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Stresses and Deformations of Hybrid Rail in Laminated FRP Composites Subjected to Transverse Loading

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Abstract—*The present investigation deals with the analysis of Stresses and deformations of hybrid rail in laminated FRP composites subjected to Transverse loading using three-dimensional theory of elasticity based on finite element method. The finite element model is validated with the available results in the literature for the Transverse loading of a rail made of isotropic material and is extended for the analysis of a Hybrid rail made of generally and specially orthotropic laminates subjected to Transverse loads for different fiber materials. Maximum stresses and deformations in Head, Bottom and composite web of rail are computed and the effect of fiber angle on these stresses and deformations are studied. The results of the present analysis reveals that the three-dimensional stress analysis is required for the analysis of Stresses and deformations of hybrid rail in laminated FRP composites subjected to Transverse loading.*

Keywords*: RAIL, FRP, C-C*

1. INTRODUCTION

Fiber reinforced plastic (FRP) materials have proven to be very successful in structural applications. They are widely used in the aerospace, automotive and marine industries. FRP materials or composites behave differently than typical metals such as steel or aluminum. A typical composite contains layers of aligned fibers oriented at different angles held together by a resin matrix, giving high strength and stiffness in different directions. This anisotropy can cause difficulties when joining two parts together, especially if the two pieces have different stiffness and strength characteristics.

Mehmet Ali Arslanand, Oguz Kayabas(11) conducted a project on 3-D Rail–Wheel Contact Analysis using FEA. In their investigation they found that, “Mechanics of the Rail–Wheel contact is one of the fundamental areas of the study in Railway Engineering, requiring both vast application expertise and dependable analysis approaches. Analytical formulations describing the physics of this phenomenon are only defined for certain type of simple contact geometries; therefore for more complicated geometries the analytical models utilizing closed formulations remain elusive. Remaining option is to utilize numerical computation methods. Railway engineers are, to the certain extent, successfully applied one of the numerical computation techniques known as Finite Element Analysis (FEA) into Rail– Wheel contact problems to validate their results by comparing them to their real life data obtained over the years. In the literature, most of the work on the Rail–Wheel contact FEA is either 2-Dimensional axi-symmetric or simple 3D Rail–Wheel models with poor mesh count/quality or undesired Tet-mesh, latter known to exhibit stiff deformation characteristics during the deformation. Also, in majority of the FEA studies, boundary conditions and/or total load are applied with some approximations. This study focuses more on the fundamental way of handling Rail–Wheel contact problems from the FEA standpoint, and highlights required steps for more realistic 3D solutions to these types of problems. 3D FE analysis results obtained show good agreement with real life problems experienced at both railway Wheel and Rail”.

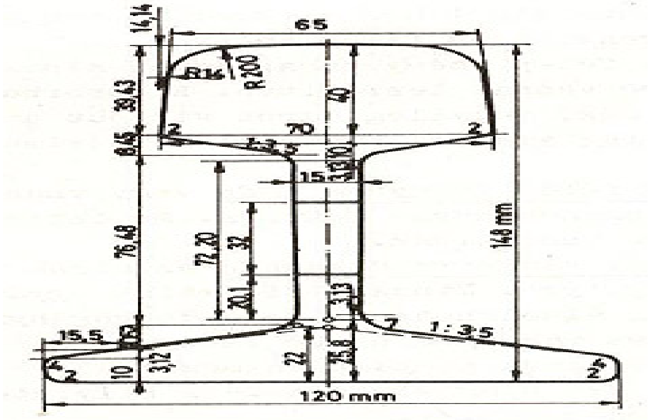
Very few works appear to have been made on the analysis of Stresses and deformations of rail made of isotropic material subjected to Transverse loading. No significant work has been reported for the analysis of Stresses and deformations of hybrid rail in laminated FRP composites subjected to Transverse loading. In this paper, attempts are made to study the stresses and deformations of hybrid rail in laminated FRP composites subjected to Transverse loading.

The objective of the present paper is to study the three-dimensional stress analysis of hybrid rail in laminated FRP composites subjected to Transverse loading with C-C end conditions. The analysis includes the evaluation of normal stresses, shear stresses and deformations in the Head, Bottom and Laminated Web for different fiber angle orientations and for different fiber materials.

2. PROBLEM MODELING

2.1 Geometry

The geometry of the hybrid rail used is shown in Fig. 1 where the dimensions taken are as follows.



