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NUMERICAL ELASTIC PLASTIC STRESS ANALYSIS IN A WOVEN STEEL REINFORCED COMPOSITE THERMOPLASTIC CANTILEVER BEAM

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Abstract

In this study, an elastic-plastic stress analysis has been carried out in a thermoplastic composite cantilever beam. The thermoplastic composite beam was reinforced by steel woven fibers. The beam was loaded uniformly. The orientation angles were chosen as 0°, 15°, 30° and 45°. The finite element models of the beams were developed by using ANSYS software. The obtained results from the nonlinear analyses show that the residual stress component of σ_x is the highest at the fixed end at the upper and lower edges for the 0° orientation. However, it is the highest on or around the elastic plastic boundaries for the 15°, 30° and 45° orientations. The magnitude of the residual stress component of τ_{xy} is found to be the highest at or around the axis of the beam at the fixed end. 30° orientation produces the highest stress component of τ_{xy} around the axis of the beam. Also, it is found that the magnitude of the residual stress component of σ_x is higher that that of the τ_{xy}.

Key Words: elastic-plastic stress analysis, residual stress, thermoplastic composite beam

1. INTRODUCTION

Thermoplastic composites have offered engineers a potential for cost-effective forming processes and the capability of integrating material processing and structure design into a single step. They offer interlaminar fracture toughness, increased impact resistance. Moreover, thermoplastic composites are gaining popularity since they can be remelted, reformed and reprocessed. They can be remelted for repairing the local cracks and delaminations. As a result of their potential for high production rates and low material costs, glass mat and woven thermoplastic composites are of interest in a wide rage of sectors including automotive, construction and furniture industries. Experimental investigations on the forming of thermoplastic composites can be found in Refs. [1-3]. Ageorges et al. [4] presented a review about some advances in fusion bonding techniques for joining thermoplastic matrix composites.

Residual stresses in the thermoplastic matrix and in the thermoplastic composites are particularly important since they may lead premature failure and large permanent deformations. Residual stresses may be used to strengthen the composite constructions. Prediction and measuring of residual stresses are particularly important in the design, production and performance of composite structures. Akay and Özden [5] measured the thermal residual stresses in injection molded thermoplastics by removing thin layers from specimens and measuring the curvature as a result of the bending moments of the specimens.

Akay and Özden [6-8] investigated the effect of residual stresses on the mechanical and thermal properties of injection molded ABS copolymer and polycarbonate. Trende et al. [9] presented a model for calculating of residual stresses in compression moulded glass-mat reinforced thermoplastic composites. In that study, both an isotropic viscoelastic and transversely isotropic elastic material model were investigated by using the finite element calculations.

Sayman et al. [10] carried out an elastic plastic stress analysis in a steel fiber reinforced thermoplastic composite disc under uniform temperature distribution. In that solution, a numerical method was developed in order to obtain the stress distribution. Teronimidis and Parkeyn [11] investigated the residual stresses in carbon fiber-thermoplastic matrix laminates. Sayman et al. [12] investigated the elastic-plastic solution of a thermoplastic reinforced by woven steel fibers cantilever beam under a bending moment by using an analytic solution. Some polynomials were proposed in the solution of the beam. Tsai-Hill theory was used in the solution. Sayman and Zor [13] developed an analytical method for the elastic-plastic solution of a thermoplastic composite cantilever under uniform loading. In this solution, the material was assumed non hardening. Aykul and Sayman [14] proposed an analytical elastic-plastic solution of a thermoplastic composite cantilever beam reinforced by steel woven fibers.

In this study, an elastic-plastic stress analysis was carried out in a thermoplastic composite cantilever beam reinforced woven steel fibers loaded uniformly. Finite element methods were used in the solution. Residual stress components of axial and shear stresses were calculated for nonlinear hardening case.

2. MATERIALS AND METHODS

The composite beam was manufactured from a low density polyethylen (LDFE, F.2.12) and woven stell fibers. The moulds were made of steels. Raw polyethylene granules were put into the moulds and then were heated 190 °C by using electrical resistance. The material was kept for 5 min under 0.5 MPa pressure at the same temperature. Then, the temperature was decreased to 25 °C under 1.5 MPa pressure in the time of 3 min. So, a polyethylene layer was obtained and second thermoplastic layer was obtained by using the mentioned way. A woven steel fiber put into the two thermoplastic layers and then it was manipulated by using the defined way. Thus, a thermoplastic composite layer was manufactured. Mechanical properties of the composite layer were measured by the INSTRON tensile test machine. The shear strength was calculated by using Arcan test apparatus. The moduli of the elasticity were measured by using the strain gauges.

