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Comparison between Finite Element Analysis and Analytical Solution for Composite Beam

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Abstract—**Composite laminated materials have been increasingly used in a various industrial field. So predicting and preventing failures of composites becomes impotent aspect now days. To minimize cost and time pre-construction test of composite is always beneficial. Finite element analysis (FEA) is one of the important tool to predict failure of composite. In this paper finite element analysis (FEA) of composite is done and results are check with analytical results.**

***Index Terms*—finite element analysis (FEA), composite laminate beam,**

I. INTRODUCTION

Composites are materials made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. Each year, composites find their way into hundreds of new applications, from golf clubs and tennis rackets to jet skis, aircraft, missiles and spacecraft. Composite materials offer designers an increasing array of as a material and system solution. At the same time, composite cost trends are highly favourable, especially when the total cost of fabrication is considered. Processes such as pultrusion offer the means to convert composite materials into finished products in a single trip through the machinery. Composite sheet moulding compounds allow the formation of complete automobile skin panels in a single stroke of a press.

Reason for use:

- Stronger and stiffer than metals on a density basis
- Capable of high continuous operating temperatures
- Highly corrosion resistant
- Electrically insulating properties are inherent in most composites
- Tailorable thermal expansion properties
- Exceptional formability and durability with Low investment in fabrication equipment
- Corrosion Resistance
- Excellent Electromagnetic properties

Shock, impact, or repeated cyclic stresses can cause the laminate to separate at the interface between two layers, a condition known as de-lamination. Composites can fail on the microscopic or macroscopic scale. Compression failures can occur at both the macro scale or at each individual reinforcing fiber in compression buckling. Tension failures can be net section failures of the part or degradation of the composite at a microscopic scale where one or more of the layers in the composite fail in tension of the matrix or failure of the bond between the matrix and fibers.

To aid in predicting and preventing failures, composites are tested before and after construction. Pre-construction testing may use finite element analysis (FEA) for ply-by-ply analysis of curved surfaces and predicting wrinkling, crimping and dimpling of composites. Materials may be tested after construction through several non-destructive methods including ultrasonic, thermography, shearography and X-ray radiography. But most of the time Pre-construction testing are used. In this paper finite element analysis is uses to analyze composite laminate structure which are subjected to different working condition.

Fig. No. 1 Show composite laminate beam made up of different material (steel, copper, brass, aluminium). 4th outer most layer is made up of steel (with young's modulus 200GPa and passions ratio 0.27) having 100mm external diameter and 80mm internal diameter. 3rd outer most layer is made up of aluminium (with young's modulus 69GPa and passions ratio 0.33) having 80mm external diameter and 60mm internal diameter 2nd outer most layer is made up of copper (with young's modulus 117GPa and passions ratio 0.36) having 60mm external diameter and 35mm internal diameter. Inner most layer made up of brass (with young's modulus 105GPa and 0.34 passions ratio) having 35mm diameter.

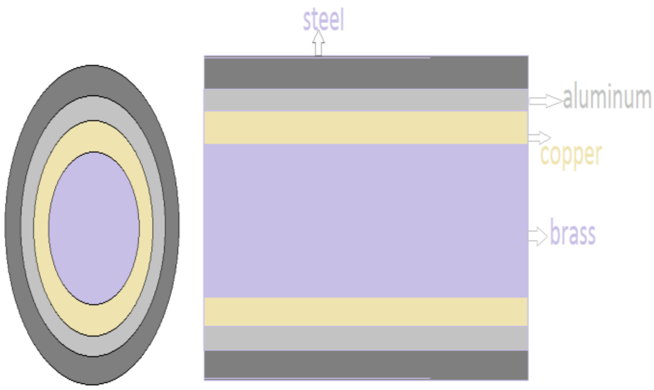

Fig 1 composite laminate beam

This composite laminate structure is fix at one end and 500KN tensile force is acting at other end. For this structure stress in deformation calculation is done both by analytically and with FEA.

II. ANALYTICAL SOLUTION

Wherever Times is specified, Times Roman or Times New Roman may be used. If neither is available on your word processor, please use the font closest in appearance to Times. Avoid using bit-mapped fonts. True Type 1 or Open Type fonts are required. Please embed all fonts, in particular symbol fonts, as well, for math, etc.

