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Research Paper

Torsional behavior of thin section glass fiber/epoxy composite filament wound tubes: Numerical modelling

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Abstract

Torsional behavior of thin section glass/epoxy composite pipes was analyzed to study the failure and fracture characteristics based on Hashin's damage criterion. The variation of shearing stress histories was investigated according to different twisting angles ($\theta=2^0$, 4^0, 6^0,8^0, and 10^0). For this purpose, composite pipes were modelled by using ABAQUS/explicit subroutine, their stress and force values whether resulting in failure or not as well as failure types in the modelled composites pipes were analyzed within the constant time of the numerical analysis. Results showed that increasing of twist angles by 8^0 and 10^0 caused the high amount of shearing failures in the composite pipes while other twist angles did not effected on damage mechanisms over the samples. In addition, increment of the twisting angle after the certain value ($\theta=6^0$) resulted a slightly increase in force, and followed a force fluctuations after the peak load, implying brittle nature of composite sample.

Keywords: Torsional behavior, glass/epoxy composites, numerical modelling, failure and fracture

1. INTRODUCTION

The applications of composite materials in aeronautical, marine, automotive and other industries have been increasing because of their highly desirable properties such as high specific strength/ stiffness, corrosion, and thermal resistance. The development of high-performance composites has initiated in many studies of the application of fiber-reinforced composites in aerospace structures [1]. Composite tubular structures are extensively used engineering structures in the requirement of load bearing structures of longitudinal space frame, crash boxes and side door impact beams, especially in fluid transferring systems [2]. Several researcher investigated the failure mechanisms of the tubular structures under the bending loads [3-6]. Rosenow [7] investigated composite tubular shafts under uniaxial and biaxial loading, and it was shown that filament wound composite tubes should be wound at 54.75 for closed-end tubes, and Bhavya et al. [8] showed similar results for failure analysis of an antisymmetric composite cylindrical tubes under open-end conditions.

Besides composite tubes, composite shafts are highly candidate for the machine components in which they have been subjected to torsional loading in service [9-11]. Gummadi and Palazotto [12] studied progressive failure analysis of cylindrical shells by using non-linear finite element analysis for prediction of failure modes. Large rotation capacity was explained associated with failure modes of fiber breakage, matrix damage and delaminations. Fujii et al. [13] investigated the failure characteristics of the fiber reinforced woven and plain composite tubes subjecting to tension-torsion loading, leading to initiate failure mechanisms of matrix cracking and fiber breakage, and delamination.

The purpose of the present paper is to investigate the numerical analysis of the torsional strength of glass/epoxy multilayered filament wound composite tubes. Different twist angles were used to analyze the force and stress characteristics of the thin section composite pipes with increasing twist angle by 2^0, 4^0, 6^0, 8^0, and 10^0. Failure modes with stress distributions were simulated by using finite element analysis by ABAQUS/Explicit software.

2. NUMERICAL ANALYSES

Numerical analyses were performed by using ABAQUS/Explicit software (ABAQUS V6.11) for the analysis of torsional behavior along with composite pipes. Composites pipes were constructed from the fiber reinforced glass/epoxy in which mechanical properties were displayed in Table 1. Number of elements and nodes used in analyses were 3950

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and 403, respectively. Element type of S4R was used for the modelling of shell structure based on four point quad dominated mesh type. Failure analyses were analyzed based on Hashin failure criterion, and mechanical properties used in this criterion were presented in Table 2. According to Hashin's failure criterion, the fiber-failure index, e_f, in tension and in compression is defined as:

$$e_f^2 = \left(\frac{\sigma_{11}}{X_t}\right) \quad \text{for } \sigma_{11} > 0$$

$$e_f^2 = \left(\frac{\sigma_{11}}{X_c}\right) \quad \text{for } \sigma_{11} < 0$$

The failure index, e_m, for matrix cracking in tension, compression and shear is defined as,

$$e_m^2 = \left(\frac{\sigma_{22}}{Y_t}\right)^2 + \left(\frac{\sigma_{12}}{S_{12}}\right)^2, \quad \sigma_{22} > 0$$

$$e_m^2 = \left(\frac{\sigma_{22}}{Y_c}\right)^2 + \left(\frac{\sigma_{12}}{S_{12}}\right)^2, \quad \sigma_{22} < 0$$

Where σi (i=1,2) are the normal stress components in each material principal direction, σij (i,j=1,2) are the shear stress components, X_T, X_C, Y_T, Y_C, Z_T and Z_C show the tensile and compressive strength in longitudinal, transverse and normal directions, *Gij* (i, j=1,2) and *Sij* (i,j =1,2) represent the initial shear modulus and shear strength in ij plane.

