53rd CONFERENCE ON EXPERIMENTAL STRESS ANALYSIS
Český Krumlov, Czech Republic, June 1–4, 2015
pp. 356–363

Determination of Strength of Composite Flexible Join

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Abstract: This thesis deals with the design of a joint for composite flexible elements using an integrated connection. For the verification of the selected layout, a wrapping loop was chosen as a simplified member, which was created on a special form designed for these samples. The material used was unidirectional fibreglass and epoxy resin. These samples were then compared by quasi-static tensile and compression tests. The tests were carried out on the Zwick-Roell Z050 machine. The resulting data of the experiment were then compared with data from numerical simulations from the finite element system Siemens NX 10 and SIMULIA Abaqus 6.13. Three dimensional strength criteria Maximum stress and direct-mode strength criterion LaRC04 were used for evaluation.

Keywords: Unidirectional Glass Fibre Composite; Numerical Simulation; FEM; Quasi-Static Experiment; Wrapped Loop.

1 Introduction

This thesis deals with design of a joint for composite flexible elements made of unidirectional glass fibers and epoxy resin. In particular it is focused on a part intended for connection of these components to a basic system. The most common type of connection, i.e. a bonded joint, can be used for connection of composite materials. But if it is necessary to enable demountability of the connection, it is necessary to create holes. Using conventionally milled openings is not effective because there is a failure of fibers and strength of the joint is given only by the strength of the matrix. For this reason, it is more convenient to use the integrated type of joint on which this paper is focused. This topic has already been dealt with in several works. However, these works were focused on carbon composites and different geometrical parameters [1, 2].

2 Manufacturing of Simplified Samples

A unidirectional wrapping loop was used as a simplified model (see Fig. 2, 3). Creating samples was done on a specially constructed form that was designed only for these samples. This form allows wrapping loops to be created in a wide range of geometric parameters. 32 samples were created (16 samples with seven threads of the fibre and 16 samples with four threads). These samples were made of fibreglass and epoxy resin. Aeroglass 2400 TEX was chosen as fibre glass roving. This type of E-Glass fibre excels in good mechanical parameters and also has perfect cohesion with the resin. This reduces the risk of osmosis and also the possibility of damage of glass fibres. This also reduces the risk of not saturated locations and possible delamination of the individual layers from each other. The matrix is composed of an epoxy resin LH298 and the hardener H512, in a mixing ratio of 100:23 [8].

Identical fibres and epoxy resin were used for experimental testing, but to ensure parallelism of fibres and the walls of the sample, a different type of production was used. The fibers in this case were wound into a special form with identical dimensions (see Fig. 3) as in the case of loops wrapped on a frame. These samples were then split into several parts.

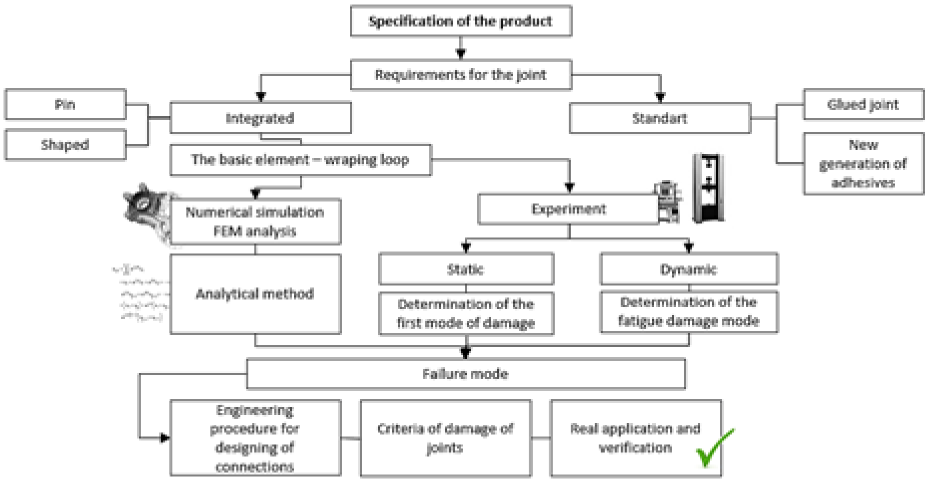


Fig. 1: Flowchart of the process solutions for integrated joints.

