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TORSION TESTS FOR STEEL SPECIMENS AND THEIR NUMERICAL AND EXPERIMENTAL SOLUTIONS

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Článek se zaměřuje na řešení torzního testu pro krátký ocelový vzorek. V průběhu řešení bylo respektováno uchycení v čelistech zkušebního stroje (3D mechanický kontakt), elastické a plastické deformace, ztráta stability a také dynamické vlivy torzního plastometru. Výsledky získané pomocí MKP (software MSC.MARC/MENTAT a software ANSYS) jsou porovnány s experimentem. Konstituční rovnice izotropního materiálu byla získaná z experimentálních měření a nové metody vyhodnocování krutové zkoušky pro ocel 14109 ČSN 42 0074.

This paper focuses on the numerical solution of a torsion test for a short steel specimen. During the solution were considered fixation effects in the jaws of a laboratory test machine (3D mechanical contact with Coulomb friction), elastic and plastic strains, shape buckling effects and also the dynamic influences of a torsion plastometer. The results acquired through the FEM (software MSC.MARC/MENTAT and ANSYS) are also compared with the experimental results. Constitutive material equation was acquired from experimental measurements using the new evaluation method for steel 14109 ČSN 42 0074.

Klíčová slova: Torzní testy, vyhodnocování torzních testů, plastické deformace, MKP.

1. THE TORSION TESTS EXPERIMENTAL EVALUATION

References [10], [11] and [12] describe in detail the new original torsion test evaluation method and its refinement [3], [7] for a quasi-static and proportionally loaded symmetric specimen, vide fig.1. This method holds for elasto-plastic domain. Thus for the equivalent plastic strain S_{ep} *[1]* holds the followed equation:

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$$S_{\varepsilon p} = f(r,\varphi,\mathrm{L}) = \frac{1}{\sqrt{3}} \ln \left(\frac{2 + \dfrac{r^2\varphi^2}{2\mathrm{L}^2} + \dfrac{r\varphi}{\mathrm{L}}\sqrt{\dfrac{r^2\varphi^2}{4\mathrm{L}^2} + 1}}{2 + \dfrac{r^2\varphi^2}{2\mathrm{L}^2} - \dfrac{r\varphi}{\mathrm{L}}\sqrt{\dfrac{r^2\varphi^2}{4\mathrm{L}^2} + 1}} \right), \tag{1}$$

where r *[mm]* is the diameter and L *[mm]* is the active length of steel specimen and $\varphi = \varphi(\mathrm{t})$ *[rad]* is a twisting angle, see fig.2.

