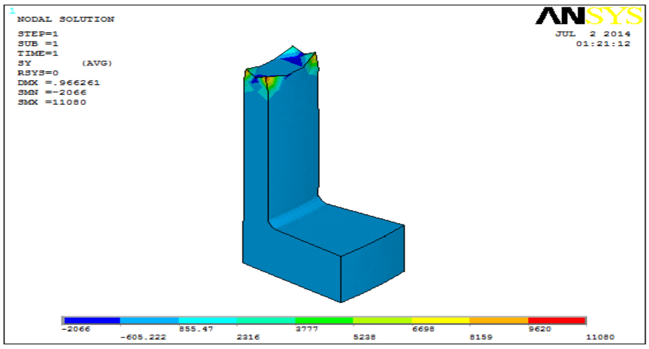


Fig-3.6: Axial stress (Y-direction) of metallic flange

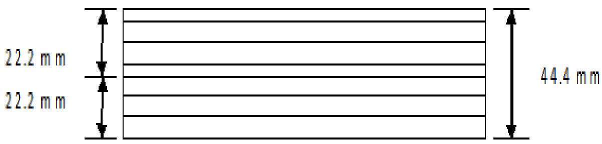
4. ANALYTICAL CALCULATIONS FOR COMPOSITE FLANGE

4.1 Orthotropic Properties of Carbon Epoxy Composite Material [16]

Young's Modulus in 1direction E_1 = 60930 MPa
Young's Modulus in 2 direction E_2 = 60930 MPa
Young's Modulus in 3 direction E_3 = 60930 MPa
Poisson's Ration in 1-2 direction ν_{12} = 0.39
Poisson's Ration in 2-3 direction ν_{23} = 0.67
Poisson's Ration in 1-3 direction ν_{13} = 0.67
Shear Modulus in 1-2 direction G_{12} = 3190 MPa
Shear Modulus in 2-3 direction G_{23} = 3340 MPa
Shear Modulus in 1-3 direction G_{13} = 3490 MPa
Density ρ = 1.6 x 10-6 Kg/

Consider the example of metallic flange of 44.4 mm flange thickness and 19mm hub thickness for flange dimensions,

1) For 44.4 mm Flange Thickness



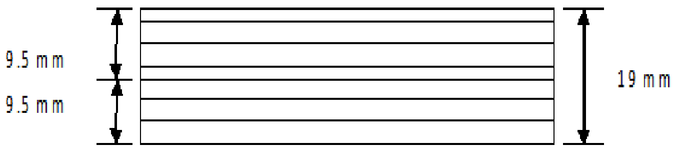
20 Layers of 2.22 mm thickness each and for [0/45] orientation symmetric

$$A = \begin{bmatrix} 2.7x10^{6} & 1.6x10^{6} & 8.07x10^{-11} \\ 1.6x10^{6} & 2.7x10^{6} & -8.07x10^{-11} \\ 8.07x10^{-11} & -8.07x10^{-11} & 5.5x10^{5} \end{bmatrix}$$

$$Q_{bar} = \begin{bmatrix} 5.3x10^{4} & 4.6x10^{4} & 3.6x10^{-12} \\ 4.6x10^{4} & 5.3x10^{4} & -3.6x10^{-12} \\ 3.6x10^{-12} & -3.6x10^{-12} & 2.1x10^{4} \end{bmatrix}$$

The above matrix is got by MAT LAB coding. The B matrix and D matrix are not considered because, the value of B matrix is very small and it is approximately equal to zero so B matrix is not considered. The value of D matrix is also very small compare to A matrix so, D matrix is not considered. Since we have considered only the resultant forces to calculate the strains and stresses so D matrix and B matrix is neglected. We have not considered the moment.

2) For 19 mm Hub Thickness



10 Layers of 1.9 mm each thickness and for [0/45] orientation symmetric

$$A = \begin{bmatrix} 1.2x10^{6} & 6.7x10^{5} & 2.7x10^{-11} \\ 1.6x10^{6} & 2.7x10^{6} & -2.7x10^{-11} \\ 2.7x10^{-11} & -2.7x10^{-11} & 2.02x10^{5} \end{bmatrix}$$

$$Q_{bar} = \begin{bmatrix} 7.1x10^{4} & 2.8x10^{4} & 0 \\ 2.8x10^{4} & 7.1x10^{4} & 0 \\ 0 & 0 & 3.19x10^{3} \end{bmatrix}$$

The above matrix is got by MAT LAB coding. The B matrix and D matrix are not considered because, the value of B matrix is very small and it is approximately equal to zero so B matrix is not considered. The value of D matrix is also very small compare to A matrix so, D matrix is not considered. Since we have considered only the resultant forces to calculate the strains and stresses so D matrix and B matrix is neglected. We have not considered the moment.

