Three-dimensional finite element analysis of composite/metal clamped joint

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ABSTRACT. Three-dimensional finite element models have been created to study the effect of layer orientation on the strength and stiffness of carbon fibre reinforced epoxy laminate tube clamped in metal tube. The model of the laminate tube was validated by comparison of deflection and natural frequencies with experimental results. Furthermore, the failure of clamped laminate tube was investigated experimentally and compared with results of numerical model using failure criterion LaRC04. The optimization of the layer fibre orientation was performed in case of purely clamped tube and then in case of simultaneous clamping, bending and torsional loading.

KEYWORDS. Clamped joint; Composite; Failure; Experiment; Finite element method.

INTRODUCTION

The clamped joint (see Fig. 1) has many advantages. For example, it is demountable, relatively inexpensive and it is not difficult to prepare jointed elements for the joint [1, 2]. Recently there is a massive tendency towards substitutions of metal parts of structures by parts made of composite materials. In these structures, the joints between the metal and the composite parts are often critical points of the structures. There are many types of the composite/metal joints, many analyses and computational models for their low-cost and reliable design must be still done [3]. The clamping is used for example in case of joint of composite seat post and frame for cycle-ball bicycle [4]. The investigation of the effect of layer orientation on the strength and stiffness of the composite (carbon fibre reinforced epoxy laminate) tube clamped in metal tube, where the composite tube loading is similar to the bicycle seat post, was the aim of this work.

Figure 1: Clamped joint.

EXPERIMENTS

Two experiments were done for validation of computational model of the composite tube. Three composite tubes made from T700 high strength carbon fibres and PR102 epoxy resin were tested. Tube A had 13 layers, tube B had 10 layers and tube C had 10 layers, all tubes had outer diameter 31 mm.

Firstly, the deflection of three composite tubes under three-point bonding was investigated (see Fig. 2) and compared to numerical results. The Zwick/Roell Z050 test machine was used for the loading and laser measurement device optoNCDT (Micro-Epsilon Company) was used for the measurement of the deflection. The difference between the results was less than 10%.

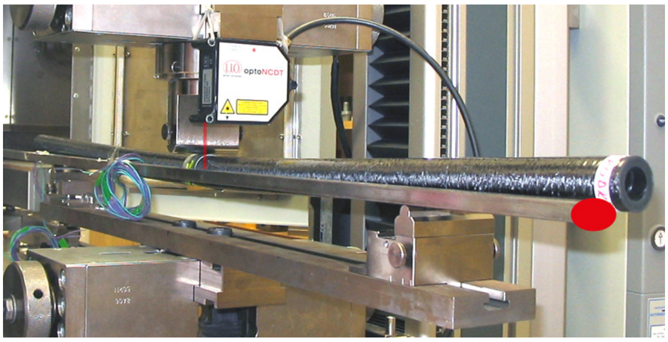

Figure 2: Investigation of deflection.

Further, first and second natural frequencies of the three composite tubes were investigated using the laser measurement device optoNCDT (see Fig. 3) and compared to the numerical results. In this case, the difference between the results was less than 4%.

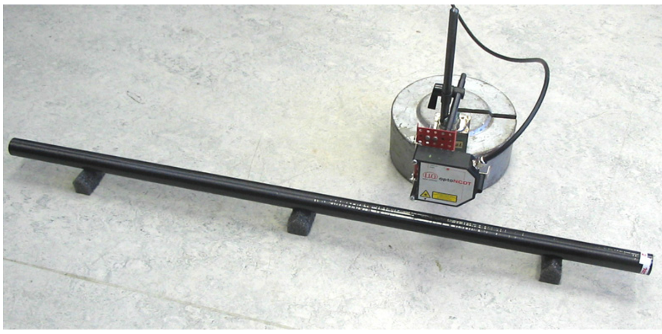

Figure 3: Investigation of natural frequencies.

Predictive capabilities of LaRC04 failure criterion [5], which was used in the computational model of the clamped composite tube, was proved experimentally using the three validation tubes. Failure of two tubes is shown in Fig. 4 and 5.

NUMERICAL ANALYSIS

Three-dimensional finite element models were created in MSC.Marc using eight-node composite brick elements (element 149 in MSC.Marc). Orthotropic material properties of the composite were considered. LaRC04 failure criterion was used for composite failure determination. Determination of location of the composite failure in several layers of two clamped composite tubes is shown in Fig. 4 and 5.