Table 1. Mechanical properties of glass/epoxy composites [14]

Material	$E_{12} = E_{21}$	E_{13}	υ_{12}	υ_{21}	υ_{13}	G_{12}	G_{21}	G_{13}
Glass/ Epoxy	26 GPa	8GPa	0.1	0.25	0.25	3.8 GPa	3.8 GPa	2.8 GPa

Table 2. Tensile, compressive and shear properties of glass/epoxy composites [14]

Xt (MPa)	Xc (MPa)	Yt (MPa)	Yc (MPa)	S_{12} (MPa)	S_{13} (MPa)	Gft (KJ/m2)	Gfc (KJ/m2)	Gmt (KJ/m2)	Gmc (KJ/m2)
414	458	414	458	105	55	10	1.562	0.625	0.14

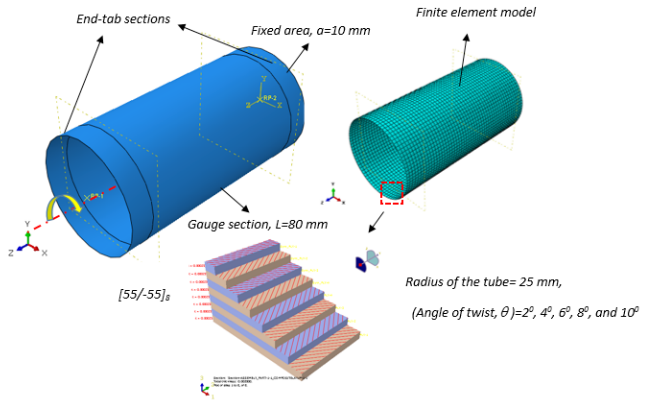

Fig. 1 Shell model and finite element model of tubular test sample

3. RESULTS AND DISCUSSIONS

Fig. 2 shows the results of torsional effects by the increment of twist angle of 2^0, indicating that maximum stress is reached to the 206.5 MPa, and stress has been increased linearly by time increment. It can be concluded that applied twist angle does not cause the failure of the tube, only remaining elastic region while applying torque.