To calculate strains

$$\begin{Bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \varepsilon_s^0 \end{Bmatrix} = \left[[A]_{44}^{-1} + [A]_{19}^{-1} \right] \begin{Bmatrix} N_x \\ N_y \\ N_s \end{Bmatrix}$$

To calculate N_x and N_y

$N_x = 15.32 \text{ x } 2\pi \text{ x } 203.2$
$N_x = 19559.70$ N/mm

$N_y = 723.9 \text{ x } 2\pi \text{ x } 12.5$
$N_y = 56854.9$ N/mm

$$\begin{Bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \varepsilon_s^0 \end{Bmatrix} = \begin{bmatrix} 1.7x10^{-6} & -1.01x10^{-6} & -3.8x10^{-32} \\ -1.01x10^{-6} & 1.7x10^{-6} & 3.8x10^{-22} \\ -3.8x10^{-32} & 3.8x10^{-22} & 6.7x10^{-6} \end{bmatrix} \begin{Bmatrix} 19559.70 \\ 56855 \\ 0 \end{Bmatrix}$$

$$\begin{Bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \varepsilon_s^0 \end{Bmatrix} = \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_s \end{Bmatrix} = \begin{Bmatrix} -0.024 \\ 0.076 \\ 1.41x10^{-17} \end{Bmatrix}$$

To calculate stress in radial (x-direction) & axial (y-direction)

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_s \end{Bmatrix} = \left[[Q_{bar}]_{44} + [Q_{bar}]_{19} \right] \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_s \end{Bmatrix}$$

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_s \end{Bmatrix} = \begin{bmatrix} 124x10^{3} & 74x10^{3} & 3.6x10^{-12} \\ 74x10^{3} & 124x10^{3} & -3.6x10^{-12} \\ 3.6x10^{-12} & -3.6x10^{-12} & 3.19x10^{3} \end{bmatrix} \begin{Bmatrix} -0.024 \\ 0.076 \\ 1.41x10^{-12} \end{Bmatrix}$$

$$\sigma_x = 2648 Mpa$$

$$\sigma_y = 7648 Mpa$$

The above values shows the values of radial stress (σ_x) and axial stress (σ_y) of carbon epoxy composite flange of [0/45] orientation

5. STRESS ANALYSIS OF COMPOSITE FLANGE BY FINITE ELEMENT ANALYSIS

Here in composite analysis also 1/16th part of the model is used to study the entire behavior of the flange.

In finite element analysis model domain is discretized into number of small regions called elements, these are selected based on geometric and analysis type. SOLID LAYERED 46 element is used for the analysis purpose of composites here in this thesis. The boundary conditions applied are same as the analysis which is done for metallic flange.

5.1 Reviewing the Results

The effect of preload on flange in radial direction (X-direction) and axial direction (Y-direction) for various fiber orientations are shown in the below figures.

