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EXPERIMENTAL DETERMINATION OF POLYMER MATERIAL CHARACTERISTICS HAVING REGARD TO THE FEM COMPUTATIONAL ANALYSIS

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Abstract: *Unfilled polymer materials exhibit a high ductility, which is moreover located in relative small neck area. Material producers deliver usually the yield strain and break (ultimate) strain values calculated on the basis of material tensile tests for normalized active sample length. Application of so defined material characteristic in the case of Finite element method (FEM) analyses of real constructions made of TSCP (typical semi-crystal polymer) led to significantly conservative (smaller) values of ultimate loads compared to the measured ones. To obtain more precise results the material characteristics used should be in correlation with the size of finite elements. A special experimental method making use of high-speed camera has been developed to determine the strain in defined small area of local strain concentration on the specimen during tensile tests. The true stress-strain curve till the sample rupture is here calculated and break strain is determined. Application of more realistic (higher) break strain value by FEM analyses of real TSCP constructions led to the much better agreement between the calculated and measured values of construction stiffness and ultimate load.*

Keywords: ***polymer, experiment, stress-strain curve, break limit, limit load, FEM analysis***

1. Introduction

The article deals with the problem to define properly selected material characteristics of the unfilled polymers material, like semi-crystalline polymer (TSCP) with regard to the following Finite element method (FEM) analysis of the construction to be in better agreement with reality. TSCP material can be taken as an isotropic one. At the beginning of loading this material behaves linear elastically. Necessary mechanical parameters like Young elasticity modulus E, yield stress σ_K, yield strain ε_K, and break (ultimate) strain ε_U are determined with the help of the standard tensile test on flat samples, see Fig.3 for the measured active length of 50 mm , see Fig. 3. It means that we gain the average values of yield strain and break strain. But near the loading end the polymer TSCP deformation becomes very inhomogeneous with the intensive strain concentration at the small neck area on the test sample, which is usually not respected.

In the area of high deformations and strains we need more precise material model for FEM analyses, taking into account the large strains and large displacement especially for the computational prediction of the limit load force and deformation. The computational model of material should be in good correspondence with behavior of the real material. Some material data (esp. break strain) obtained from TSCP material producer are not suitable for correct FEM analysis, because they were determined as average values for measured standard sample length. Considering that FEM is able to model stress and strain in each body element, also in the neck area, some material parameters, esp. break strain should reflect this situation. A method of experimental detection of real break strain in the neck area has been developed based on the extension measurement of the defined sample part during the tensile test making use of sample grid deformation. The complete test is made by using

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high-speed camera, and the strain and stress are calculated from real record. The details of the method are explained below.

2. Experimental detection of the real TSCP ultimate strain used for FEM analyses

The break strain values delivered by TSCP material producer (Material characteristics of the TSCP) do not correspond to the real break strain which occurs in the neck area and leads to the break of the construction made of this material. The producer gives the break strain limit about 30% for our TSCP material. The FEM analysis of selected constructions led to very conservative results (much smaller) for construction ultimate loading and final displacement.

The break strain value from material producer is normalized and it is calculated as an average value for the active length of the sample, in our case of 50 mm. As it was already mentioned this value is not suitable for FEM analyses especially in the neck area, where the final failure happens. For this calculation we need the real break strain value, corresponding to the conditions in the neck place.

The normalized tensile samples ISO 527-1/2 have been used for the experimental determination of the ultimate strain in the neck area. On each sample the horizontal grid with distance 5mm, see Fig.1b has been drown. The stationary grid has been placed on the tensile test machine, see Fig.1a. The sample deformation during the loading process has been recorded making use of the high-speed camera with sampling of 100pictures/sec.

