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Finite element analysis of composite tubes with integrated loop technology joints

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This paper presents Finite Element (FE) models of integrated loop technology joints. The composite tubes with integrated joints are developed in order to improve the connections of composite beams to achieve the continuous stress transfer through the connection, and in order to fulfil the strength and stiffness requirements. Therefore, FE models of composite beams with integrated joints have been created, also they have been compared with the experiments, which were performed in tension and compression loading. Due to the results of the experiments and the simulations of the first design of integrated loop joints (presented in [2] and [3]) the technology of the production has been changed.

The second generation has been developed and analysed by FE simulations. The differences between the first and second generation can be observed in Fig. 1 and Fig. 2. The pins (Fig. 2) are used for the manufacturing by fibre winding and placement technology. The pins allow the fibres to be placed in the area between the loops and the placement of fibres on tube body is more unified, without thin-walled areas near the integrated joint.

Fig. 1. First generation specimen

Fig. 2. Second generation specimen

The set of nine specimens (see Table 1) of the second generation has been numerically simulated in order to select the best of them for future manufacturing and experimental testing. They have been composed from four differently wound layers: SN (DEG), A1, A2 and Hoop (see the description below Table 1). Numerical models were created on the basis of the knowledge gained in modelling of the first generation. Damage represented by Inverse reverse factor (IRF) and the occurrence of local damage have been monitored. Based on these results four of the second generations specimens were selected for experimentally testing in tensile and compressive loading scenarios, namely SN02, SN07, SN08 and SN09. These specimens were provided with a glued composite tube, by which the FEM model of these components was extended.

The pair SN02 and SN08 has been selected for comparison of change of lay-up sequence (1st and 3rd layers are swapped) and the pair SN07 and SN08 has been selected to observe the effect of wrapping the fibres around the joined tube. Specimen SN09 is without SN (0), which is replaced by another layer A1 because of technological requirements.

Table 1. Lay-up of second generations specimens

Specimen type	First area	Second area	Third area	Fourth area	Fifth area
SN_01	SN (45)	A1	Hoop	SN (0)	SN (45)
SN_02	SN (45)	A2	Hoop	SN (0)	SN (45)
SN_03	SN (60)	A1	Hoop	SN (0)	SN (60)
SN_04	SN (60)	A2	Hoop	SN (0)	SN (60)
SN_05	SN (30)	A1	Hoop	SN (0)	SN (30)
SN_06	SN (30)	A2	Hoop	SN (0)	SN (30)
SN_07	Hoop	A1	SN (45)	SN (0)	SN (45)
SN_08	Hoop	A2	SN (45)	SN (0)	SN (45)
SN_09	Hoop	A1	A1	SN (45)	SN (45)

SN (“DEG”) – the body of the tube bounded by pins, when the fibres are placed in angles $\pm DEG_S$

A1, resp. A2 – wound ring around the tube in axial direction, whose fibres form the ILT joints. A1 fibres are wrapped with one more ring around the joined tube, A2 fibres are not.

Hoop – the body of the tube without the area near ILT joint when the fibres are placed at angle nearly 90°.

The comparison of experiment to numerical models has shown that the differences in displacements were about 20% to 60%. Therefore, the models were further modified. The connection between ILT joint and the glued tube was modelled as a bonded connection with a contact debonding function, the connections between pins and the glued tubes were modelled as contacts with the friction. The pins, which represented the boundary conditions and loading, were modelled as rigid. The FE model of strain gauges have been added on the tubes body. Due to added strain gauges in the model the evaluation was more accurate as shown in Table 2. Subsequently, more sophisticated methods of experimental displacement evaluation have been used, also they have been refined to be more accurate as a result of the knowledge of the numerical simulations.

Table 2. Displacements/deformations evaluation of FE models to experimental testing

	FEA percentage deviation to experiment [%]			
	displacement		deformation	
	TENSION	COMPRESSION	TENSION	COMPRESSION
SN_02	-20	-55	-6	-27
SN_07	-48	-55	-6	-29
SN_08	-28	-59	-13	-35
SN_09	-58	-53	-4	-19

The SN 09 specimen has been chosen as a technologically more advantageous variant of the variants. It summarizes the advantages of the composite windings of the previous types of components with integrated joints. The using of double A1 is chosen as the axial reinforcement. It is wound with a double layer SN (45) with angle of ± 45 ° and it is underlaid with the technological sublayer Hoop. The experiment and numerical simulation evaluation both found the critical places (see Fig. 3), where the failures have occurred. The differences in the behaviour of the models are evident from Fig. 4. According to the results, the SN 09 specimen can be chosen as the most suitable variant.

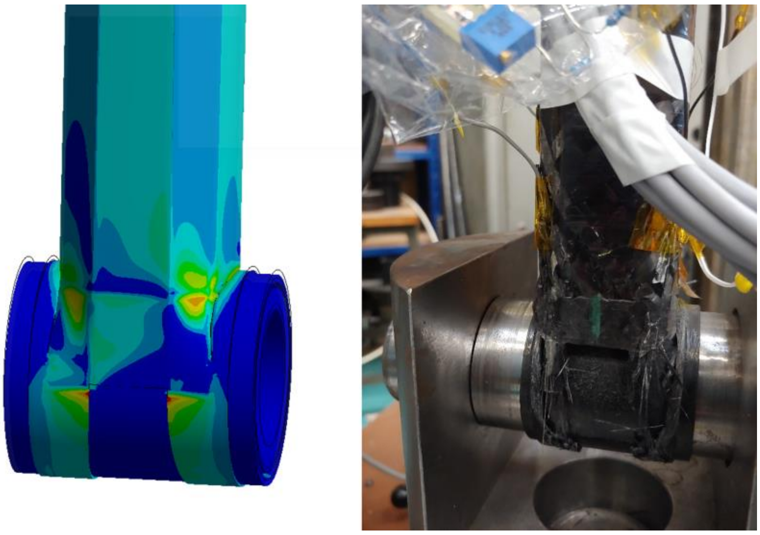

Fig. 3. SN 09: FE model – maximal principal stress (left) and experiment (damage in ILT joint) (right)

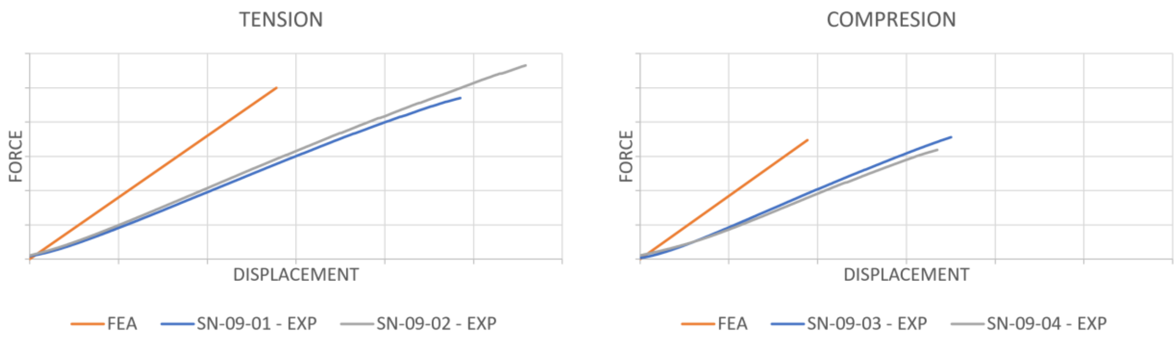

Fig. 4. Force/displacement curves for the specimen SN 09

The optimal variant, SN 09, has been also tested in the other loading scenarios, such as torsion, bending etc. These results will be published separately.

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