DETERMINATION OF STRUCTURAL PROPERTIES OF GLASS/POLYESTER COMPOSITE FOR 10 kW WIND TURBINE BLADES

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DETERMINATION OF STRUCTURAL PROPERTIES OF GLASS/POLYESTER COMPOSITE FOR 10 kW WIND TURBINE BLADES

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Abstract: The aim of this paper is to determine the optimal composite material structure for 10 kW wind turbine blades. For this purpose four different sets of specimens of laminated glass/polyester composite material plates in ANSYS Parametric Design Language (APDL) were modelled. Test pieces were subjected to stretching with a force of 10, 20 and 40 kN. According to obtained results the laminate with the required properties was determined. Further, to verify the accuracy of composite materials data input into (APDL) the specimens with high resistance properties will be manufactured and tested at a testing machine. These data will be necessary for FEM analysis of the wind turbine blade.

Key words: structural properties, glass/polyester, compositez, tests, speciments, FEM analysis.

1. INTRODUCTION

1.1. Properties of glass/polyester composites

Rotor blades of laminated fibre glass composites with polyester resin as the matrix material are still widely used today. The glass used in blade construction is E-glass, which has good structural properties in relation to its cost (Burton and Sharpe, 2001).

The plate elements forming the spar of a GFRP blade are normally laminates consisting of several plies, with fibres in different orientations to resist the design loads. Within a ply (typically 0,25–0,6 mm in thickness), the fibres may all be arranged in the same direction, i.e. UD or unidirectional or they may run in two directions at right angles in a wide variety of woven or non-woven fabrics.

Although the strength and stiffness properties of the fibres and matrix are well defined, only some of the properties of a ply can be derived from them using simple rules. Thus, for a ply reinforced by UD fibres, the longitudinal stiffness modulus, E_1, can be derived accurately from the rule of mixtures formula:

$$E_1 = E_f V_f + E_m(1 - V_f)\ , \text{[GPa]} \qquad (1)$$

where E_f is the fibre modulus (72,3 GPa for E-Glass), E_m is the matrix modulus (in the range 2,7–3,4 GPa) and V_f is the fibre volume fraction. On the other hand, the inverse form of this formula, e.g.,

$$\frac{1}{E_2} = \frac{(1 - V_f)}{E_m} + \frac{V_f}{E_f}\ , \text{[GPa]} \qquad (2)$$

significantly underestimates the transverse modulus, E_2, and the in-plane shear modulus, G_{12}.

The longitudinal tensile strength of a ply reinforced by UD fibres, σ_{1t}, can be estimated from:

$$\sigma_{1t} = \sigma_{fu}\left[V_f + \frac{E_m}{E_f}\left(1 - V_f\right)\right], \text{[MPa]} \qquad (3)$$

where σ_{fu} is the ultimate tensile strength of the fibres. However, the tensile strengths of E-glass single fibres (3.45 GPa) cannot be realized in a composite, where fibre strength reductions of up to 50% have been measured. Accordingly, a value of σ_{fu} of 1750 MPa should be used in Equation (2) . (Bostan et al, 2007).

The longitudinal compressive strength of a ply reinforced by UD fibres is always significantly less than the tensile strength because of microbuckling of the fibres, which is governed by the shear strength of the matrix and the degree of fibre misalignment. A strength reduction of at least 15% should be allowed for, assuming minimum fibre misalignment.

Clearly, longitudinal stiffness and strength are both limited by the fibre volume fraction obtainable. For hand lay-up, fibre volume contents of 30–40% are typical, but the use of *vacuum bagging*, in which trapped air and excess volatile compounds, such as residual solvent, are extracted, consolidates the composite and allows a volume fraction of 50% or more to be achieved.

2. NUMERICAL MODELING OF SPECIMENTS

2.1. Numerical modelling and analysis of speciments

To determine the properties of materials used in blade structure, according to (GOST 25.601-80) standard a sample was dimensioned (figure 1). Specimens were modeled from UD ply with well known orthotropic properties. Ply input data are shown in Table 1 (Banu, 2007).