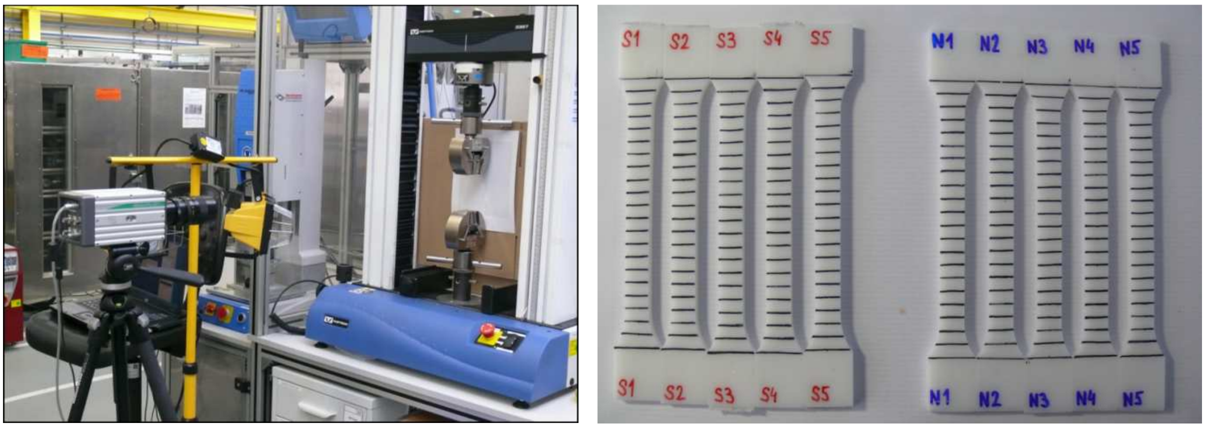

Fig. 1: a) The measure system with fast-cam, b) Tensile samples with horizontal grid

Going out of the known sample loading and measured extension of defined sample part the following material characteristics can be obtained for the stress, strain and strength analysis on constructions made of plastic material TSCP, for example

- Engineering stress/strain relation from prolongation of standard sample length 50 mm
- True stress/strain relation from prolongation of standard sample length 50 mm
- Engineering stress/strain relation from prolongation of necked area
- True stress/strain relation from prolongation of neck area
- Real break (ultimate) strain at the failure place (neck area)

This approach can be also used for any measured sample length corresponding for example to the finite elements size.

3. Experimental results

Time course of the sample deformation during the loading is illustrated in following Fig. 2

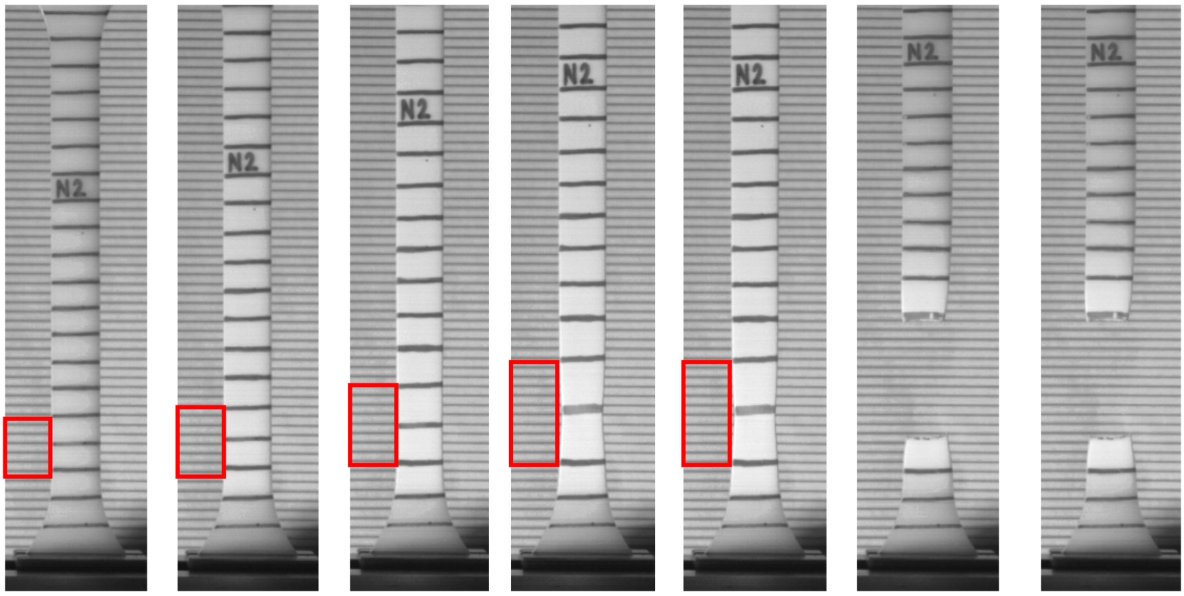

Fig. 2: Deformation of the sample during tensile test (load velocity 50mm/min)