In this study, the solution was performed under the linear hardening case. In the plastic region, the Ludwik equation was used as;

$$\sigma = \sigma_o + K\varepsilon_p^n$$

where K and n are the plasticity constants and σ_o is almost the same as σ_y, which is the yield point of the composite layer. σ_x is the greatest stress components in this solution. σ_y can be neglected in comparison with the σ_x and τ_{xy} stress components. The mechanical properties of the composite layer are given in Table 1.

Table 1. The mechanical properties of woven steel fiber reinforced thermoplastic composite layer

E_1 [MPa]	**E_2 [MPa]**	**G_{12} [MPa]**	**σ_y [MPa]**	**υ_{12}**	**S [MPa]**	**K [MPa]**	**n**
2760	2760	220	26.0	0.14	10.5	103	0.614

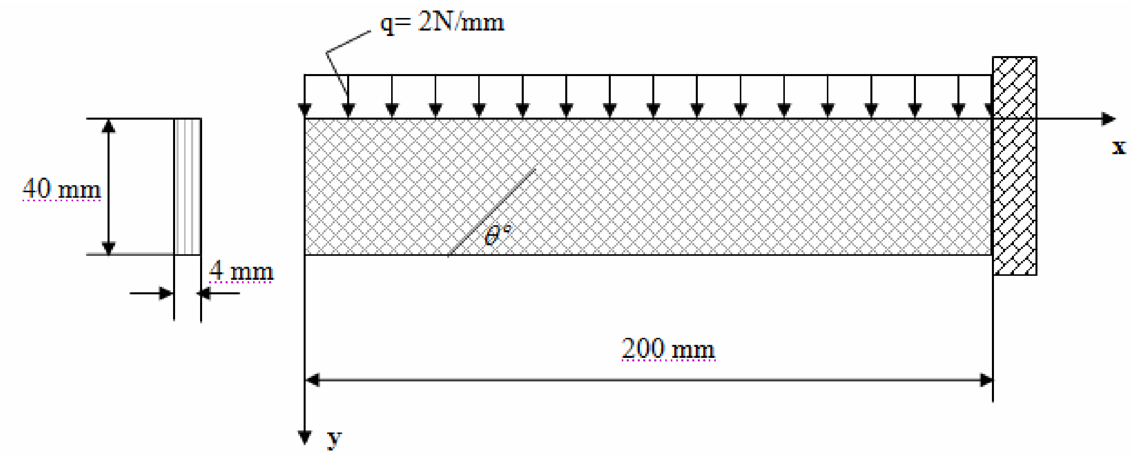


Figure 1 Schematic view of the cantilever composite beam under uniform loading of 2 N/mm

3. FINITE ELEMENT SOLUTION

Elastic plastic solution of the composite cantilever beam under a uniform load was solved by polynomials [13]. In that solution, the material was assumed no hardening or ideal plastic. The stress components for the elastic and elastic-plastic cases were calculated. Thus, the residual stress components of σ_x and τ_{xy} were calculated. However, σ_y was neglected in comparison with the other components due to its small values.

In this solution, the analysis was performed by using FEM solution. Shell181 element was used in the solution. 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 is suitable for analyzing thin to moderately-thick shell structures. It is a 4-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.SHELL181 accounts for follower (load stiffness) effects of distributed pressures. SHELL181 may be used for layered applications for modeling laminated 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).