Table 1. Summary of material properties for a ply employed in the specimen design (Banu, 2007)

Property	E-Glass Fiber/Polyester Composite
Fiber orientation	UD
Fiber Volume Fraction	50%
Tensile Modulus E_{11}, GPa	34
Transverse Modulus E_{12} , GPa	8,5
Shear Modulus G_{12}, GPa	3,7
Poisson's ratio, υ_{12}	0,28
Poisson's ratio, υ_{21}	0,06
Strength limit σ_B, MPa	450

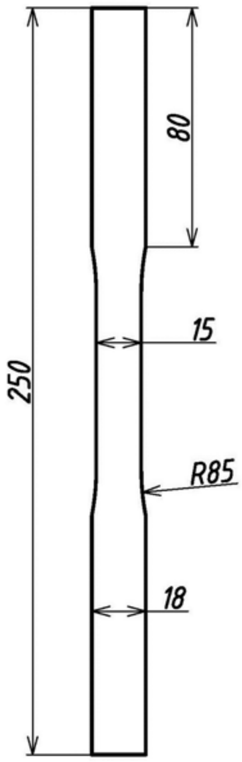

Fig. 1. Specimen dimensions

Numerical simulations were performed in ANSYS Parametric Design Language. The speciments was modeled with SHELL99 8-node layered shell elements (figure 2) (Wetzel et al., 2006). The laminates structure is shown in Table 2.

Test pieces were subjected to stretching with a force of 10, 20 and 40 kN, respectively (figure 3).

Table 2. Laminate specification employed in the specimen design

Set nr.	Fiber orientation	Laminate thickness, *mm*
1	$\pm45_{13}$/CSM/$\pm45_{13}$	6,3
2	$0\text{-}90_{13}$/CSM/$0\text{-}90_{13}$	6,3
3	$0\text{-}90_7$/$\pm45_7$/CSM /$\pm45_7$/$0\text{-}90_7$	6,5
4	$\pm45_7$/$0\text{-}90_7$/CSM/$0\text{-}90_7$/$\pm45_7$	6,5