The true stresses σ_{true} and true strains ε_{true} are calculated in standard way from known sample loading and measured extension of defined sample length

$$\varepsilon_{nom} = \varepsilon_{nom,elastic} + \varepsilon_{nom,plastic} \tag{1}$$

$$\varepsilon_{true,plastic} = \varepsilon_{true} - \sigma_{true} / E \tag{2}$$

$$\sigma_{true} = \sigma_{nom}(1+\varepsilon_{nom}) \tag{3}$$

$$\varepsilon_{true} = \ln(1+\varepsilon_{nom}) \tag{4}$$

ε_{nom} , ε_{true} … *total nominal strain , true total strain [-]*

$\varepsilon_{nom,elastic}$ … *plastic nominal strain [-]*

$\varepsilon_{nom,plastic}$ … *elastic nominal strain [-]*

$\varepsilon_{true,plastic}$ …*true plastic strain [-]*

σ_{nom} , σ_{true} …*engineering stress, true stress [MPa]*

E … *Young's modulus [MPa]*

In the article two measured sample lengths were utilized for the strain evaluation, namely standard length 50 mm and length 10 mm, corresponding to the neck size, see Fig. 2. The both measured sample parts are shown in following Fig. 3.

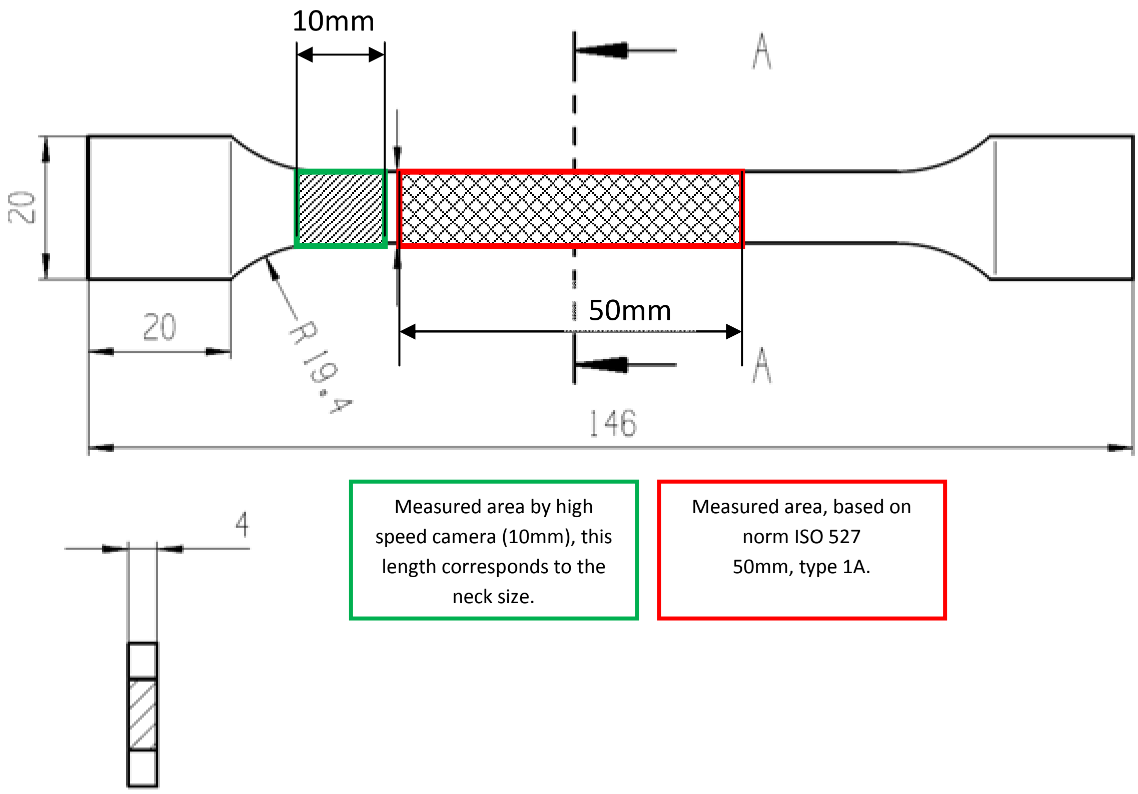

Fig. 3: Tensile test sample ISO 527-2, type 1A

The sample part extension is determined with the help of stationary grid. For more exact measurement it is possible to apply some graphic software utilizing the movement monitoring of selected points on the sample surface and evaluating the displacement and strain during the loading process. The calculated engineering as well as true stress-strain curves are presented in Fig. 4 for measured sample part of length 50 mm (short curves) and length 10mm (long curve).