- **4^{th} outermost layer is "steel"**
  External diameter (D_{st}) = 100mm
  Internal diameter (d_{st}) = 80mm
  $(A)_{steel} = \frac{\pi}{4} * (D_{st}^2 - d_{st}^2)$
  A_{steel} = 2.8727* 10^-3 m^2

- **3rd outermost layer is "aluminium"**
  External diameter (D_{al}) = 80mm
  Internal diameter (d_{al}) = 60mm
  $(A)_{aluminium} = \frac{\pi}{4} * (D_{al}^2 - d_{al}^2)$
  $(A)_{aluminium}$ = 2.119* 10^-3 m^2

- **2rd outermost layer is "copper"**
  External diameter (D_{cu}) = 60mm
  Internal diameter (d_{cu}) = 35mm
  $(A)_{copper} = \frac{\pi}{4} * (D_{Cu}^2 - d_{Cu}^2)$
  $(A)_{copper}$ = 1.8653* 10^-3 m^2

- **Inner most layer is "brass"**
- External diameter (D_{br}) = 35mm
  $(A)_{brass} = \frac{\pi}{4} * (D_{br}^2)$
  $(A)_{brass}$ = 9.6211* 10^-4 m^2

Total force 500KN force acting on composite laminate panel is taken by each lamina by some amount. So that total force acting is equal to sum of force acting on each layer.

$P_{Total} = P_{al} + P_{st} + P_{cu} + P_{br}$ -------- (1)

For finding out force taken by each layer we have to use compatibility condition.

$[PL/AE]_{steel} = [PL/AE]_{copper} = [PL/AE]_{brass} = [PL/AE]_{aluminium}$

$$\frac{P_{st}}{2.8274 * 10^{-3} * 200 * 10^9} = \frac{P_{cu}}{1.86532 * 10^{-3} * 117 * 10^9} =$$

$$= \frac{P_{br}}{9.6211*10^{-4}*105*10^9} = \frac{P_{al}}{2.1991*10^{-3}*69*10^9}$$

Therefore, total equation becomes

$$\frac{P_{st}}{565.48*10^6} = \frac{P_{cu}}{2182.4244*10^5} = \frac{P_{br}}{1010.2155*10^5} = \frac{P_{al}}{1517.37*10^5} \quad \text{------------------(2)}$$

From equation 1st and 2nd we have to find out force acting on each layer.

Force acting on steel layer,
P_{st} + 0.38594 P_{st} + 0.17864 P_{st} + 0.268334 P_{st} = 500*10^3
P_{st} = 272.789 * 10^3 N

Force acting on copper layer,
2.591 P_{cu} + P_{cu} + 0.4628 P_{cu} + 0.695272 P_{cu} = 500*10^3
P_{cu} = 105.283*10^3 N

Force acting on aluminium layer,
3.7268 P_{al} + 1.4382 P_{al} + P_{al} + 0.6657 P_{al} = 500*10^3
P_{al} = 73.198*10^3 N

Force acting on brass,
5.5979 P_{br} + 2.1603 P_{br} + P_{br} + 1.5020 P_{br} = 500*10^3
P_{br} = 48.733*10^3 N

Stress in each layer of composite laminate,
Stress in 4th outermost layer (steel layer) = P_{st}/A_{st}

Stress in 4th outermost layer (steel layer) = 96.480 MPa

Stress in 3th outermost layer (aluminium layer) = 33.285 MPa

Stress in 2th outermost layer (copper layer) = 56.4423 MPa

Stress in innermost layer (brass layer) = 50.6522 MPa

Deformation in composite laminate beam = PL/AE
= 0.3859 mm

III. FEA SOLUTION

Fist we have to construct composite laminate beam model as par the given dimension in workbench.