Fig. 2: Manufacturing process of wrapping loops.

3 Experimental Tensile Test of the Wrapping Loops

Experimental tensile tests were carried out at ambient temperature 20.5 °C by quasi-static load (0.5 mm/sec) on the Zwick/Roell Z050 machine (see Fig. 4). Two different types of attachment of the samples were used, especially a free fastening (hereafter FF) and tight fastening (hereafter TF) of the samples were done.

The samples were attached with special jaws during the test with FF. The jaws were designed only for this specific test. On one side, the tight fastening was used (with axial preload of sample). On the other side, the free sample attachment was by pin in cradle fitting. This type of fitting ensures the visibility of sides of wrapped loops, therefore the monitoring of initialization and progress of loop failure is enabled. The test was recorded by DSLR camera with synchronization of date of tensile testing. This method of attachment was based on experience which has already been verified on the same type of measured samples in other theses [1,2].

In the chart below (see Fig. 5) you can see the results of the failure of the samples of wrapping loops with free fastening. Comparing graphical results and video recording it was found that after a failure of the matrix for most samples failure began from the region inside the loop. It was in the area of contact with the pin connection. The wrapping loops were damaged at approximately 45 ° relative to the longitudinal plane of the test sample. Subsequently the remaining filaments of glass fibre were damaged in the same region as the first, and this continued 'fibre after fibre' until complete failure of the sample [see Fig. 6].

In case of the tight fastening, the samples were tightly attached into the jaws on both sides with a prescribed axial preload which was secured using a torque wrench. The tensile loading method was identical to that used with the freely fastened samples.

Unlike the freely fastened samples for this type of attachment of the samples failure of filaments occurred simultaneously, as can be seen in charts (see Fig. 7).

4 Experimental Compression Test of the Wrapping Loops

Experimental compressive tests were carried out at ambient temperature 22.1 °C by quasi-static load (1.3 mm/sec) on the Zwick/Roell050 machine (see Fig. 8). Together twelve samples (six samples with seven fibers and six samples with eleven fibers) were tested, which were loaded in compression in a direction trans-

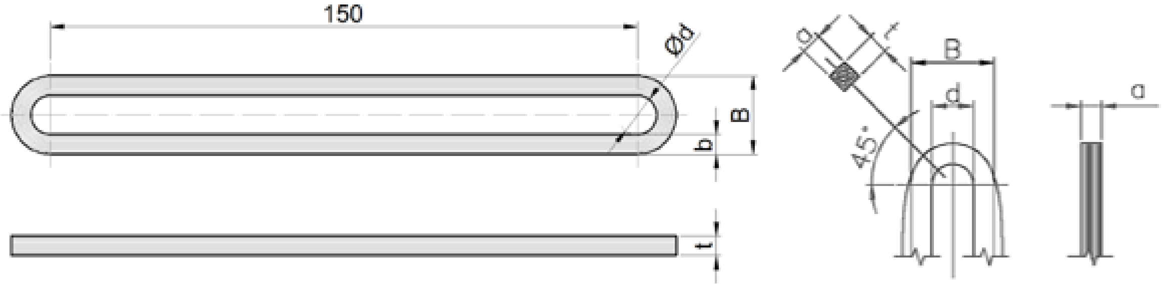


Fig. 3: The geometric parameters of wrapping loops.

Fig. 4: The process of tensile experimental test of glass fibre wrapping loops – Free fastening.