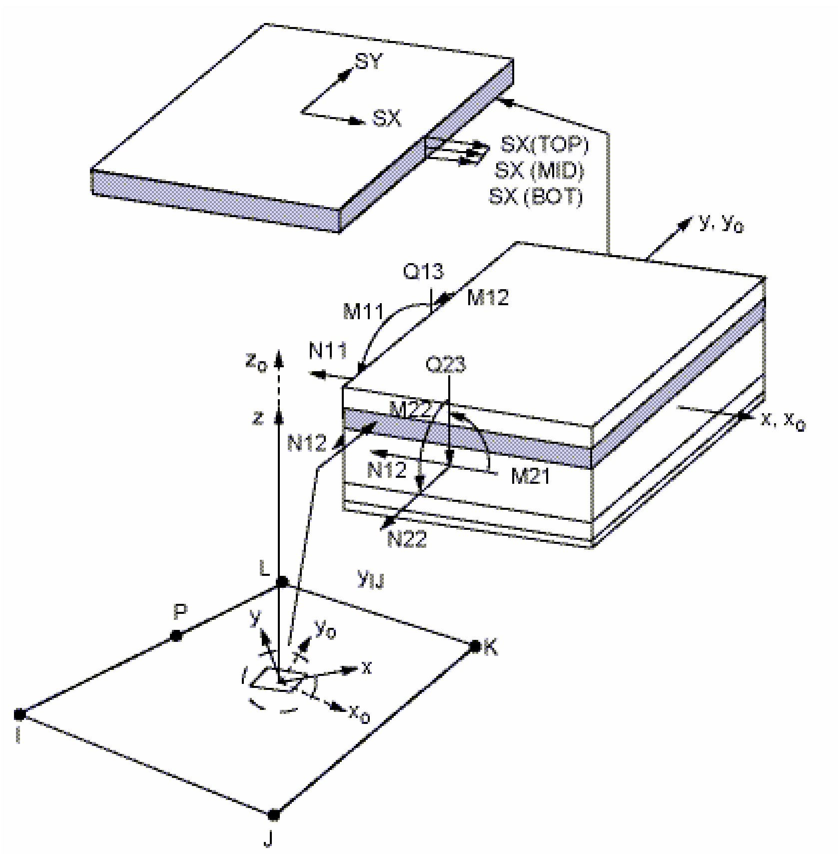


Figure 2 SHELL181 element

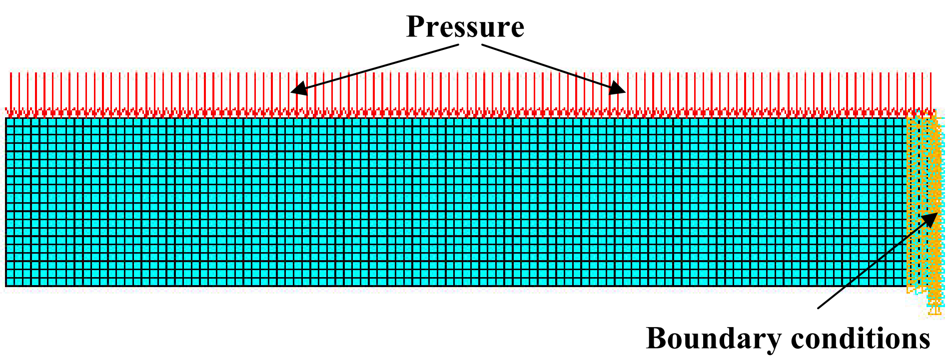
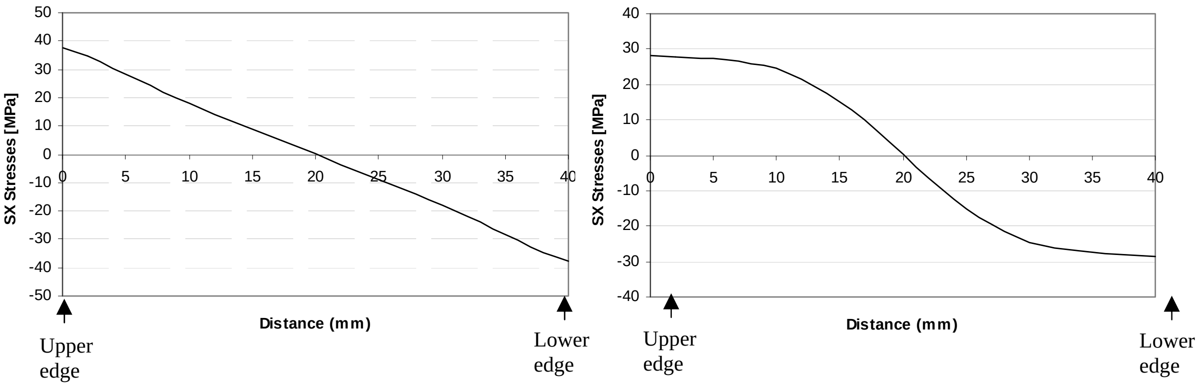


Figure 3 Finite element model of the composite beam

3. RESULTS AND DISCUSSION

The distribution of the σ_x stress component in the elastic and elastic-plastic solutions along the section of the beam at 200 mm for 0° orientation is shown in fig 4a and 4b, respectively. As seen in the fig 4a, σ_x stress component varies linearly for elastic solution. σ_x has the same stress intensity at the upper and lower edges of the beam. However, the distribution of the stress component of σ_x for elastic-plastic solution changes nonlinearly. The difference between the plastic and elastic solutions provides the residual stresses, as shown in Fig. 5 at the distance x=200 mm from the free edge. As seen in this Figure, the residual stress of σ_x is compressive and tensile at the upper and lower surfaces of the beam, respectively. The distribution of the residual stress component of σ_x satisfies the static equilibrium in the beam without an external force.