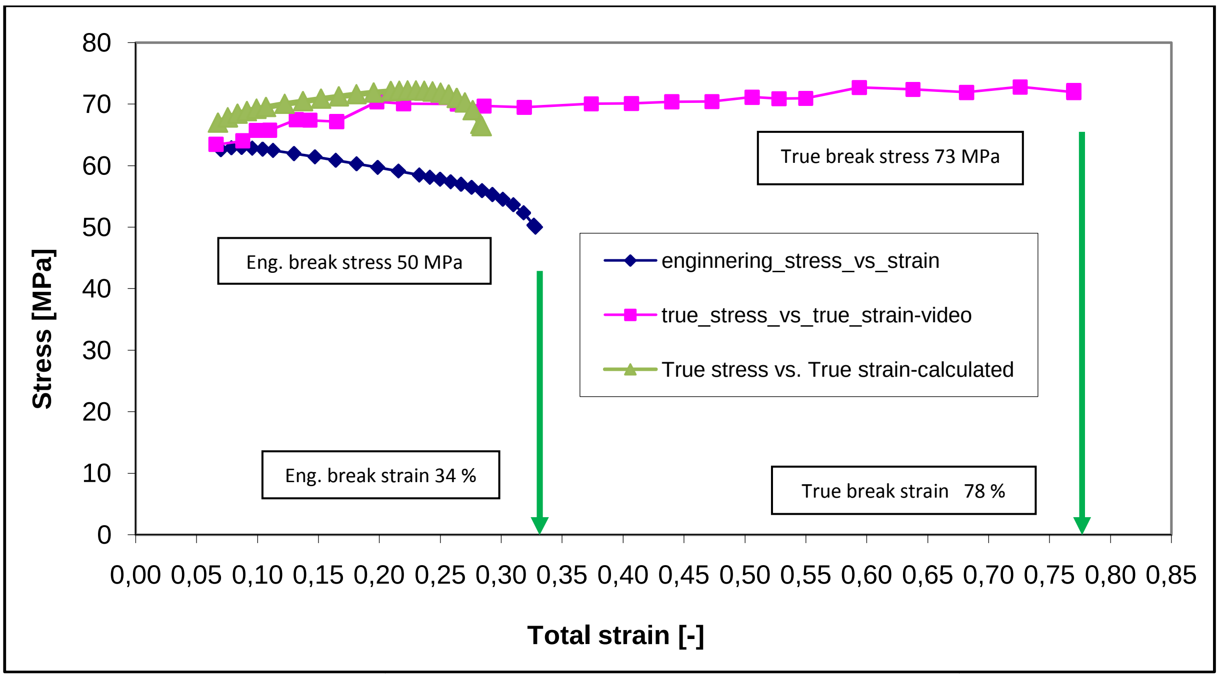

Fig. 4: Comparison of stress-strain curves obtained from experiment

4. Comparison of the experiment and computational analysis

The comparison has been done for a real car construction element of hydraulic connector of the fuel sub-module, made of TSCP polymer material, see Fig. 6. For this component the bending test is prescribed, where the connector must withstand the concrete loading force. From this reason the real loading test is performed till the component break. This experiment was simulated by FEM analysis. For the loading test the investigated component was fixed to the basis with the help of special clips, see Fig. 6. The computational analysis was made for the same boundary conditions as in the real test, namely of the stiff connection. The material model was defined by the true stress-plastic strain curve, see Fig. 5.