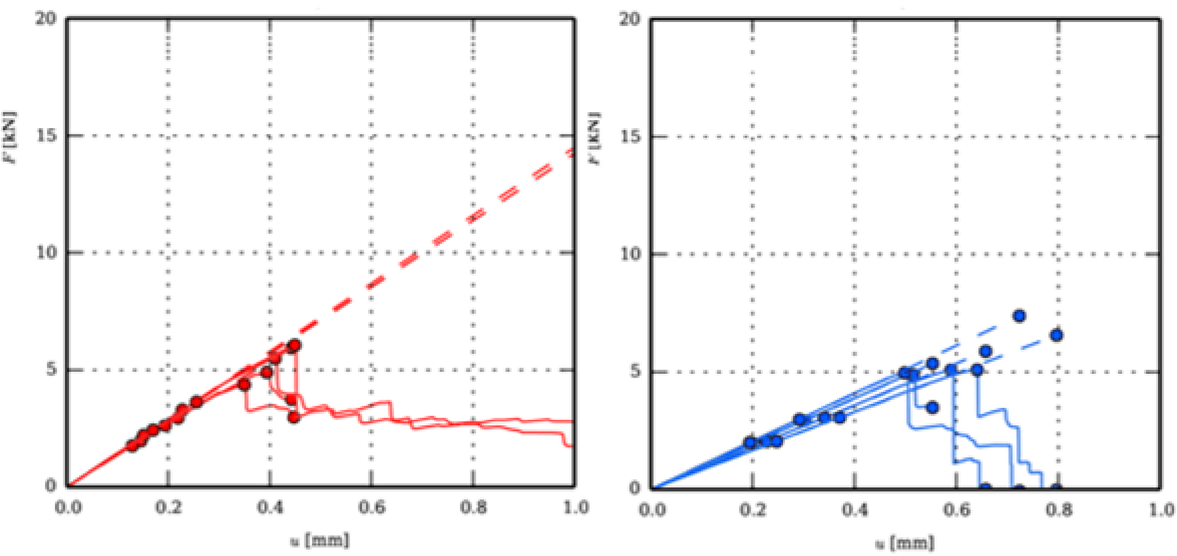
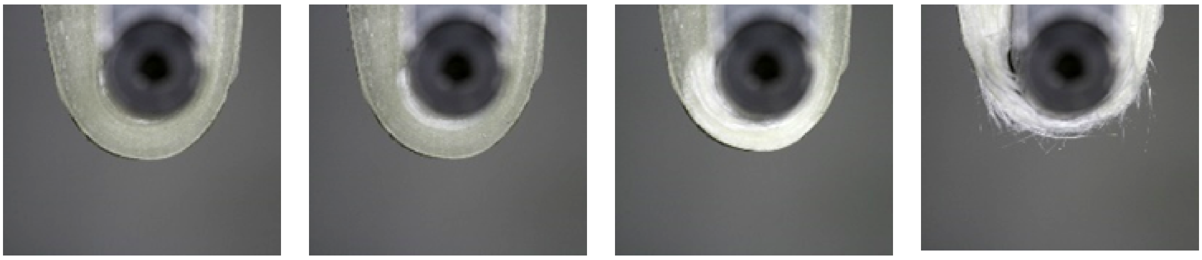


Fig. 5: The results of the failure of the samples of wrapping loops with free fastening; a) with seven threads of fibres, b) with four threads of fibres.



a) initial condition | b) beginning failure of the matrix | c) failure of the first fibre | d) the full failure of the loop

Fig. 6: The process of failure the wrapping loop.