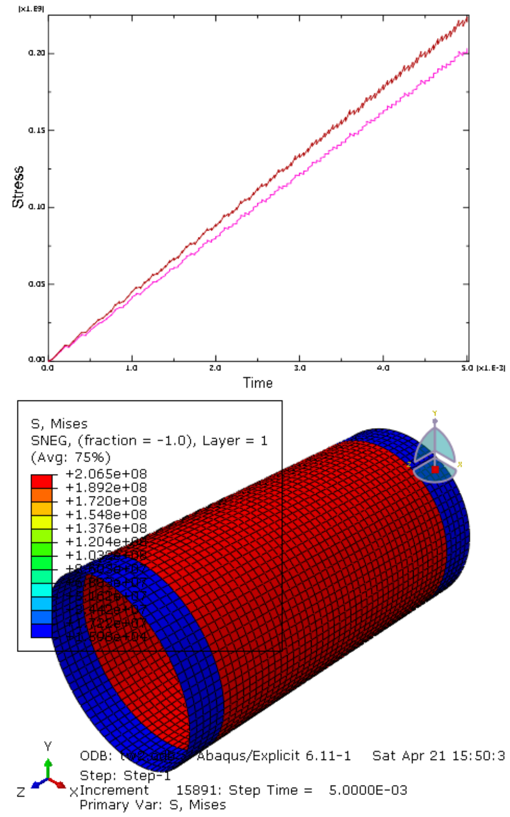

Fig. 2 Results for θ= 2^0

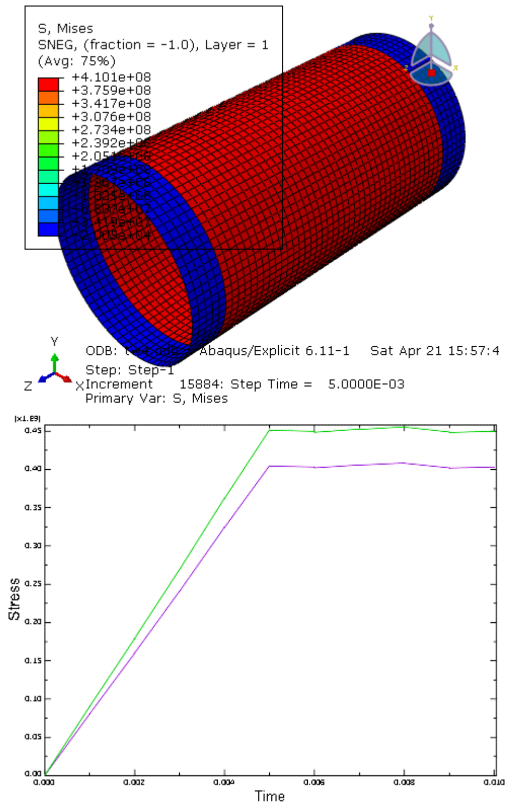

Fig. 3 Results for θ= 4^0

Figure 3 shows the results of the torsional behavior while applying angle of twist by 4^0, indicating that applying external torque does not failure or fracture. However, external torque resulted in 410.1 MPa in the gauged section of the pipe with indicating an enhancement of shearing stress by 98 % as compared with angle of twist by 2^0. Similarly, it is