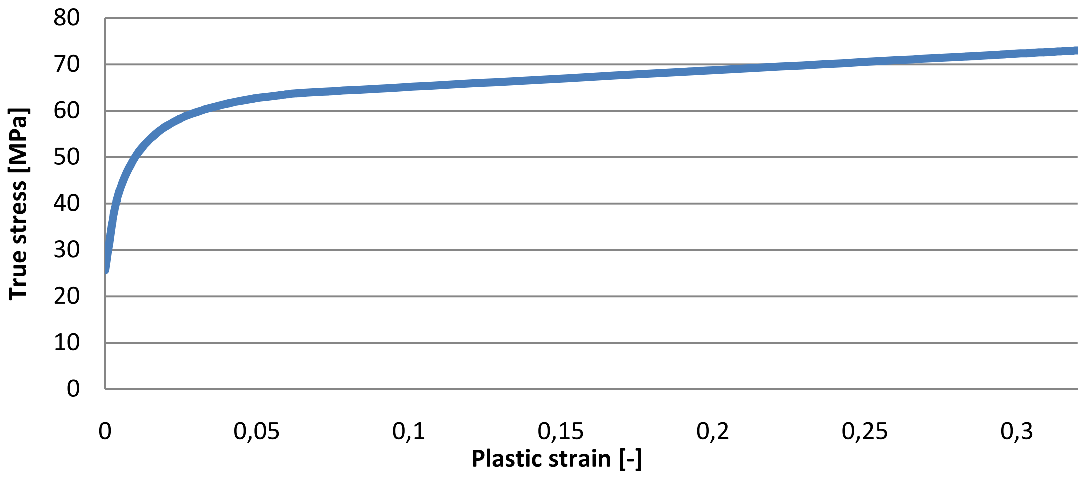

Fig. 5: Multi-linear material model for FEM analysis

The boundary conditions correspond to the real test. The connector flange is fixed in the fixing device, see Fig. 6. The loading place is defined by the norm. The load is realized by displacement in prescribed direction. The loading force is evaluated from sensors. The requirements on the hydraulically connectors by bending test are defined in two perpendicular direction; in the article is showed only one. The reaction forces from experiments on the tensile machine and FEM analysis are shown bellow.

During the FEM computation simulation (ANSYS 14.5-help, 2012) the loading was applied in lot of steps, with respect to the material as well as geometrical nonlinearity. The large deformation and large displacement approach has been accepted making use of Cauchy-Green deformation tensor (Theory of the large deformation and strain) regarding the high grade of geometrical nonlinearity.

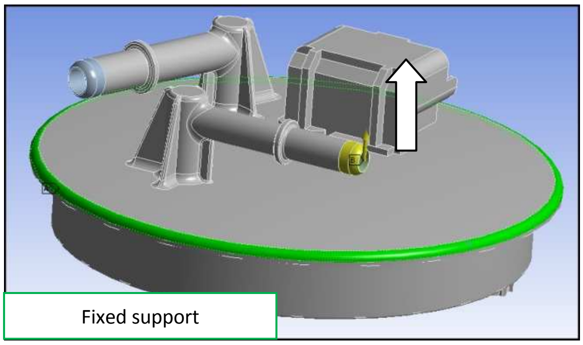

Fig. 6: Loading and boundary conditions

4.1. Results of the experiments and computational simulation

The main result from experiments is loading force at the break moment, limit displacement and critical area of the crack initialization. The dependences of the loading force and equivalent total strain on the displacement at the load place are illustrated in Fig. 7 and Fig. 8 for two tests.