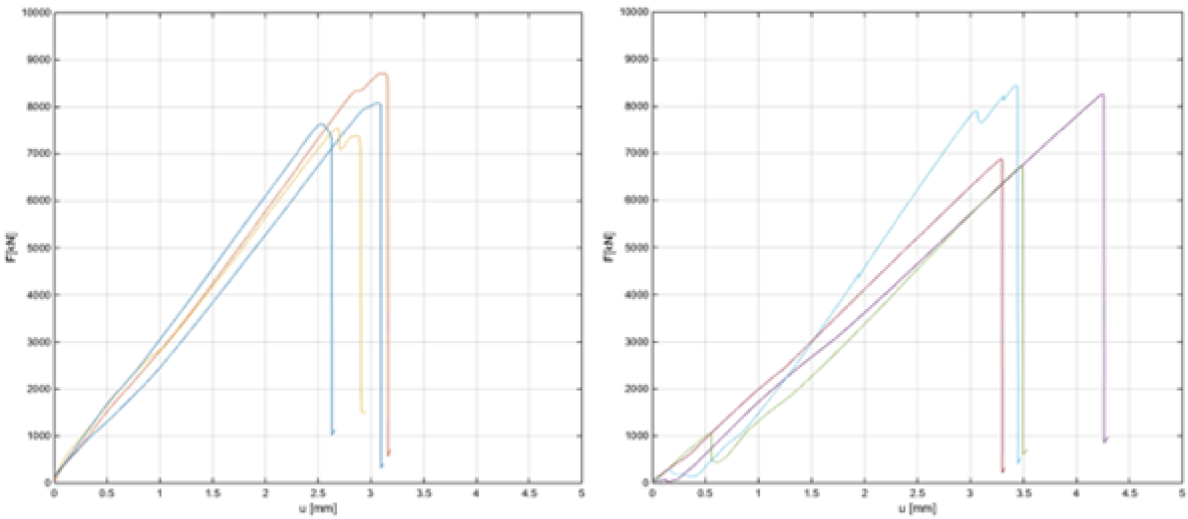


Fig. 7: The results of the failure of the samples of wrapping loops with tight fastening; a) with seven threads of fibres, b) with four threads of fibres.

verse to the fibers. From the compression test the values were determined; Y^C = 78 MPa (see diagram in Fig. 9) and α_0 = 55°.

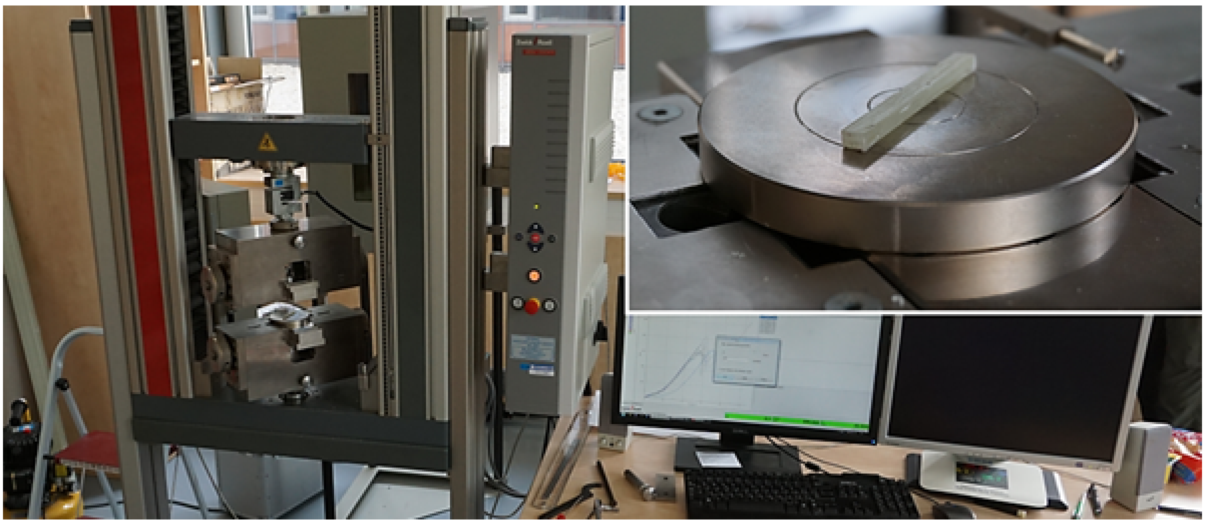


Fig. 8: The process of compression experimental test of glass fibre samples.