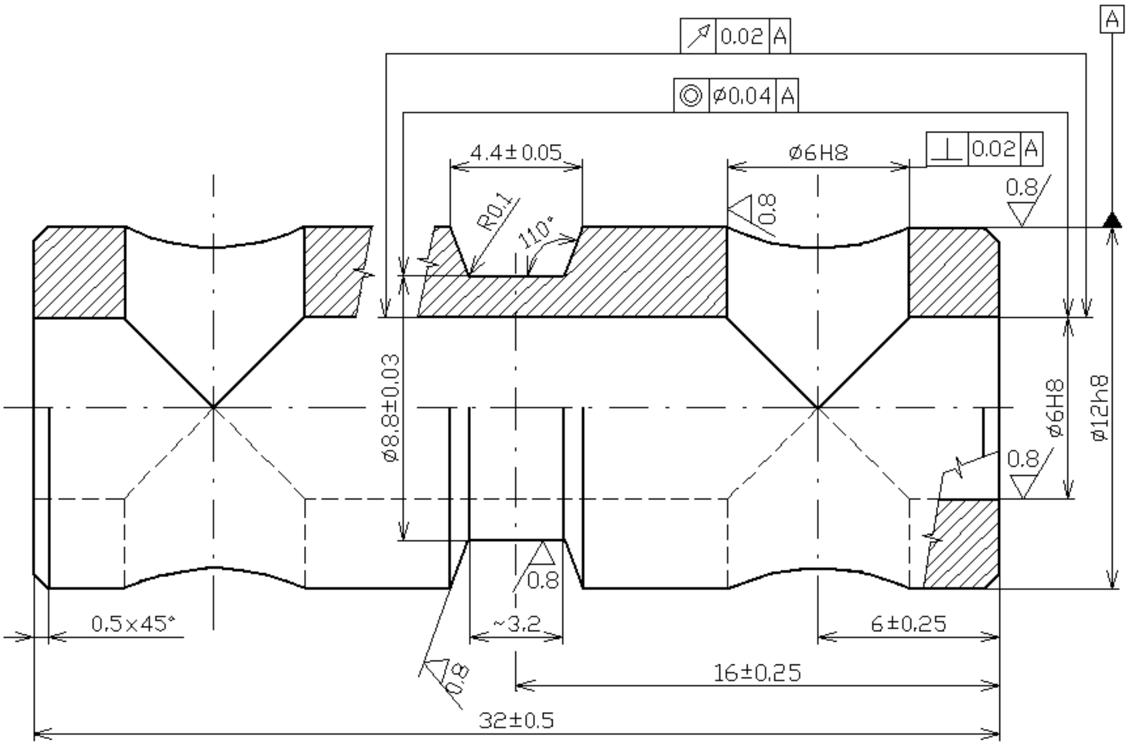

Fig.1 An enlarged manufacturing diagram of the laboratory short specimen from steel 14 109.

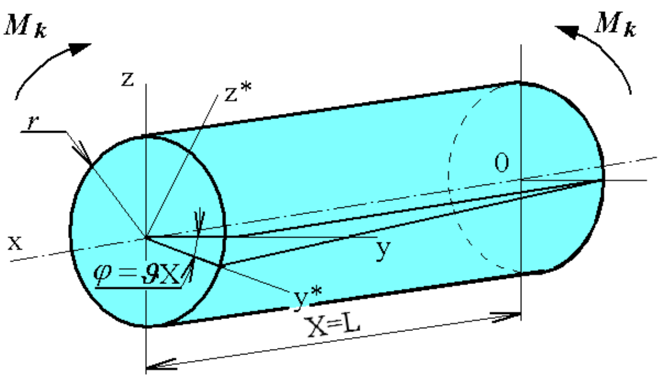

Fig.2 The basic parameters for torsion tests.

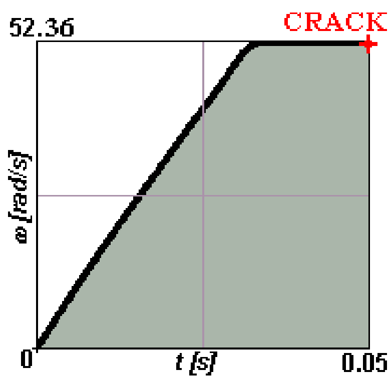

Fig.3 Angular velocity.

The material equation acquired from experimental measurements for steel 14109 (ČSN 42 0074) is in the fields of plastic strains described by:

$$S_\sigma \cong 232.956 + 939.702\, S_{\varepsilon p}^{0.507}, \qquad (2)$$

where S_σ *[MPa]* is the equivalent von Mises stress. The general Hook's law also holds for elastic and plastic solving domains. The limiting surface of plasticity was determinated from equation (2) by the von Mises yield criterion with isotropic hardening rule.

A fracture caused by torsion appeared after a short time t = 0.05 *s*. All measured and solved values hold for the time-changing values of a twisting angle $\varphi = \varphi(\mathrm{t})$ *[rad]*, angular velocity $\omega = \omega(\mathrm{t})$ *[rad/s]* (see fig.3) and strain rate intensity $S_U = S_U(\mathrm{t})$ *[1/s]*.