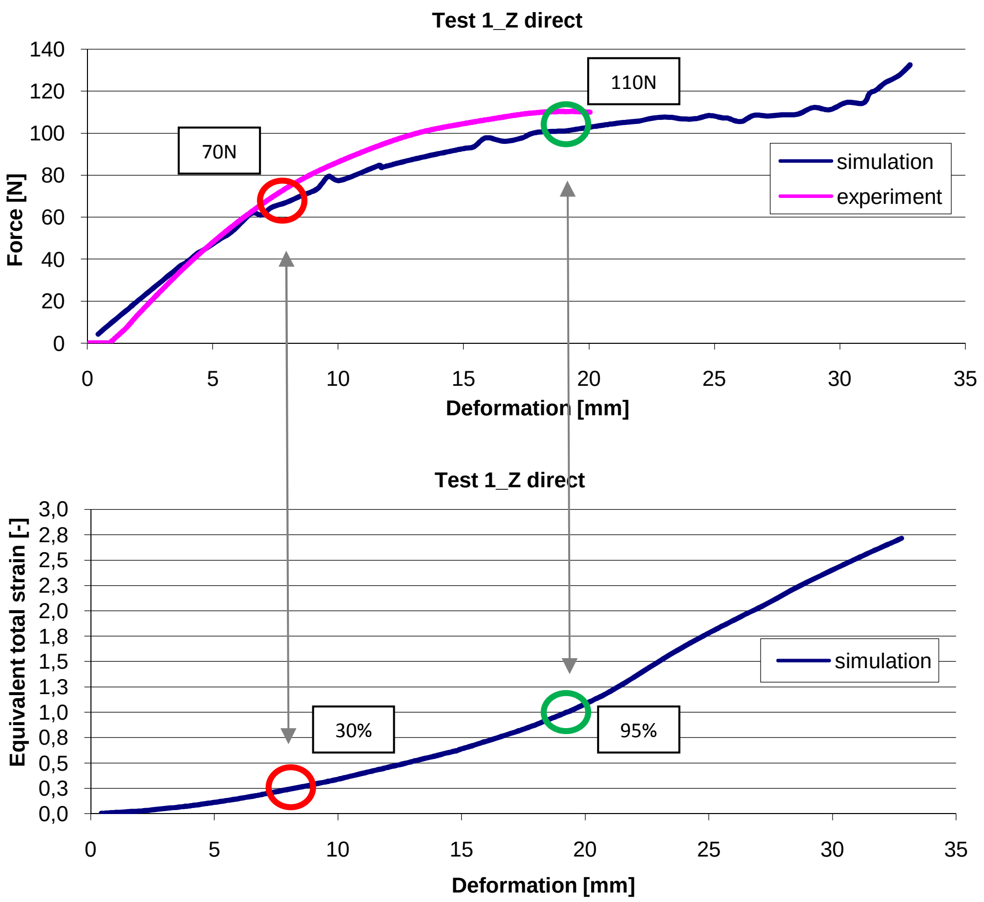

Fig. 7: Dependences of the loading force and equivalent strain on the displacement (test 1)

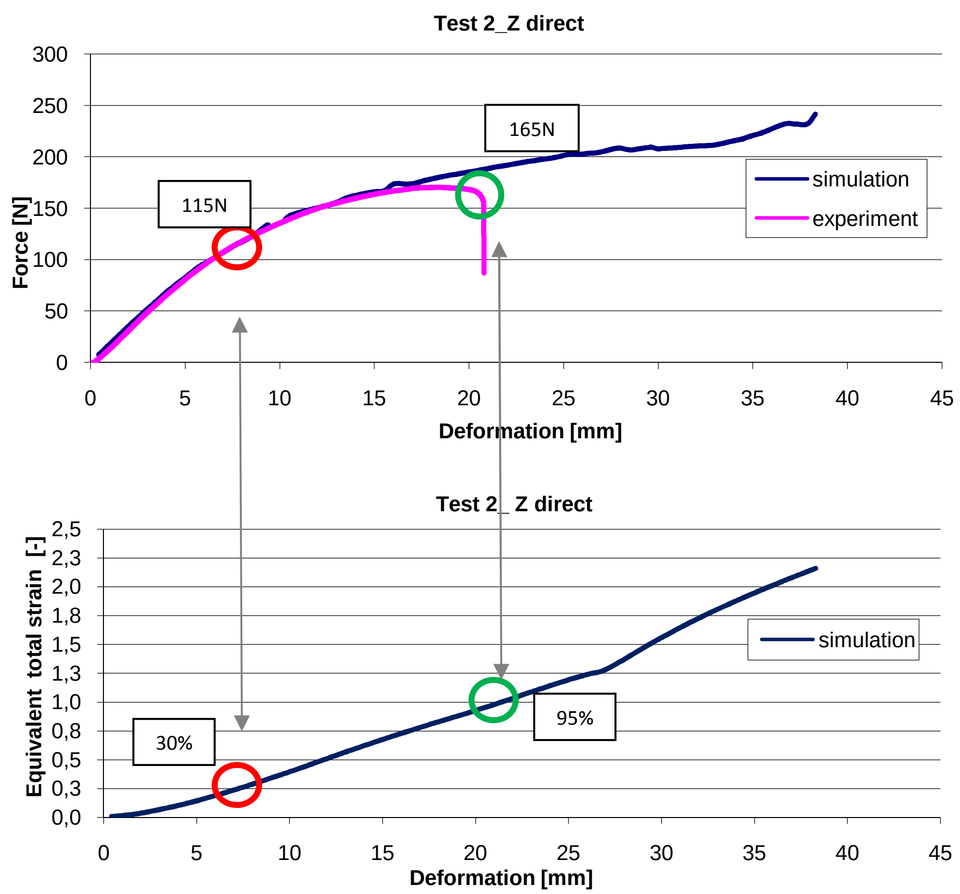

Fig. 8: Dependences of the loading force and equivalent strain on the displacement (test 1)