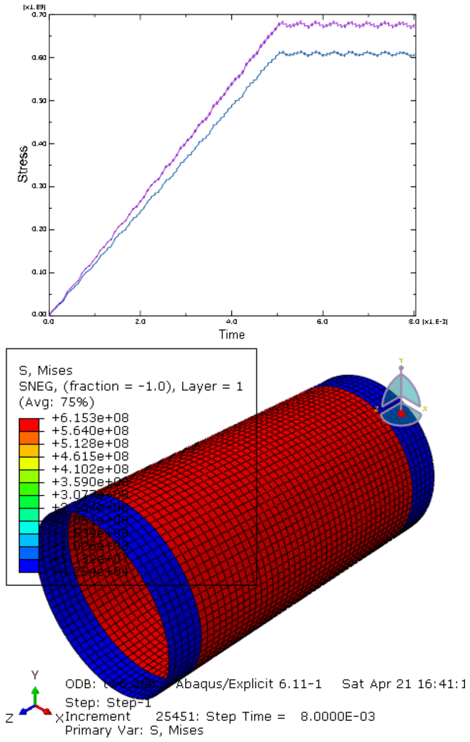

Fig. 4 Results for θ= 6⁰

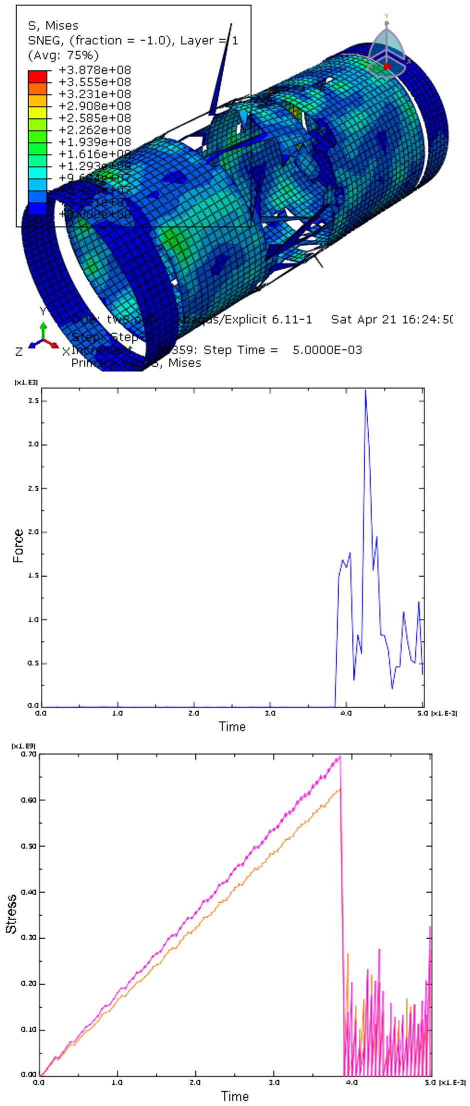

Fig. 5 Results for θ= 8⁰

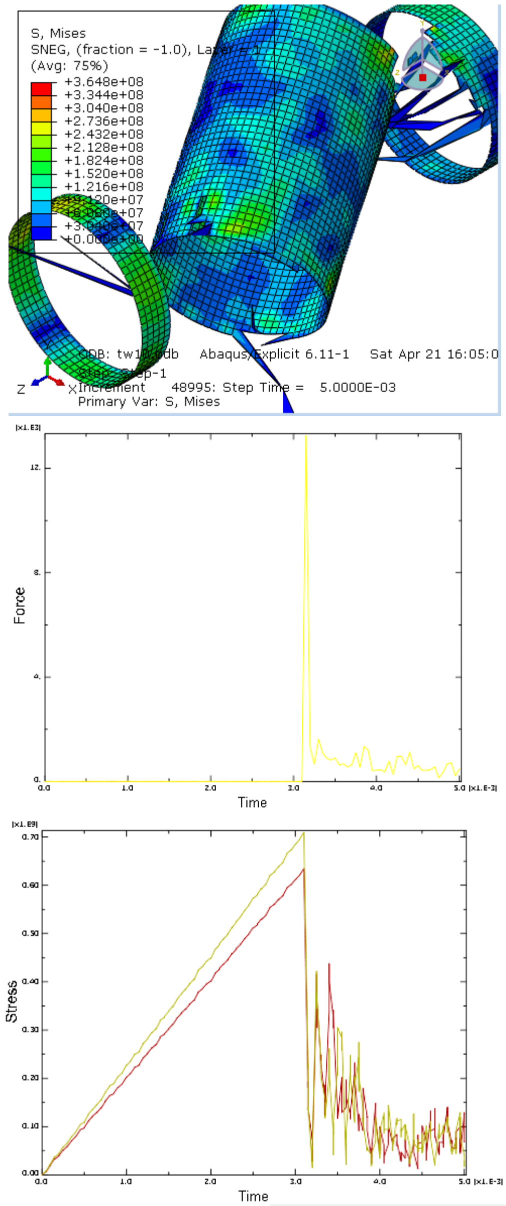

Fig. 6 Results for θ= 10⁰

clear from Figure 4 that stress increases linearly up to the certain point (615.3 MPa) without any failure or yielding, then follows stable condition with increment of the time. This linear increment is attributed to the brittle nature of the composite sample.

Figure 4 displays the torsional behavior of the composite pipes with increment of twist angle by 6⁰. It is clear that failure and fracture have been occurred while applying external torsional effect after the critical stress point. It was clear that stress was increased up to the 700 MPa, then suddenly dropped showing the brittle nature of glass/epoxy composites. When the force history was observed, force was increased up to the 3.5 kN, then it was suddenly dropped as a series of fluctuations with time increment. Similar behavior was also seen in Figure 5 and 6 for the angle of twist by 8⁰ and 10⁰. It was also recorded that same behavior regarding stress values was observed resulting in more amount of failure and fracture when it was compared with twist angle of 6⁰.

Here, it is also important that maximum force due to inc-

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reasing of twist angle from 6^0 to 8^0 has been increased from 4kN to 15 kN, resulting in 275 % of improvement. After the critical level of twist angle corresponding to the applied maximum force, increasing of the twist angle does not sufficiently effect on the stress values while significantly effecting on damage mechanisms such as fiber ruptures and delaminations.

4. CONCLUSION

Torsional behavior of fiber reinforced glass/epoxy filament wound composite tubes was explored numerically. It is concluded that modelled composite pipe sample showed a brittle characteristics, and samples showed without any failure at the twist angles of 2^0, 4^0, and 6^0 within the elastic region. However, increasing of twist angle after 6^0 resulted in failure and fractures in the pipe samples due to the shear stress as a result of the torsion loading. Finally, results implied that optimum twist angle could be selected to meet requirement of the cylindrical composite tubes for sustaining service of the life.

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