All dimensions are in mm

Fig. 1: Geometry of hybrid rail

2.2 Finite Element Model

The finite element mesh is generated using a three-dimensional brick element 'SOLID 185' of ANSYS [1]. This element (Fig. 2) is a structural solid element designed based on three-dimensional elasticity theory and is used to model thick orthotropic solids. The element is defined by 8 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions.

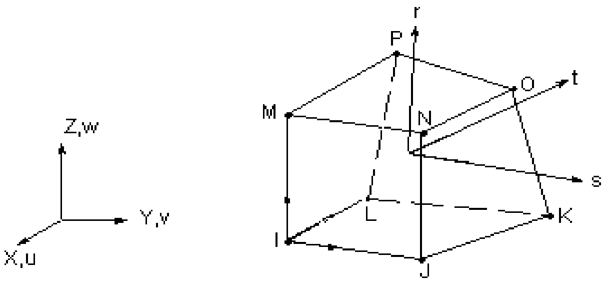


Fig. 2: SOLID 185 Element

2.3 Loading

The following types of loads are applied for the prediction of the response of the structure for the present analysis. A point load i.e 138320 N along the length of rail at 4 equidistant points is applied for the validation and analysis of the present finite element model used for *Rail*

2.4 Boundary Conditions

In this case, both the ends and bottom of rail are fixed and a Transverse uniform pressure of 138320 N is applied.

2.5 Material Properties

The following mechanical properties are used for the analysis purpose.

Property	E GLASS	KEVLAR	GRAPHITE
Longitudinal modulus, E1, GPa	41	80	147
Transverse in-plane modulus,E2	10.4	5.5	10.3
Transverse out-of-plane modulus, E3	10.4	5.5	10.3
In-plane shear modulus, G12, GPa	4.3	2.2	7.0
Out-of-plane shear modulus, G23	3.5	1.8	3.7
Out-of-plane shear modulus, G13	4.3	2.2	7.0
Major in-plane Poisson's ratio,ν12	0.28	0.34	0.27
Out-of-plane Poisson's ratio,ν23	0.50	0.40	0.54
Out-of-plane Poisson's ratio,ν13	0.28	0.34	0.27

2.6 Laminate sequence

i) One $+\theta^0/-\theta^0/-\theta^0/+\theta^0$ laminated FRP composite plate is used as Web for the present analysis. The value of θ is measured from the longitudinal direction of the structure (x-axis) and varied from 0^0 to 90^0 in steps of 15^0.