2. FINITE ELEMENTS MODELS

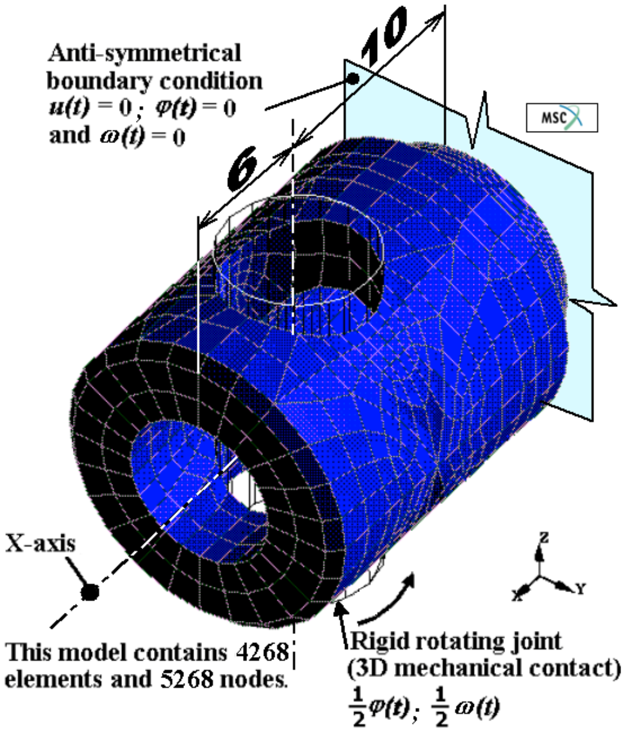

Fig.4 FE model with total length (MSC.MARC/MENTAT software).

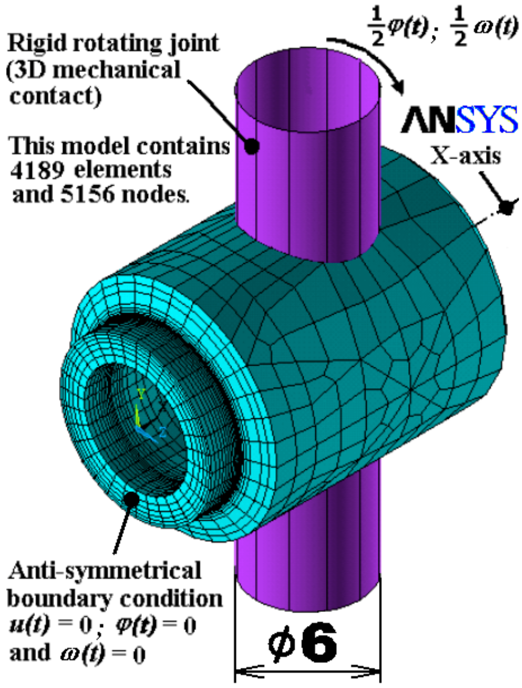

Fig.5 FE model with total length (ANSYS software).

A geometrical planar anti-symmetry was successfully used for FE mesh modelling in the cylindrical co-ordinate system in plane symmetry YZ ($u(\mathrm{t}) = 0$ *[mm]*, $\varphi(\mathrm{t}) = 0$ and $\omega(\mathrm{t}) = 0$). That means that in half of the laboratory specimen the displacement on the X-axis and the twisting angle and angular velocity around X-axis are zero. As an external time dependent condition, one half of the angular velocity $\omega = \omega(\mathrm{t})$ (rotating around rotation axis X) was applied to the joint of the specimen. This angular velocity was acquired from experiments and correlates with the dynamical starting effects of a torsion plastometer. For more information see [3], [7], [10], [11] and [12].

Figures 4 and 5 show two different FE models created and solved in MSC.MARC/MENTAT and ANSYS software.

The fixation of the specimen in the joints is approximate to a case of 3D mechanical contact between the joints and holes of the specimen. The above-mentioned arguments of plane symmetry are sufficient to modelling only one joint, which can be considered as a rigid (undeformed) body. But one half of the specimen, along with a contact hole, is a deformed body. The influence of a Coulomb friction (friction coefficient $\nu_{\mathrm{T}} = 0.1$) was applied between the joint and hole. The contact boundaries are described more accurately by the analytical description of Coons surfaces. For more details see [1], [2] or [3].

The solution was found at time period $t \in \langle 0\,;0.05 \rangle\, s$ subdivided into 144 intervals of various sizes. Large strain rate velocities (the sudden fracture of a plasticity cross-section reached in a short time) were considered during the solution. The tensor of elastic and plastic strains was used in the whole plasticity time solution history.