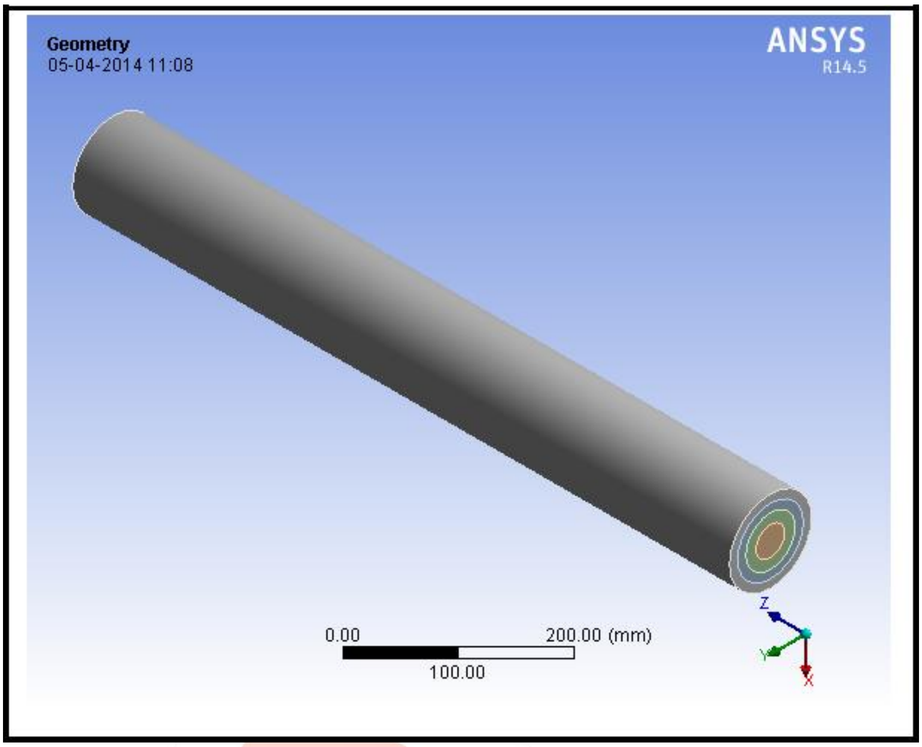

Fig 2 Plot 1. Geometry

After construction of model we have to apply material property. As it is composite structure made up of different layer material so each layer have different material property. So create material file firstly for all material, then apply each material film to respective layer.

In given data model is fixed at one end and 500KN tensile force is applied at other end, so in ansys we have to apply fix support at one end of composite laminate beam and remote force (coupled tensile) of 500 KN is applied at other end.

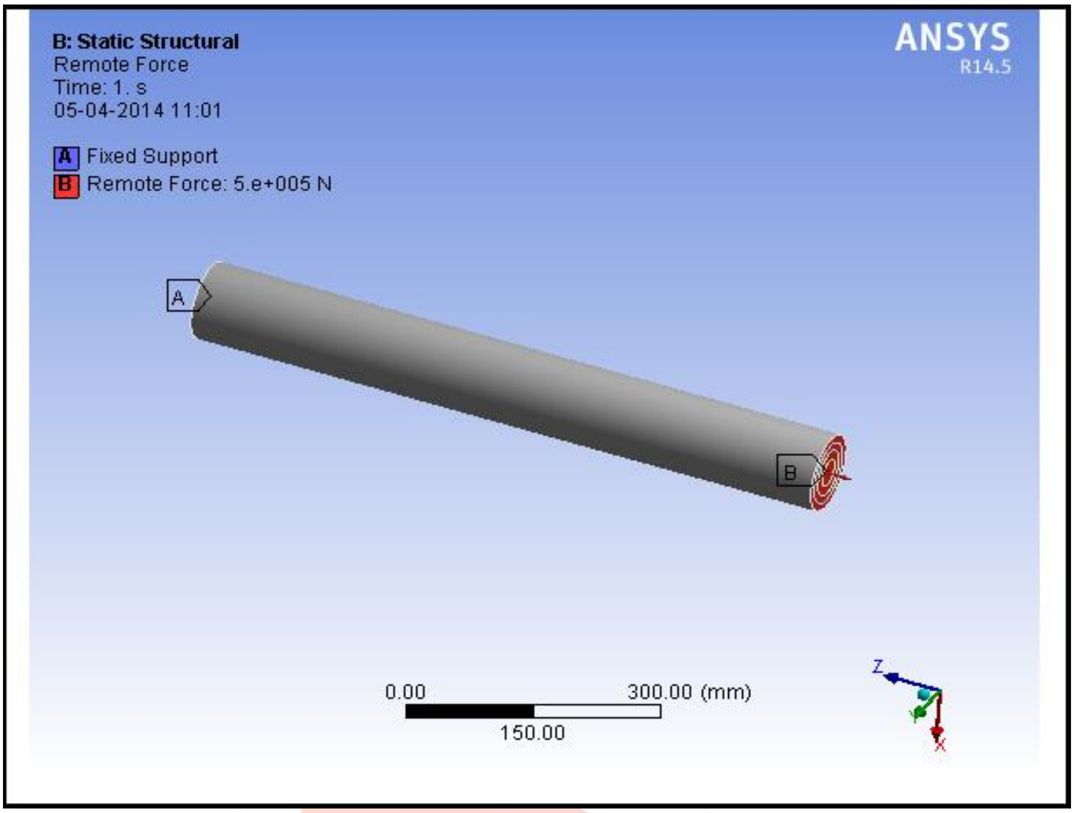

Fig 3 Plot 2. Loading and boundry condition

Then meshing of complete model is done.