3. RESULTS

3.1 Finite element mesh of Hybrid Rail:

Fig. 3 shows the finite element mesh of Hybrid Rail

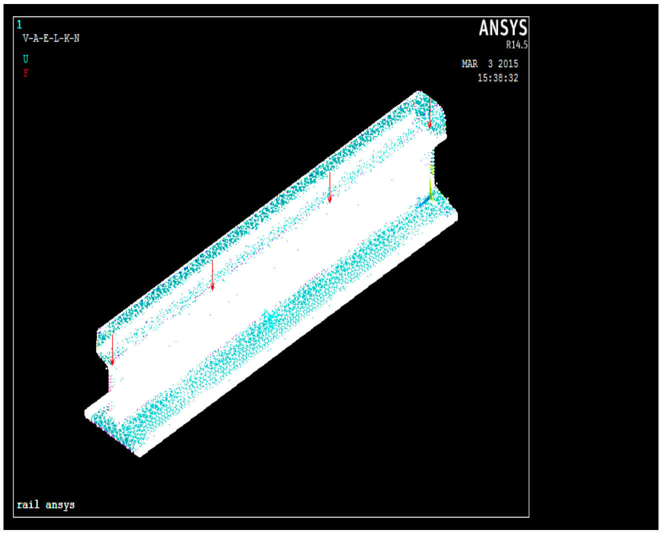


Fig. 3: Finite Element Mesh of Hybrid Rail

3.2 Stresses and deformations in the Hybrid rail with respect to the fiber angle θ

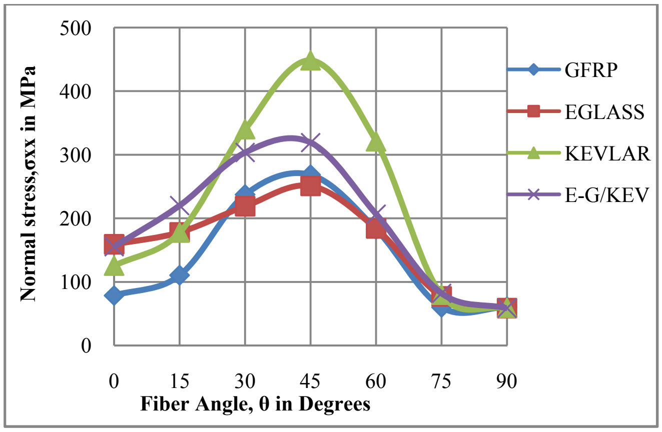


Fig. 4: Variation of σ_{xx} w.r.t θ

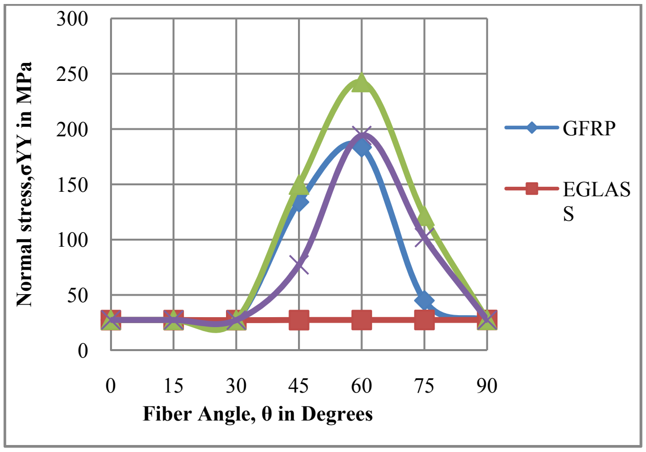


Fig. 5: Variation of σ_{yy} w.r.t θ

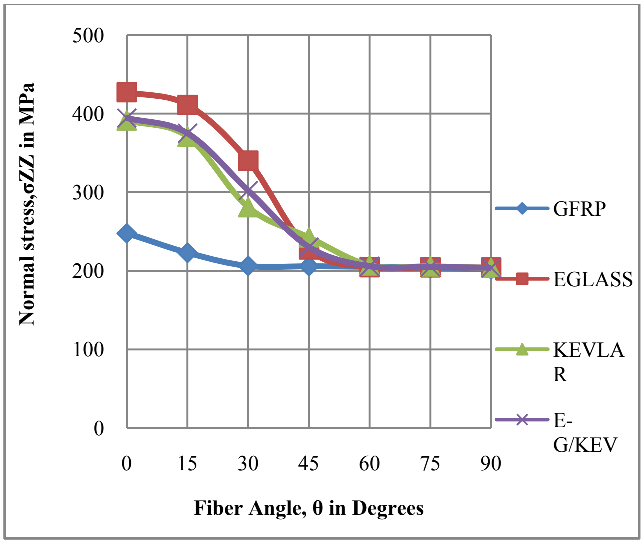


Fig. 6 Variation of σ_{zz} w.r.t θ

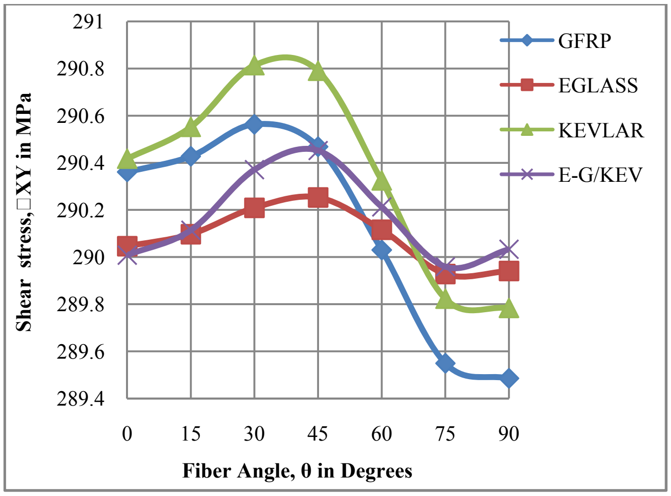


Fig. 7: Variation of τ_{xy} w.r.t θ

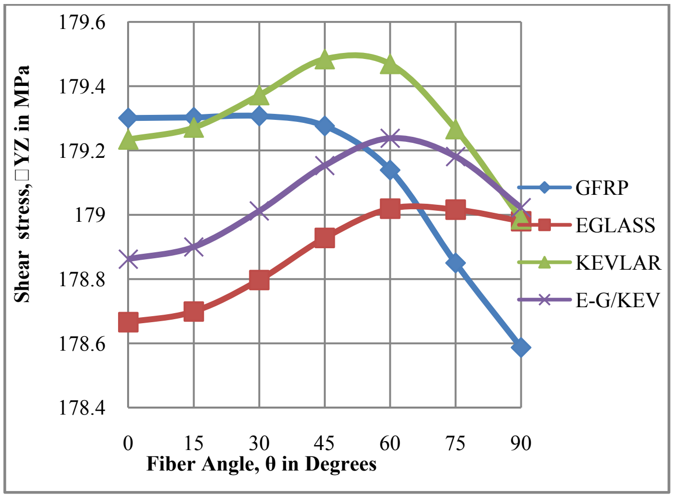


Fig. 8: Variation of τ_{yz} w.r.t θ

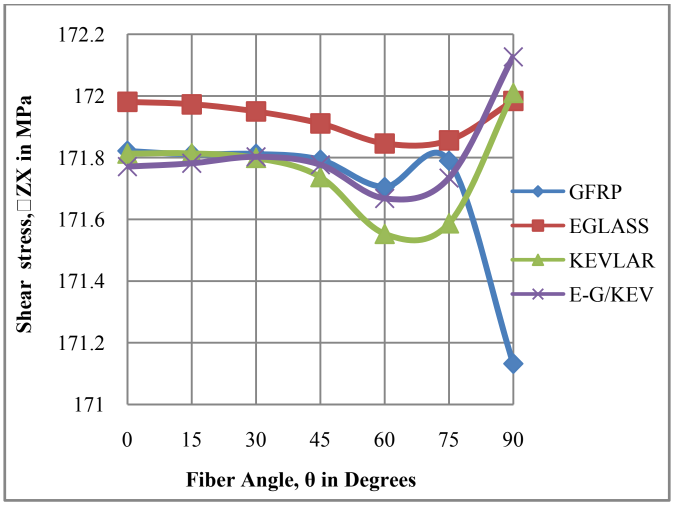


Fig. 9: Variation of τ_{zx} w.r.t θ

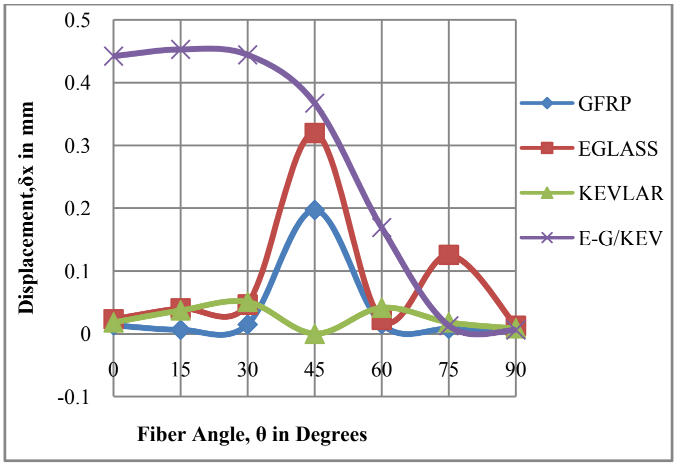


Fig. 10: Variation of δx w.r.t θ

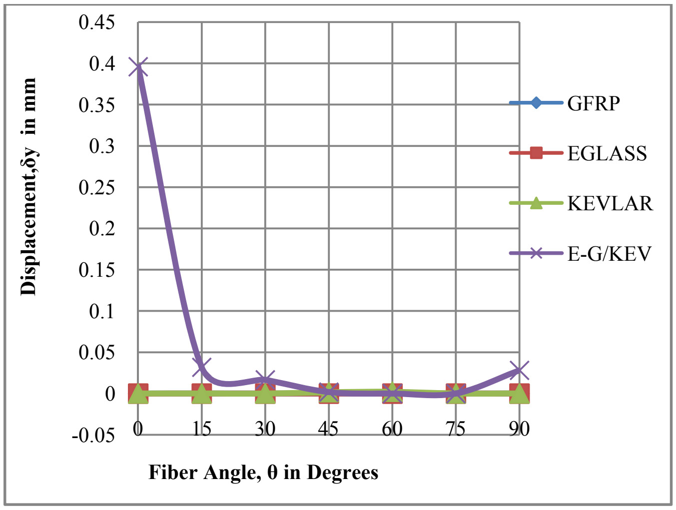


Fig. 11: Variation of δy w.r.t θ

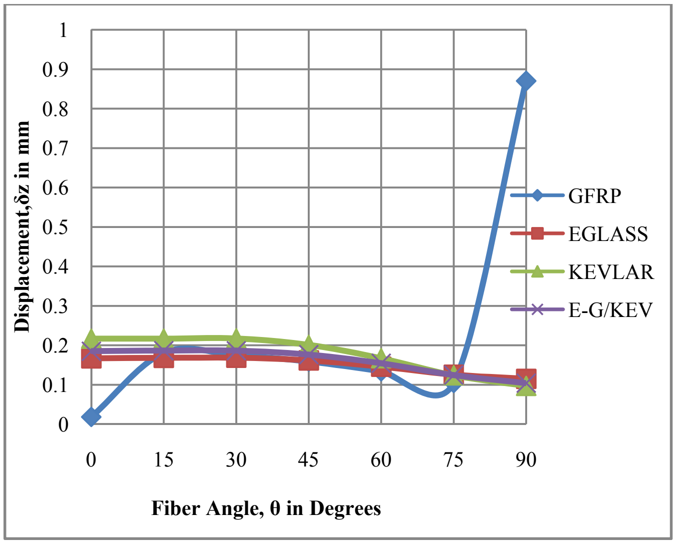


Fig. 12: Variation of δz w.r.t θ

One of the reasons for the variation of the stresses in the structure is due to the non-uniform arrangement of the fibers in the width direction except at $\theta=0^0$ and 90^0. The second reason is due to the coupling between bending, shear, and extensions in the deformations of the laminates. Another reason is due to the inter-laminar effect at the free edges of the structure.