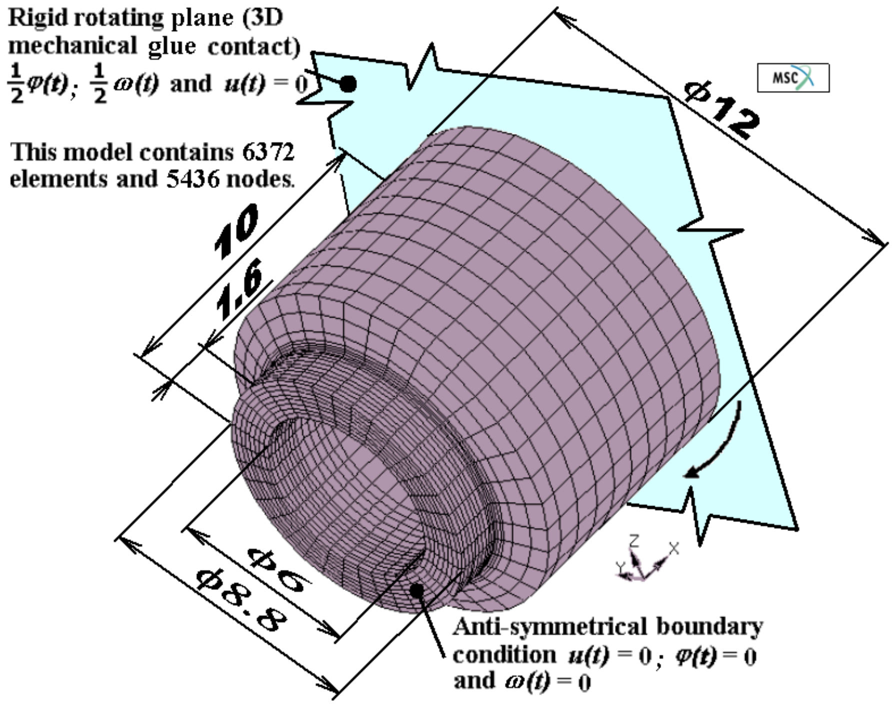

Fig.6 FE model with reduced length (MSC.MARC/MENTAT software).

One half of the laboratory specimen from fig.1 was also solved in publications [3], [6] and [7], but only to the joint axis distance (i.e. the length of modeled specimen is equal to one half of reduced length L_R = 20 *mm*), see fig.6 and 1. The action of distributed contact pressures in the contact surfaces was not directly considered in this case.

3. COMPARISON OF FEM SOLUTIONS AND EXPERIMENTAL RESULTS

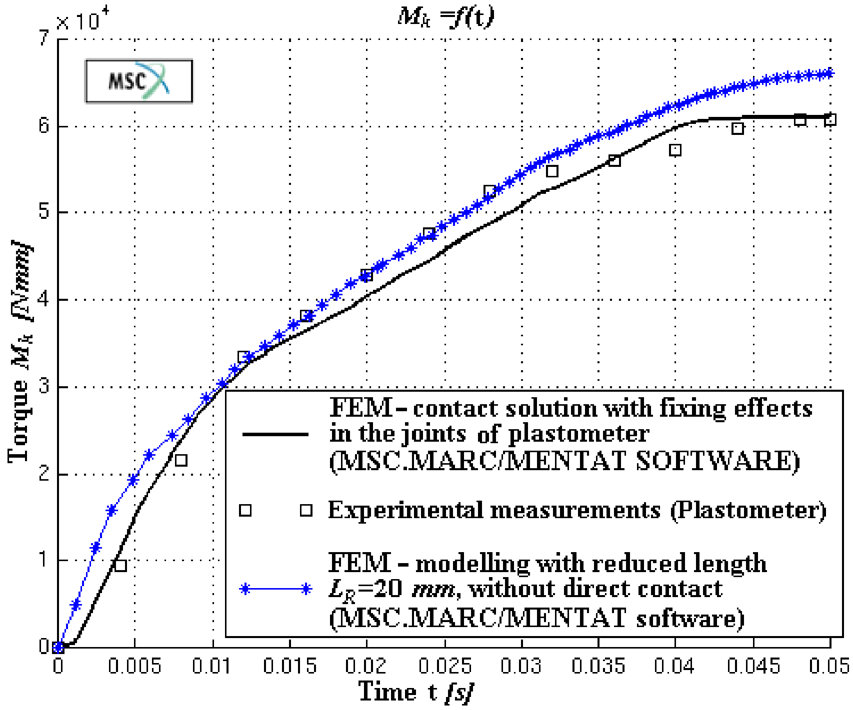

Fig.7 Comparison of time-torque dependencies in the whole torsion test process (evaluated from experiments and FEM simulations by MSC.MARC/MENTAT software).