(a) (b)

Figure 4 The distribution of the σ_x stress component in the elastic (a) and elastic-plastic (b) solutions along the section of the beam at 200 mm for 0° orientation

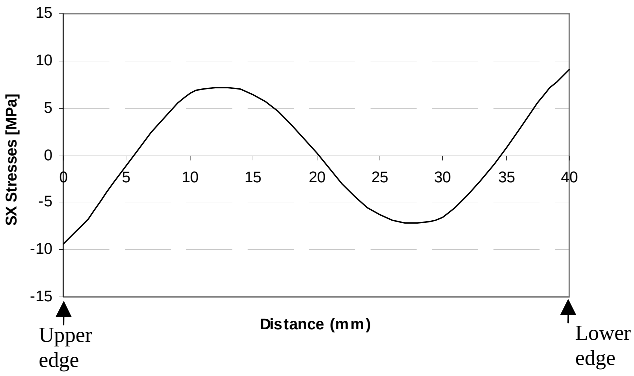


Figure 5 Residual stress component (σ_x) of the composite beam with $[0]_2$ orientation for 200 mm

Residual stress component of the σ_x for the 0° orientation at the distances from the free and at 100, 150, 180, 190 and 200 mm is shown in Fig. 6. It is seen that the intensity of σ_x is the highest at the upper and lower edges for the distance of 200 mm. It is the smallest for instance at the distance of 100 mm. When the distance increases, the intensity of the residual stresses increases.

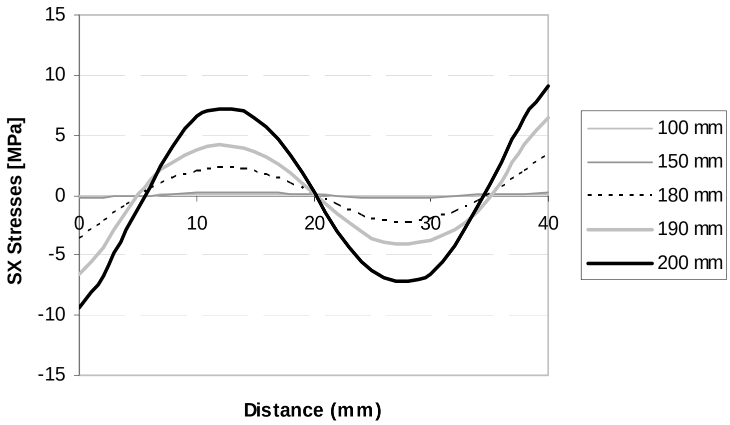


Figure 6 Residual stress component (σ_x) of the composite beam with $[0]_2$ orientation

Residual stress component of σ_x along the beam sections at different distances for the 15° orientation in Fig. 7. As seen in this figure, the largest stress component are found again at the fixed end of the beam at 200 mm. Where the intensity of the residual stress component of the σ_x reaches the highest value at the elastic-plastic boundary. Especially, it arrives the highest value at the upper side of the beam. When the distance from the free end increases, the residual stress component of σ_x reaches high values.

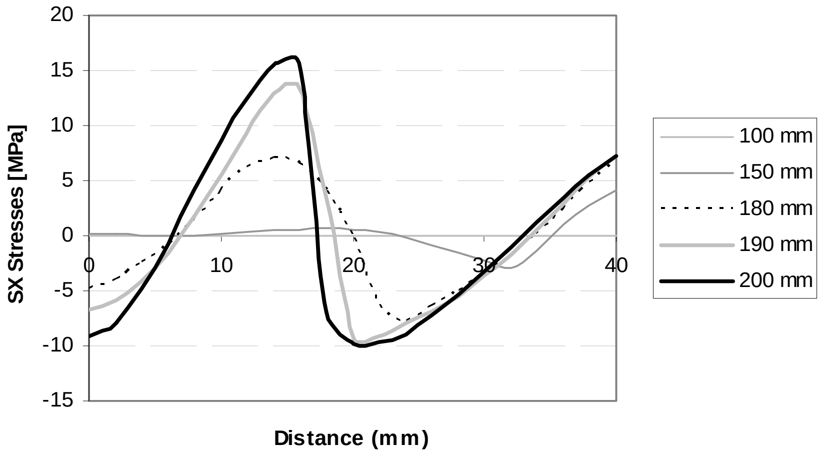


Figure 7 Residual stress component (σ_x) of the composite beam with $[15]_2$ orientation