The layer fibre orientation was optimized with the aim to maximize the stiffness and the strength of the composite tube. The tube with 10 layers and 0.2 mm layer thickness was studied. Evolution algorithm included in OptiSLang software was used. Firstly, the optimization was performed in case of purely clamped tube, then in case of simultaneous clamping, bending and torsional loading. Computational model of the composite tube is shown in Fig. 6. Optimal layer fibre orientations are listed in Tab. 1 (orientation θ = 0° means direction of tube axis, number 1 position of the layer means outer layer).

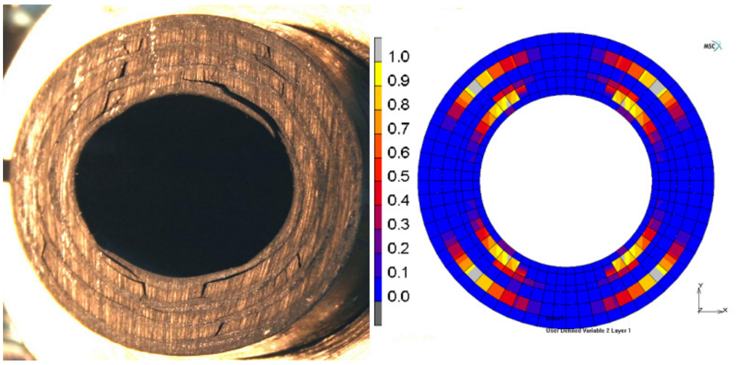

Figure 4: Failure of tube A in case of experiment and numerical model.

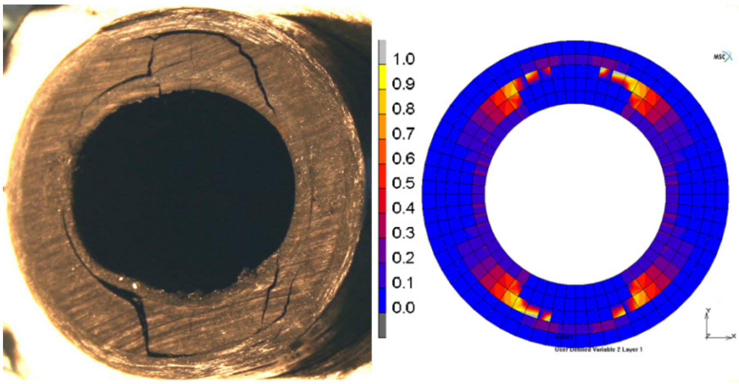

Figure 5: Failure of tube B in case of experiment and numerical model.

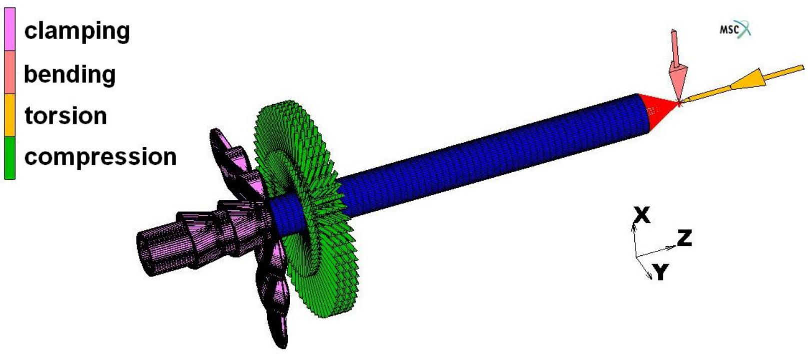

Figure 6: Computational model.

Layer position	1	2	3	4	5	6	7	8	9	10
Fibre orientation θ [°] in case of purely clamped tube	90	90	90	90	0	0	0	0	90	90
Fibre orientation θ [°] in case of simultaneous clamping, bending and torsional loading	0	0	+20	–20	+20	–20	+10	–10	+75	–75

Table 1: Optimal layer fibre orientation.

Conclusions

The optimization of the layer fibre orientation of carbon fibre reinforced epoxy laminate tube clamped in metal tube was performed using three-dimensional finite element models. The models including LaRC04 failure criterion was validated experimentally. In case of purely clamped tube, the layer fibre orientation is parallel or perpendicular to tube axis (the perpendicular fibres support the stiffness and strength of clamped part of the tube, the parallel fibres transfer the compressive loading from clamped part to the unclamped parts of the tube). In case of simultaneous clamping, bending and torsional loading, the relationship between the loadings and tube geometry influenced the orientation. In principle, the perpendicular fibres close to inner diameter help to withstand the compression from clamping; the parallel fibres close to outer diameter are ideal in case of bending.

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