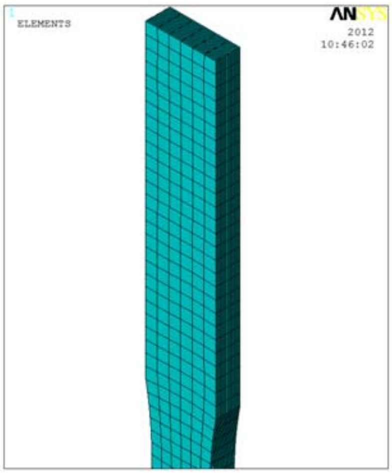

Fig. 2. Finite element model of specimen

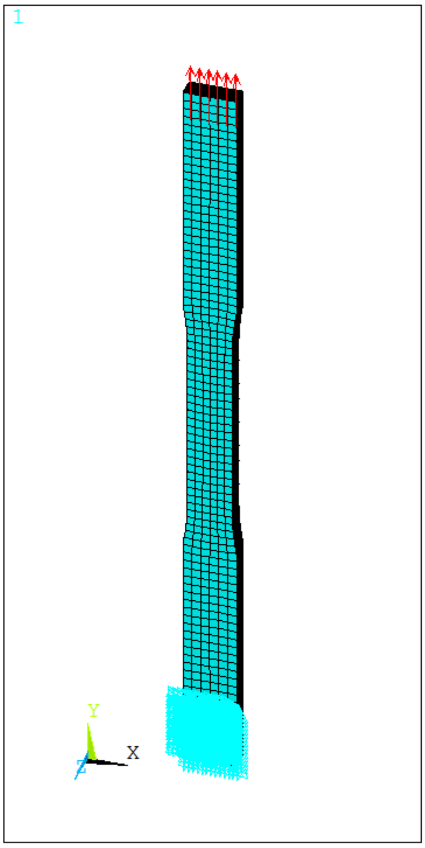

Fig. 3. Specimen load modeling

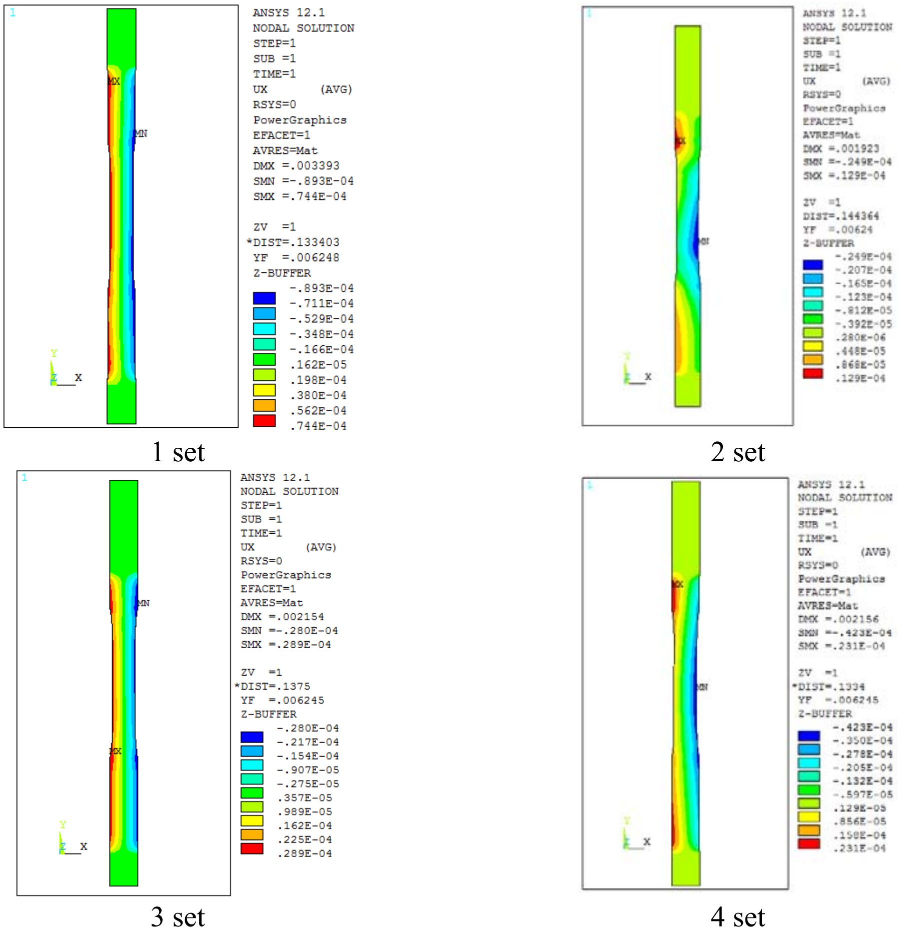

Fig. 4. Sample UX displacements for 20 kN stretching

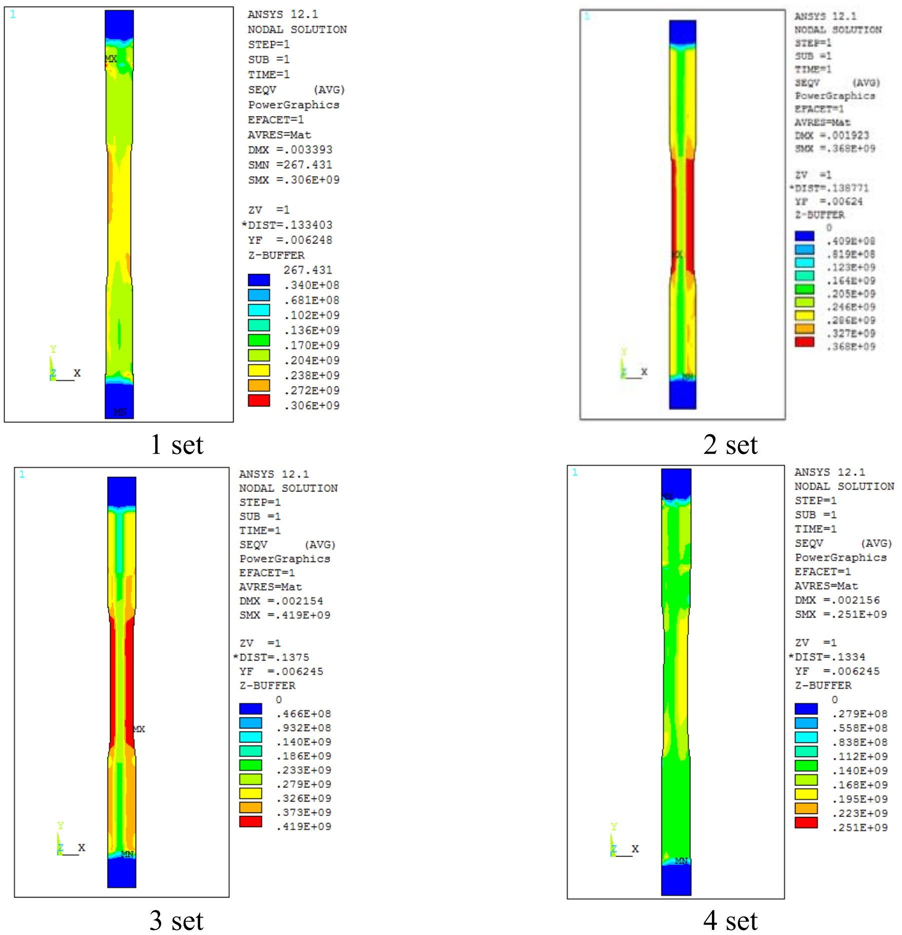

Fig. 5. Sample von Misses stress for 20 kN stretching

2.2. Analysys results

The paper presents the results of numerical analysis of specimens subjected to a 20 kN force because in this case is not exceeded laminate strength limit (450 MPa) (figure 4 and 5).

Samples UX and UY displacements for all load cases are shown in figure 6 and 7 respectively.

Von Misses stress for 10, 20 and 40 kN load stretching for all sets is shown in figure 8.

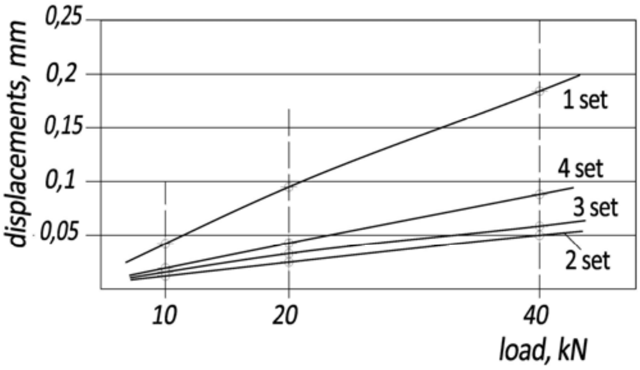

Fig. 6. Samples UX displacements for 10, 20 and 40 kN load stretching

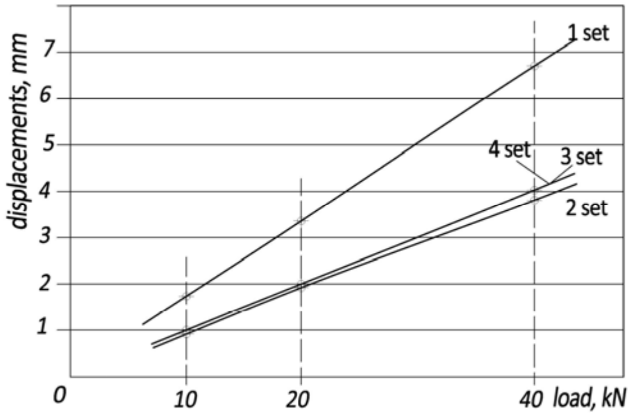

Fig. 7. Samples UY displacements for 10, 20 and 40 kN load stretching