The residual stress component of σ_x along the cross sections of the beam for the 30° orientation is shown in Fig. 8. As seen in this figure, the intensity of the residual stress component of σ_x is the largest at or around the elastic-plastic boundaries. It reaches the maximum point at the upper side at the fixed end.

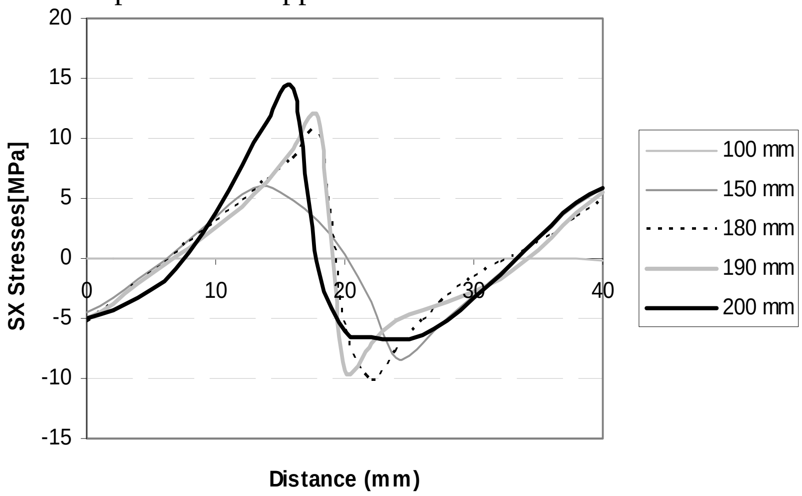
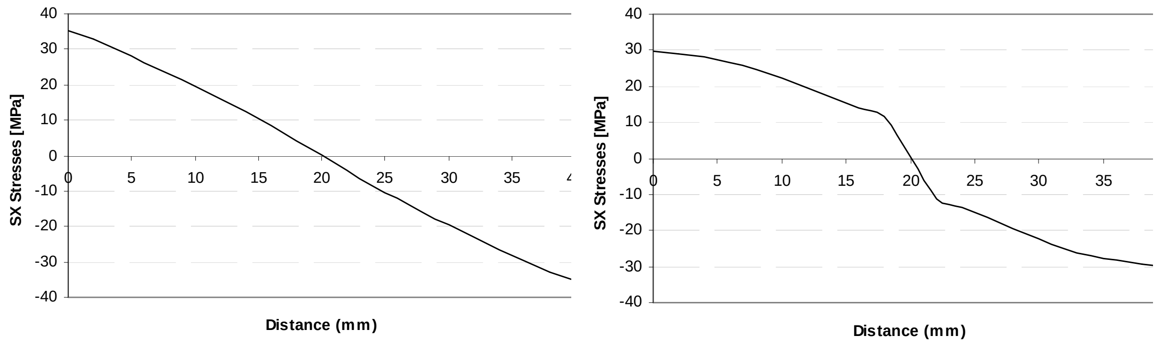


Figure 8 Residual stress component (σ_x) of the composite beam with $[30]_2$ orientation

The stress distribution of σ_x along the section for 200 mm in the elastic solution is shown in Fig. 9a and for the plastic solution is shown in Fig 9b at the fixed end.



(a) (b)

Figure 9 The distribution of the σ_x stress component in the elastic (a) and elastic-plastic (b) solutions along the section of the beam at 200 mm for 45° orientation

The residual stress component of σ_x at different sections of the beam oriented 45° is shown in Fig 10. As seen that the greatest stress component occurs at or around the elastic-plastic boundary.