Figs 4 to 6 depicts the variation of Normal stress in the Hybrid rail .The Normal stress σ_{xx} is increasing from 0^0 to 45^0 fiber angle orientations and then decreasing up to 90^0 in E-Glass/Kevlar. Finally found minimum at 90^0. Fig.5.shows that the Normal stress σ_{yy} is decreasing from 0^0 to 30^0 fiber angle orientation and increasing up to 75^0 and then decreasing upto 90^0 in E-Glass. Finally it is found to be minimum at 30^0 .Fig.6 depicts that the Normal stress σ_{zz} is decreasing from 0^0 to 90^0 fiber angle orientation in GFRP and it is minimum at 90^0.

Figs 7 to 9 depicts the variation of Shear stress in the Hybrid rail. The shear stress τ_{xy} is increasing from 0^0 to 30^0 fiber angle orientation and then decreasing up to 90^0 in GFRP. Finally it is minimum at 90^0. The Shear stress τ_{yz} is increasing from 0^0 to 30^0 fiber angle orientation and then decreasing up to 90^0 in GFRP. Finally it is minimum at 90^0.The Shear stress τ_{zx} is fluctuating from 0^0 to 90^0 fiber angle orientation and finally found minimum at 90^0 in GFRP.

Figs 10 to 12 show the variation of Displacement in the structure. The displacement,δ_x is increased from 0^0 to 15^0 fiber angle orientation and then decreasing up to 90^0 in E-Glass/Kevlar. Finally found minimum at 90^0. The Displacement δ_y is linearly varying for Kevlar and minimum at 30^0 fiber angle orientation. The Displacement δ_z is increased from 0^0 to 15^0 fiber angle orientation and then decreased up to 90^0 in GFRP. It is minimum at 0^0.

4. CONCLUSIONS

Three-dimensional finite element analysis has been taken up for the evaluation of the stresses and deformations of hybrid rail in laminated FRP composites subjected to Transverse loading. The following conclusions are drawn:

- The fiber angle range from 75^0 to 90^0 is recommended as the normal stresses are observed to be minimum in that range for all fiber materials to keep the structure safe.
- It is found that the increase in shear stresses up to 45^0 and later decreasing with the increase of fiber angle. The shear stress values are less for fiber angle orientation between 75^0 and 90^0
- As the normal stresses, shear stresses and deformations are found to be minimum for GFRP composites between 75^0 and 90^0 fiber angle orientations, the fiber angle orientations 75^0 to 90^0 is recommended to keep the structure safe i.e to prevent the failure.

- It is also observed that the coupling effect in the Rail Web influences the deformations and stresses, and causing for the increase in their magnitudes up to some value of fiber angle and then decreasing of the values later.
- The displacement of the structure in x, y and z directions is very less for all the types of fiber materials for all fiber orientations.

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