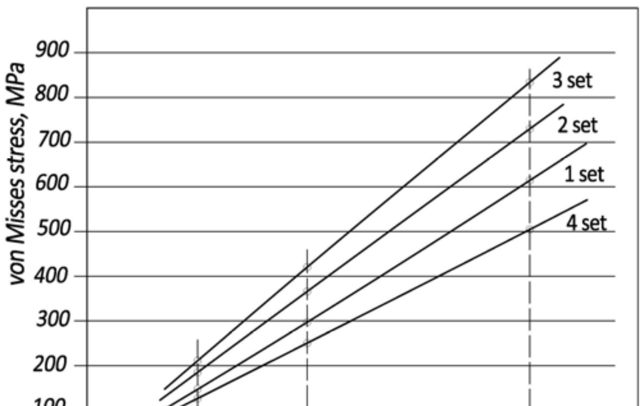

Fig. 8. Samples von Misses stress for 10, 20 and 40 kN load stretching

3. CONCLUSIONS

From results of numerical analysis the following facts have been observed:

- in specimen 1 there were attested the biggest displacement value (in X direction 0,089 mm, in Y direction 3,4 mm);
- maximal values for von Misses stress have been attested in specimens 3 (419 MPa) and 2 (368 MPa);
- stress concentration were detected in specimens 1 and 4;
- from specimens that have the best strength properties the specimens from set 2 are more rigid and from set 3 are more elastic.

Further, there were foreseen numerical simulations for composite material specimens' compression and shear loads in order to determine the optimal composite material structure for computational simulation in the framework of FEM of the wind turbine blade.

4. REFERENCES

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