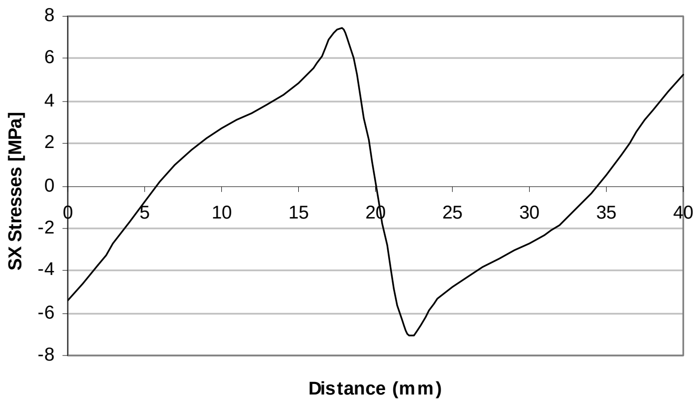
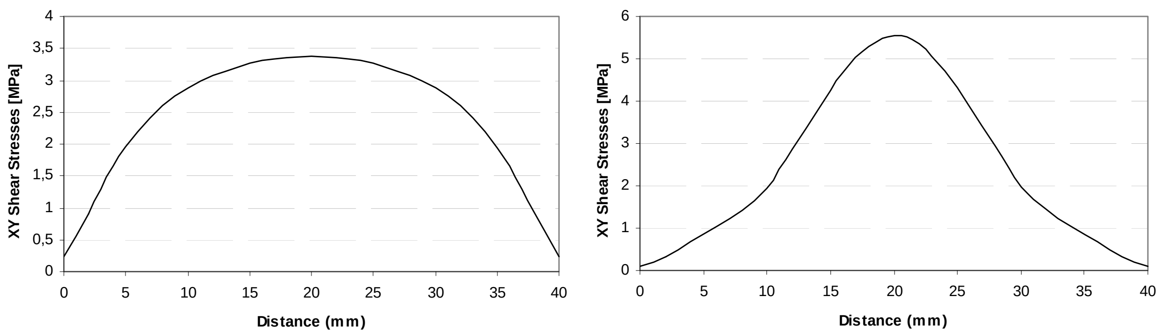


Figure 10 Residual stress component (σ_x) of the composite beam with $[45]_2$ orientation for 200 mm

The distribution of τ_{xy} along the section of the beam oriented 0° at the fixed end, the elastic and plastic solutions are represented in Fig. 11 a- b, respectively. The difference between the elastic-plastic and elastic solutions gives the residual stress component of τ_{xy}, as shown in Fig. 12. It is the highest at the axis of the beam. It is smaller than the magnitude of the residual stress component of σ_x.



(a) (b)

Figure 11 The distribution of τ_{xy} along the section of the beam oriented 0° at the fixed end, for the elastic (a) and plastic (b) solutions

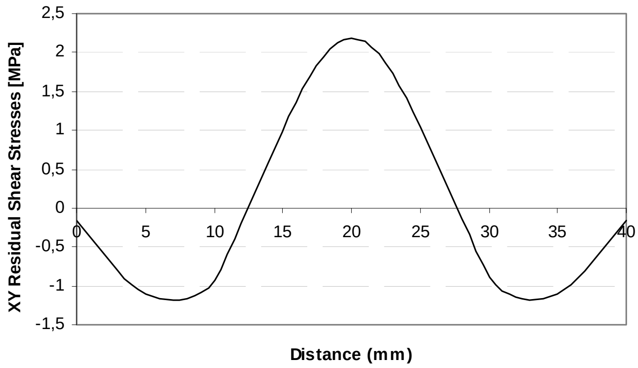


Figure 12 Residual stress component (τ_{xy}) of the composite beam with $[0]_2$ orientation for 200 mm

The residual stress component of τ_{xy} at the fixed end for the beam oriented 45° degrees is shown in Fig. 13. It is the highest around the axis of the beam.

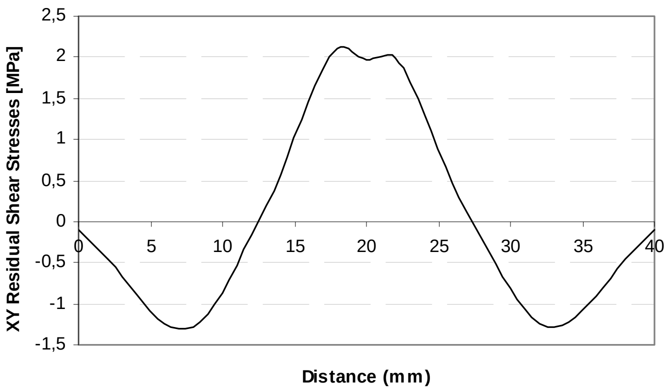


Figure 13 Residual stress component (τ_{xy}) of the composite beam with $[45]_2$ orientation for 200 mm

The residual stress component of τ_{xy} for 0°, 15°, 30° and 45° orientations is shown in Fig 14. It is the highest for 0° and 45° orientations at or around the axis of the beam. It is smaller than the intensity of the residual stress component of σ_x.