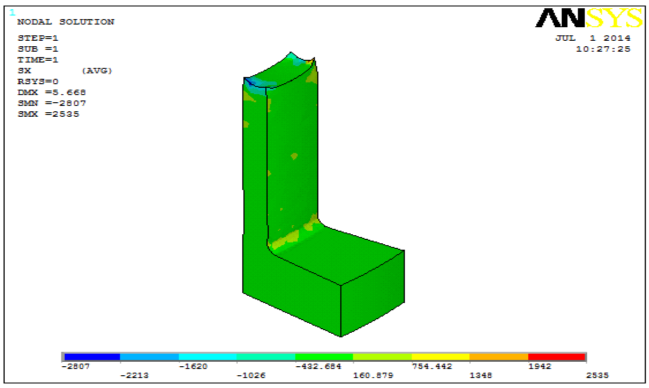


Fig-5.1: Radial Stress (X - Direction), [0/0] orientation

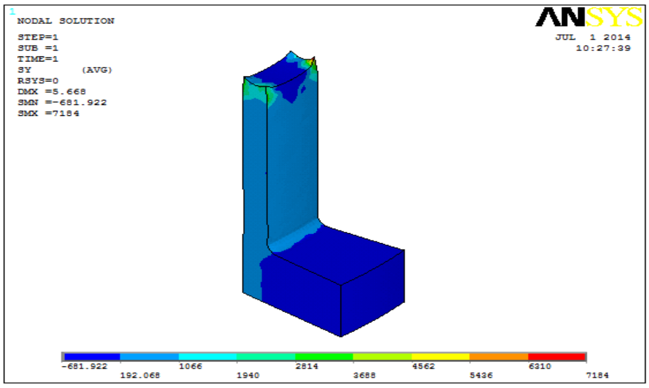


Fig-5.2: Axial Stress (Y - Direction), [0/0] orientation

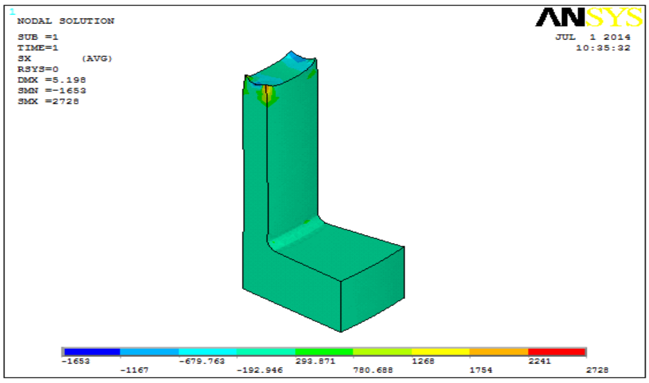


Fig-5.3: Radial Stress (X - Direction), [0/45] orientation

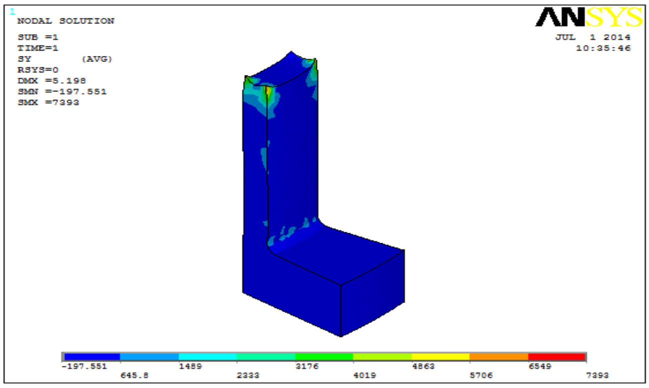


Fig-5.4: Axial Stress (Y - Direction), [0/45] orientation

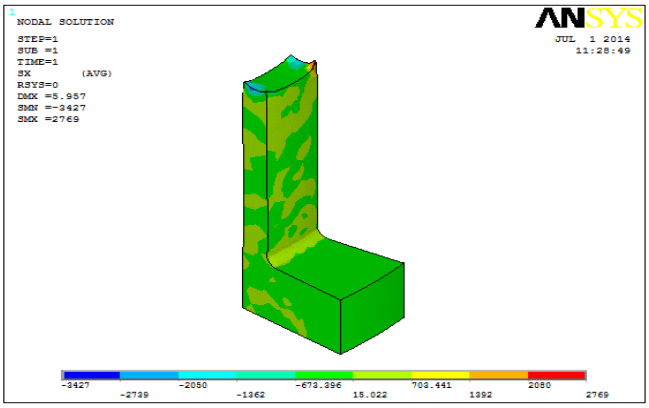


Fig-5.5: Radial Stress (X - Direction), [0/60] orientation

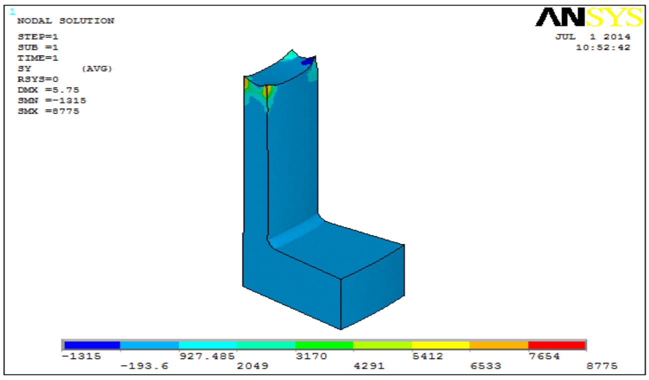


Fig-5.6: Axial Stress (Y - Direction), [0/60] orientation

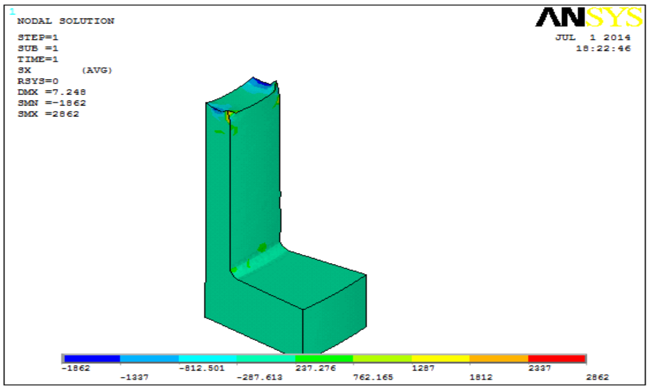


Fig-5.7: Radial Stress (X - Direction), [0/90] orientation

6. RESULTS AND DISCUSSION

The results consist of radial stresses (X-direction) and axial stresses (Y-direction) which are analyzed for metallic flanges and composite flange in various fiber orientations. The radial stresses and axial stresses in composite flange are calculated analytically and verified with FEA results.