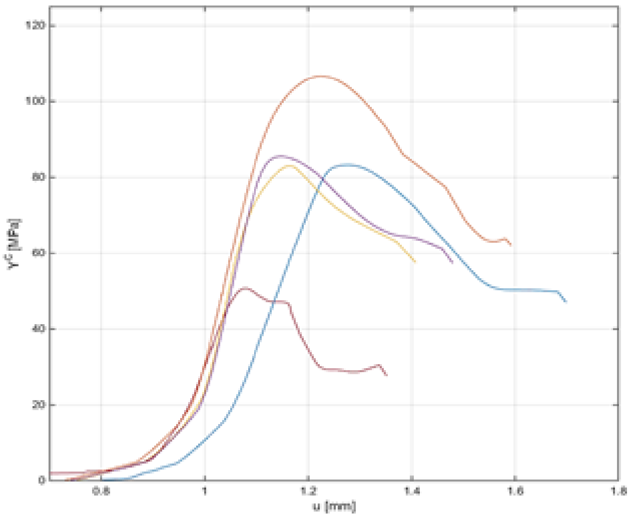


Fig. 9: Diagram of the compression tests of glass fibre samples.

5 Numerical Simulation

Finite element software Siemens NX (with solver NX Nastran 10) and SIMULIA Abaqus 6.14 were chosen for numerical simulation. Finite element models were created on parametric three-dimensional models with identical geometric parameters as the test samples. Brick elements with eight nodes (in NX Nastran type CHEXA8 and for Abaqus were used elements C3D8) were chosen for the meshes. The appropriate material orientation was assigned for each element of the mesh. The pin was modelled as a rigid surface. Displacement of the rigid surface was prescribed.

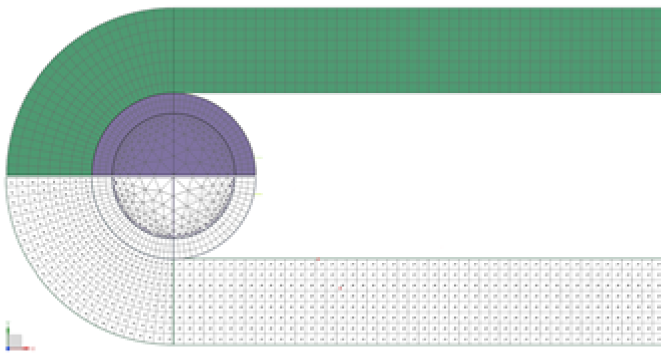


Fig. 10: FE model, including material orientation of the elements.

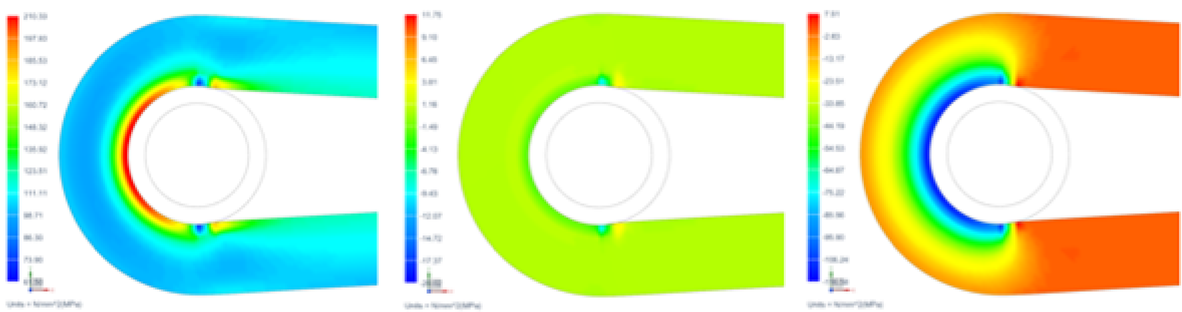


Fig. 11: Results of normal stresses (L, T, & T').

The individual components of the normal stresses L, T, T' (see Fig. 10) and shear stresses LT, TT' LT' were subjected to strength criterion 'Maximum stress'. According to this theory, failure occurs if any component of stress has reached the ultimate strength of the material [3]. These two indexes are the most critical. The first

Tab. 1: Mechanical properties of the unidirectional glass-fibers and the matrix.