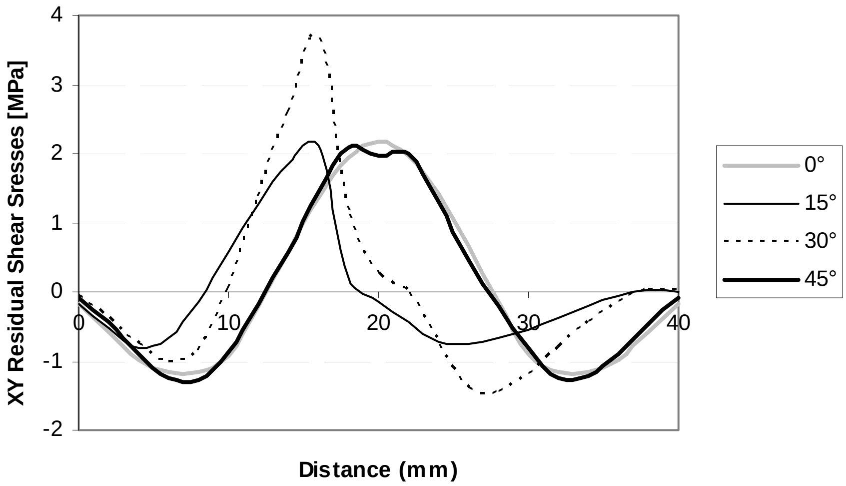


Figure 14 Residual stress component (τ_{xy}) of the composite beam for 200 mm

The residual stress component of σ_x at the fixed end of the beam for all the mentioned orientations is shown in Fig. 15. It is greater than the intensity of the greatest τ_{xy}. It reaches the highest points around the elastic-plastic boundaries for 15° and 30° oriented beams.

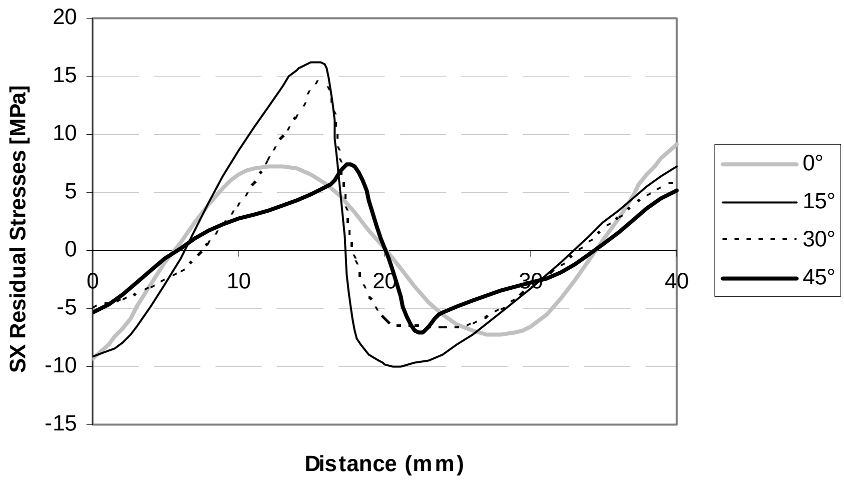


Figure 15 Residual stress component (σ_x) of the composite beam for 200 mm

4. CONCLUSION

In this investigation, an elastic plastic solution was performed in the steel woven fibers reinforced thermoplastic composite beam. It is concluded from the analysis that:
FEM gives an easy solution for the nonlinear analysis of composite structures.

- It is found that the residual stress component to be the highest at the upper and lower edges for 0° orientation, at the fixed end. However, it is the highest at or around the elastic plastic boundaries for 15°, 30° and 45° orientations, at the fixed end.

- The residual stress component of τ_{xy} is calculated to be the highest at or around the axis of the beam at the fixed end.
- The residual stress component of σ_x is greater than that of τ_{xy}

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