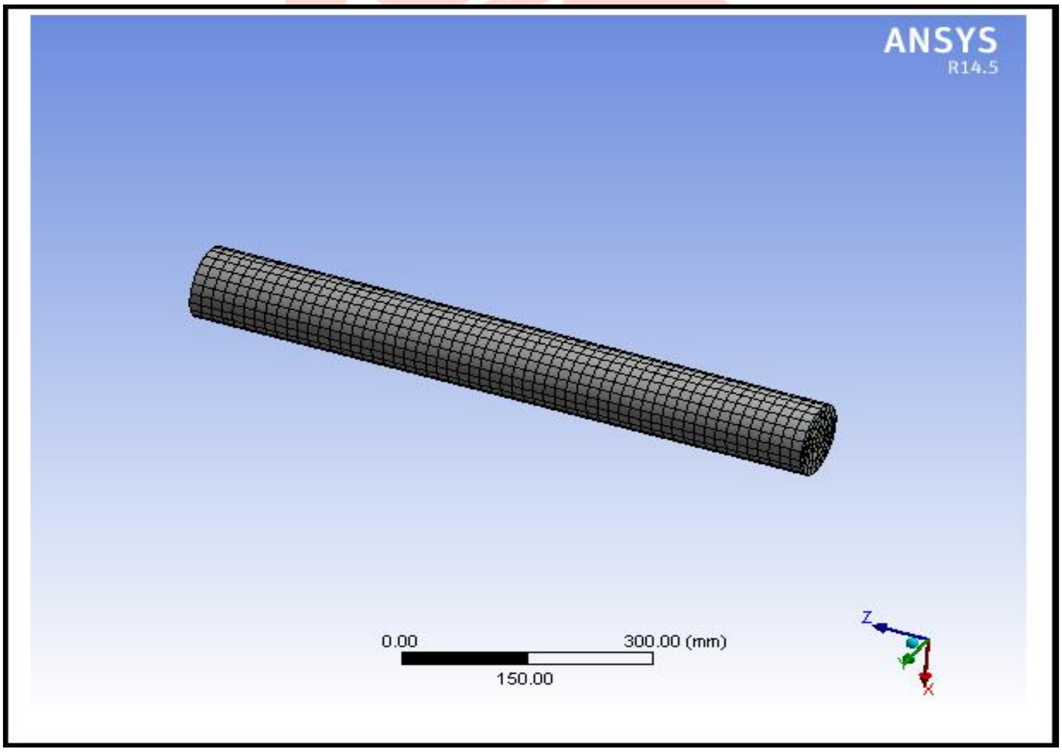

Fig 4 Plot 3. Meshing model

After this solve the model and check the result for stress in each layer and total deformation.