6.1 Comparison of Analytical and FEA Results for Composite Flange

Table-6.1: Analytical and FEA results of radial and axial stresses in composite flange

Sl No	Fiber Orientation	Radial Stress (Mpa) Analytical	Radial Stress (Mpa) FEA	Axial Stress (Mpa) Analytical	Axial Stress (Mpa) FEA
1	[0/0]	2880	2535	8428	7184
2	[0/45]	2648	2728	7648	7393
3	[0/60]	2761	2769	7930	8775
4	[0/90]	3023	2862	6948	7657
5	[45/-45]	2296	2512	8792	7454
6	[60/-60]	2400	2366	7500	8391

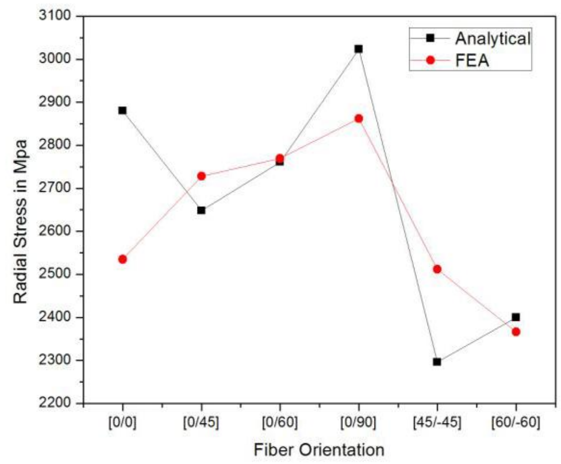


Fig-6.1: Analytical and FEA results of radial stresses for various fiber orientations

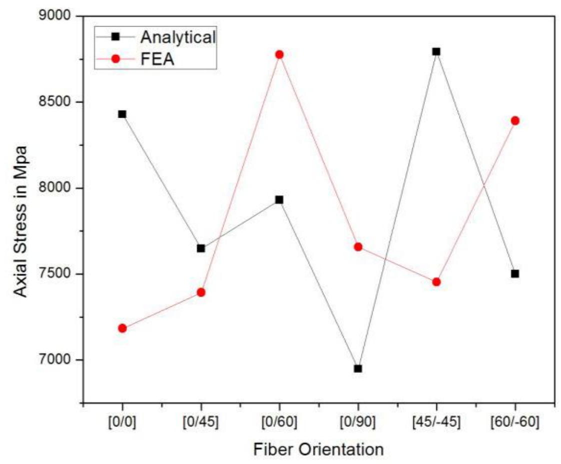


Fig-6.2: Analytical and FEA results of axial stresses for various fiber orientations

6.2 Comparison of [0/0], [0/45], [0/60], [0/90], [45/-45], [60/60] Orientation Composite Flanges and Metallic Flange

Table-6.2: Radial and axial stress of composite flanges of different fiber orientations and metallic flange

Sl.No	Flange Material	Radial Stress (Mpa)	Axial Stress (Mpa)
1	Composit [0/0]	2535	7184
2	Composit [0/45]	2728	7393
3	Composit [0/60]	2769	8775
4	Composit [0/90]	2862	7657
5	Composit [45/-45]	2512	7454
6	Composit [60/-60]	2366	8391
7	Metallic	3983	11080

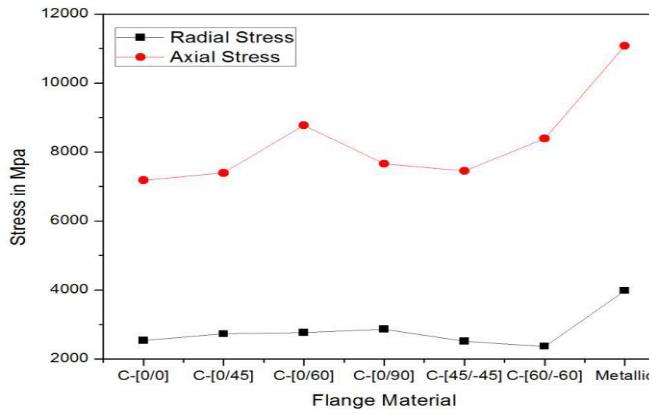


Fig-6.3: Radial and axial stress of composite flanges of different fiber orientations and metallic flange

7. CONCLUSION

The analytical results of the composite flange for various orientations are in line matching with the finite element analysis results of the composite flange of various orientations and the orientation of [0/45] and [0/60] showed nearly exact results in comparison with analytical and finite element analysis results. From these we can conclude that the composite flange i.e. the carbon epoxy flange in different orientations give better results when compared to the metallic flange of same flange thickness and hub thickness. The radial stress and axial stress developed in the composite flange is less when compared with the metallic flange. The orientation which is best suitable for the manufacture of composite flange is the [0/45] and [0/60] orientation.

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