Glass fibres + epoxy resin (LH298 + hardener H512)			
Vf	[-]	0.73	volume of the fibers
Vm	[-]	0.27	volume of the matrix
E1	[MPa]	52640	Young's Modulus, direction L
E2	[MPa]	8576.16	Young's Modulus, direction T
E3	[MPa]	8576.16	Young's Modulus, direction T'
G12	[MPa]	1986.75	Shear Modulus, plane 12
G23	[MPa]	1986.75	Shear Modulus, plane 23
G13	[MPa]	3264.20	Shear Modulus, plane 13
$\nu 12$	[-]	0.295	Poisson's Ratio, plane 12
$\nu 23$	[-]	0.31366	Poisson's Ratio, plane 23
$\nu 13$	[-]	0.295	Poisson's Ratio, plane 13
X_T	[MPa]	2000	Tensile stress allowable in 1–direction
X_C	[MPa]	1033	Compressive stress allowable in 1–direction
Y_T	[MPa]	315	Tensile stress allowable in 2–direction
Y_C	[MPa]	78	Compressive stress allowable in 2–direction
Z_T	[MPa]	315	Tensile stress allowable in 3–direction, normal to the laminate
Z_C	[MPa]	51	Compressive stress allowable in 3–direction, normal to the laminate
S or S_{12}	[MPa]	48	Shear stress allowable in 12 plane
S_{13}	[MPa]	42	Shear stress allowable in 13 plane
S_{23}	[MPa]	48	Shear stress allowable in 23 plane

corresponds to compressive stress in the T' direction and the second one corresponds to the shear stress in LT plane, (see Fig. 11).

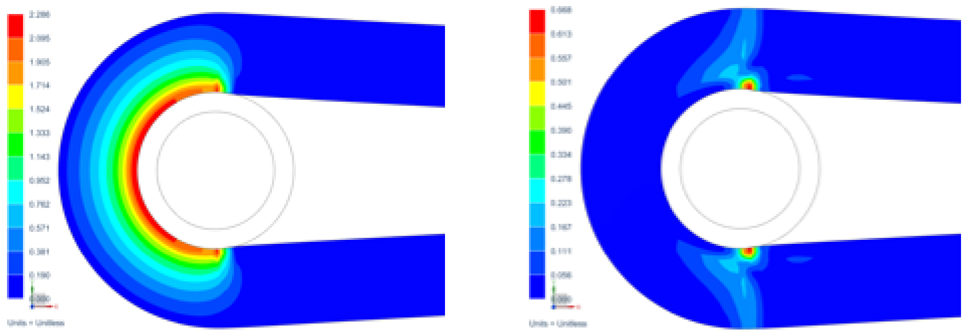


Fig. 12: Results of strength criterion Maximum stress - for 3th and 6th index.

From the results of strength criterion 'Maximum stress' it is however clearly evident that the results differ significantly from the experimental tests. For this reason, the LaRC04 strength criterion was chosen (Laminates and Reinforced Composites, which was proposed in NASA Langley Research Center in 2004 [5]). It belongs to the group of so-called interactive criteria and so-called direct mode criteria. The interactive criteria include the relationship between components of stresses.

For the modes LaRC04 #02 and LaRC04 #03 strength criterion LaRC04 was modified, according to [1,2]. The modification assumes that the strength of the matrix at loading pressure in the direction transverse to the fibre is also dependent on the tension in the direction of the fibers σL. However the stress σL causes hardening of the matrix. Then, for the second mode (LaRC04 #2 – matrix failure), if $\sigma_{T'} < 0$, $\sigma_L \geq 0$;

$$FI_M = \left(\frac{\tau^T}{S^T - \eta^T \sigma_n + \sigma_L P_M} \right)^2 + \left(\frac{\tau^L}{S^L - \eta^L \sigma_n + \sigma_L P_M} \right)^2 \leq 1. \tag{1}$$

And, for third mode (LaRC04 #3 – fibres failure), if $\sigma_L > 0$;

$$FI_F = \frac{\sigma_L}{\frac{X^T + X^T P_F}{Y^C + X^T P_M} \sigma_{T'} P_F + X^T} \leq 1, \tag{2}$$

where $P_F$and$P_M$are adjusting parameters, which were investigated using the comparison of the experiments and τ_T and τ_L are stresses in the plane of the failure, S_T is the transverse shear strength and S_L is the longitudinal shear strength and η_T and η_L are coefficients of the friction.