Two types of hydraulic connectors were loaded in vertical direction z – see Fig.6, namely of diameter 8 mm (Test 1) and diameter of 10 mm (Test 2). The measured relations loading force versus displacement at loading place are presented in Fig.7 and Fig. 8 (upper pictures – shorter curves) together with FEM computational simulation (longer curves) considered as nonlinear geometrical problem (large strains, large displacements) as well as nonlinear material problem described by the true stress – true strain curve according Fig. 5. Lower pictures in Fig. 7 and Fig. 8 show relation between vertical connector displacement and average equivalent strain in most loaded finite elements. For the rupture (ultimate) displacement this parameter can be taken as a break (ultimate) strain ε_u = 0,95.This value corresponds relatively well with the experimental tensile test value for neck area of length 10 mm – ε_u = 0,78, see Fig. 4, being determined for little bit different TSCP material with the help of proposed experimental method, utilizing the high-speed camera. Application of the break strain value ε_u = 0,30 from material producer for FEM computational simulation of hydraulic connector would lead to the much smaller break (ultimate) displacements w_u as well as break (ultimate) loads F_u compared with values from experiments - w_u = 8 mm, F_u = 70 N for Test 1, w_u = 7,5 mm, F_u = 115 N for Test 2, compared with values from experiments - w_u = 19 mm, F_u = 110 N for Test 1, w_u = 21,5 mm, F_u = 165 N for Test 2 – see Fig. 7 and Fig. 8.

The destroyed connector after loading test in z direction is presented in Fig. 9 and corresponding FEM analysis is presented in Fig 10. It is evident that the breaking place agrees with the place of maximum principal stress (tensile stress) and also with the place of maximum strain. The average value from most deformed finite elements was taken as the break (ultimate) strain ε_u = 0,95 of the material used.

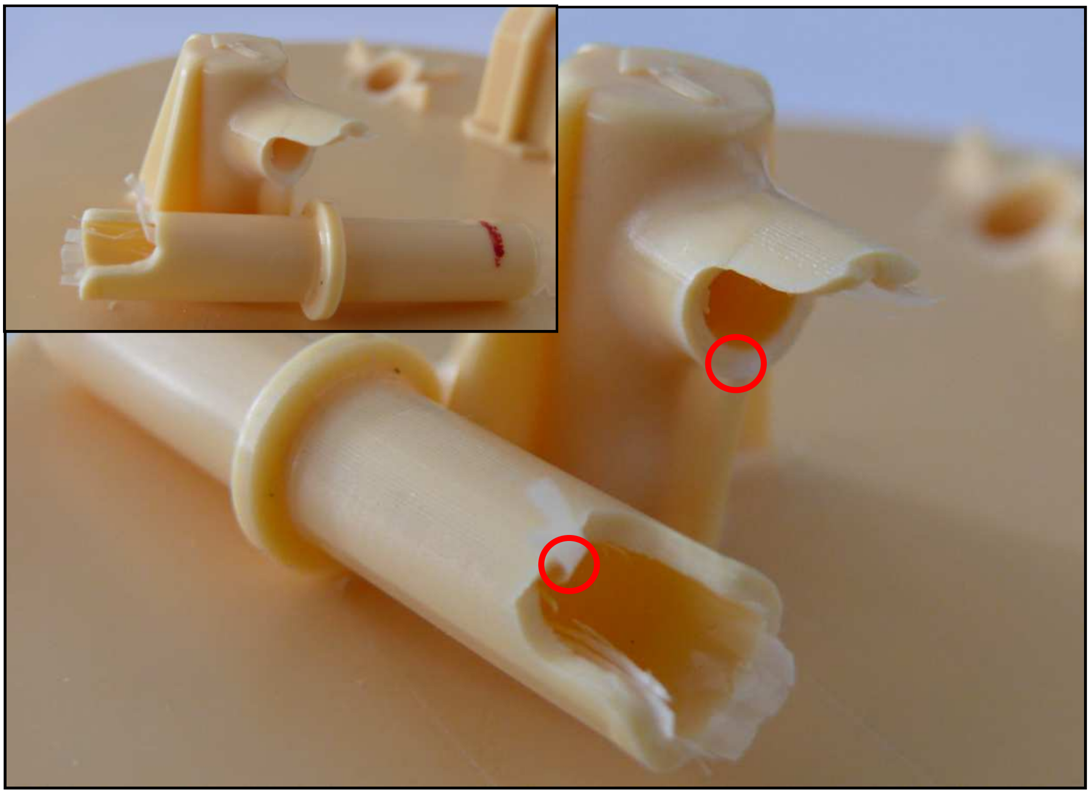

Fig. 9: The cracking areas on the real test sample (Z direct)