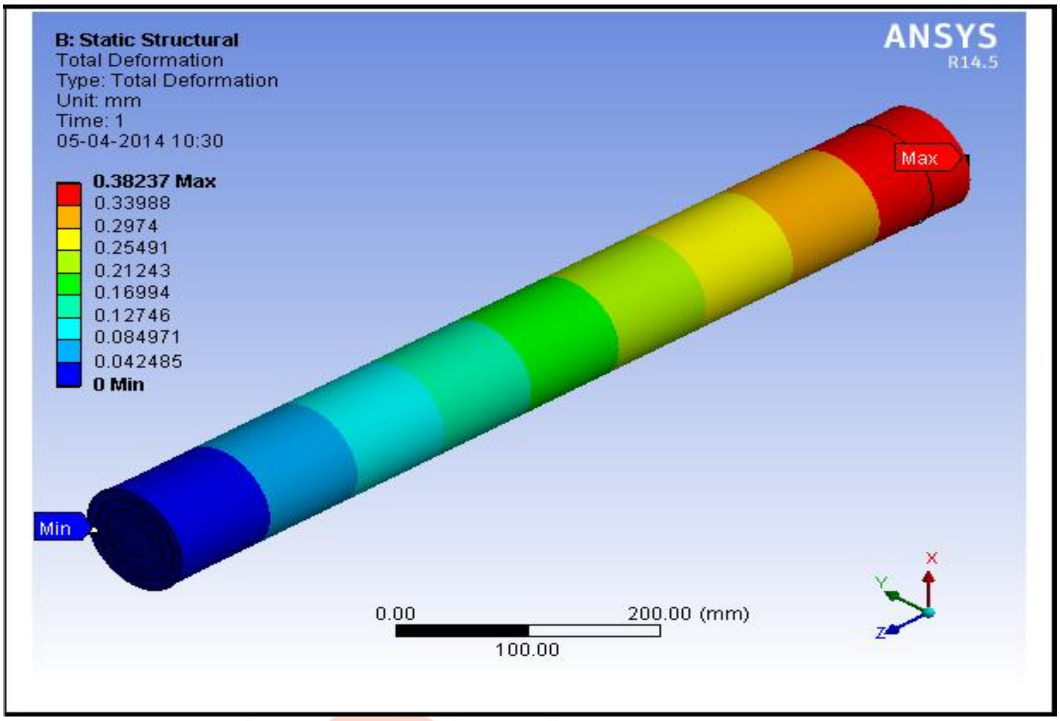

Fig 5 Plot 4. Deformation plot

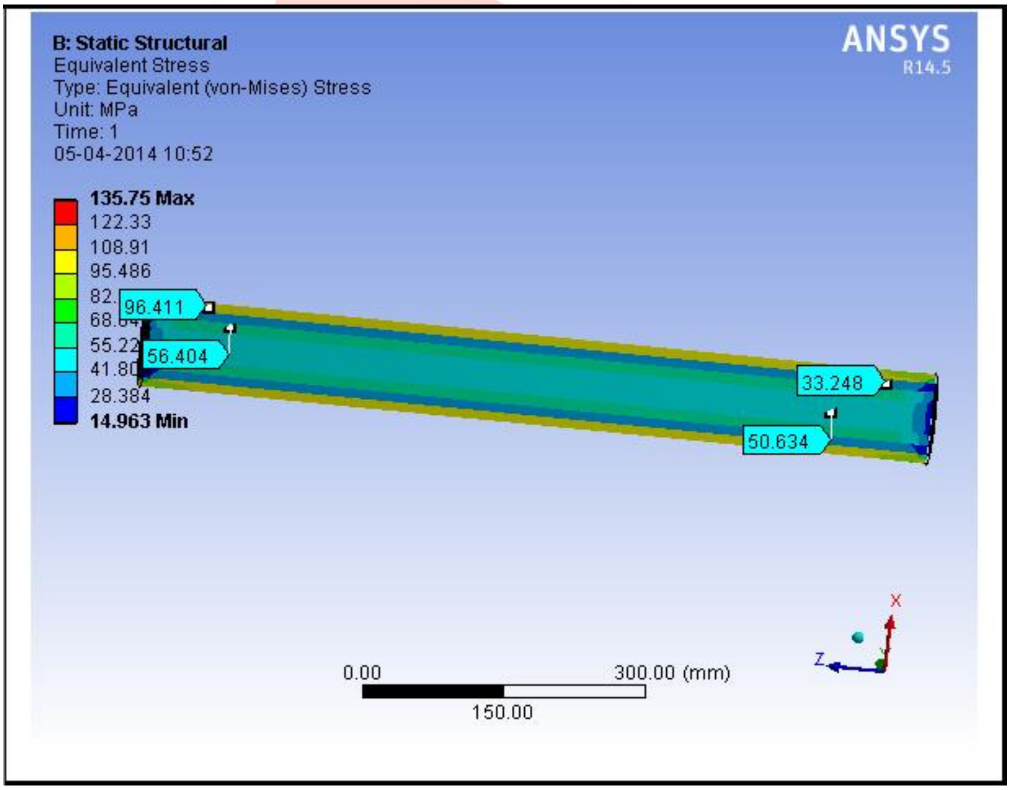

Fig 6 Plot 5. Stress plot

IV. RESULT

Comparison Of Analytical And Fea Results

	ANALYTICAL RESULT	FEA RESULT	% OF ERROR
STRESS IN 4TH LAYER (STEEL)	96.480 MPa	96.411 MPa	0.0715%
STRESS IN 3RD LAYER (ALUMINIUM)	33.285 MPa	33.248 MPa	0.1111%
STREE IN 2ND LAYER (COPPER)	56.4423 MPa	56.404 MPa	0.067%
STRESS IN INNER MOST LAYER (BRASS)	50.6522 MPa	50.634 MPa	0.0359%
DEFORMATION IN COMPOSITE LAMINATE BEAM	0.3859 mm	0.3823 mm	0.932%

From comparison we can see that % of error in between analytical result and FEA result for stress are less than 0.2% and for deformation less than 1%. All the finite element analysis (FEA) result are closely matching with the analytical result. Hence result obtained from finite element analysis (FEA) are correct. Hence by using finite element analysis (FEA) we get the accurate result in minimum time and in minimum cost.

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