In the finite element model of the freely fastened loop, the model was also divided in cross-section at an angle α_0, at the point where the second mode of modified strength LaRC04 criteria # 2; FI_M = 1 = FI_{Mmax}. The contact, without considering friction of the type ”touching”, was defined between the separate parts and the base part.

6 Comparison of Experimental Test and Numerical Simulation

On the graph below (see Fig. 12) it is possible to see a comparison of the resulting values of numerical analysis by using a modified strength criterion LaRC04 (critical indices are shown; for failure of the matrix LaRC04 #02 and failure of fibre LaRC04 #03) for freely fastened (FF) and also tight fastened (TF) samples of the wrapped loops. By using the modified strength criterion LaRC04 the maximum difference of 27 % was created to conformity compared with the experiments (compared to the strength criterion ’Maximum stress’, the accuracy was increased by more than 80 %).

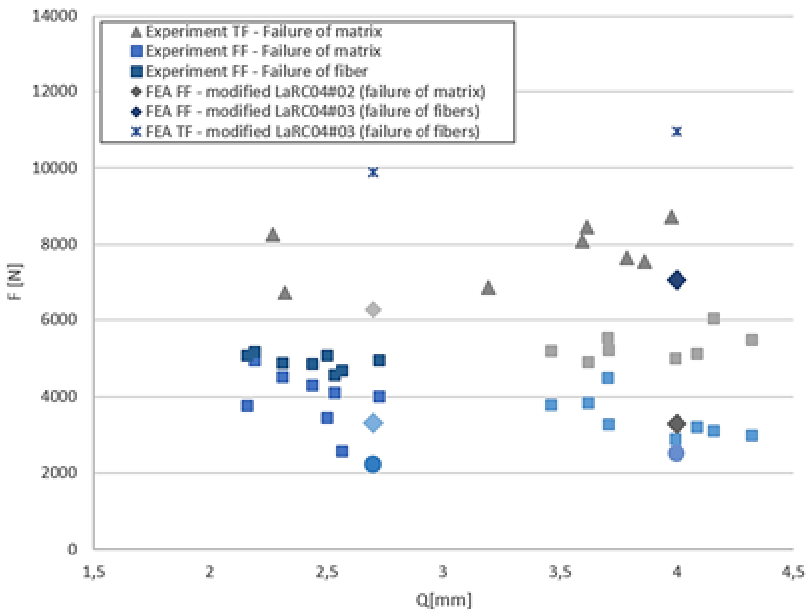


Fig. 13: The comparison of the resulting values of numerical analysis with experimental tests.

7 Conclusion

The experimental tests on the simplified samples of fibreglass wrapping loops provided us with much useful information to carry out a possible comparison by using numerical analysis. We found that using strength criterion ’Maximum stress’ provides a significant mismatch with the results of the experimental data. Therefore we used iterative strength criterion LaRC04, which included a modification in the most critical modes (LaRC04

#02 and LaRC04 #03). The modification of the LaRC04 includes the influence of stress in the direction of the fibres σ_L and adjusting parameters ($P_F$andP_M), which were investigated using the comparison of the experiments. This modified strength criterion ensures good agreement with the experimental data, but we are still working to increase the accuracy of this criterion, including the verification for more complex geometry.

Acknowledgements

This paper is based upon work sponsored by project RTI - Regional Technological Institute reg. no. CZ.1.05/2.1.00/03.0093 and TAČR TA project TE01020075.

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