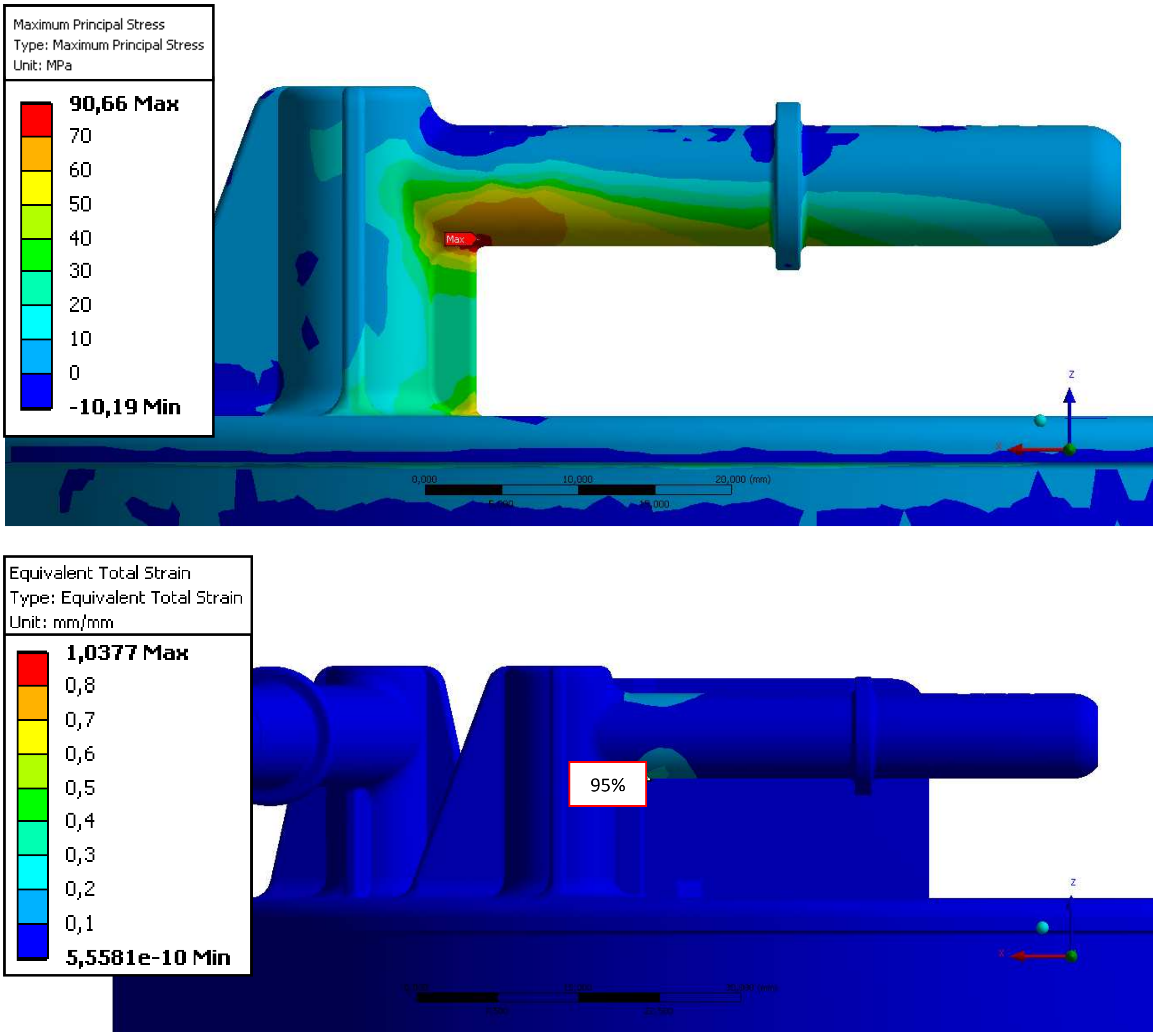

Fig.10: The distribution of the maximum principal stress and total strain

5. Conclusion

In the article a new experimental method specially proposed for plastic materials has been presented to determine the strain in defined small area of local strain concentration (neck area) during the specimen tensile test, making use of the speed camera record. The true stress and true strains are calculated here during the sample loading process and corresponding true stress-strain curve till the sample rupture is determined. For the investigated strain concentration area of length 10 mm on the plastic material TSCP sample the calculated break (ultimate) strain ε_u was about 2,3 times higher than the data from material producer. Application of this more realistic material values for the FEM analysis of the real hydraulic connectors made of TSCP material led to the much better agreement between calculated and measured limit loads and limit displacements values.

Acknowledgement

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