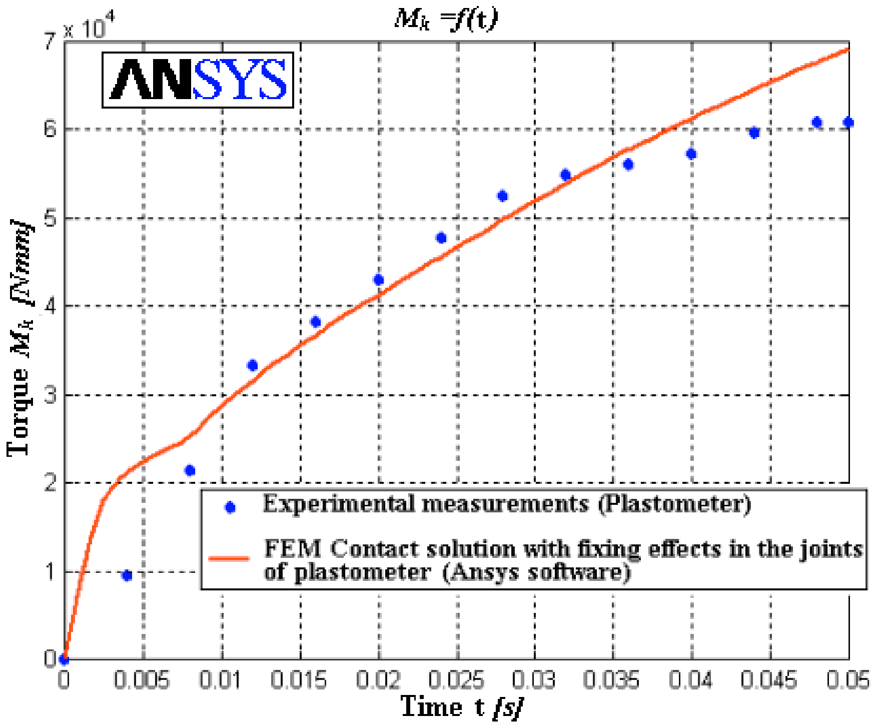

Fig.8 Comparison of time-torque dependencies in the whole torsion test process (evaluated from experiments and FEM simulations by ANSYS software).

The comparisons of all mentioned FEM approaches with experiments are shown in fig.7 and 8. The main credibility criterions of the FEM (MARC/MENTAT and ANSYS) packages are the determinated values of torque M_k *[Nmm]* dependent on time t. These relations are compared with experimental values in fig.7 (for MSC.MARC/MENTAT software) and fig.8 (for ANSYS software).

The MSC.MARC/MENTAT modelling with reduced length and without direct influence of fixation in a joint gives higher values of M_k than these experiments. On the contrary, the solution with the direct fixing in the contact joint is evidently a lower estimate of function $M_k = f(\mathrm{t})$, see fig.7.

The credibility criterions of the ANSYS software are the determinated values of torque. These relations are compared with experimental values in fig.8. The biggest differences between ANSYS software and experimental measurements are in the time of beginning and ending of the torsion test.

The differences between the FEM mathematical models and the mathematical model of experiment are caused by their "different" approaches of description of stress-strain states, see [3], [4], [6], [7], [9], [10], [11] and [12]. Interesting are also the differences between MSC.MARC/MENTAT software and ANSYS software, see fig.7 and 8. An important input function that can greatly alter the results is the approximation of material behaviour, see equation (2).

Thus from the given information it is clear that the MSC.MARC/MENTAT and ANSYS computations give us satisfactory solutions.

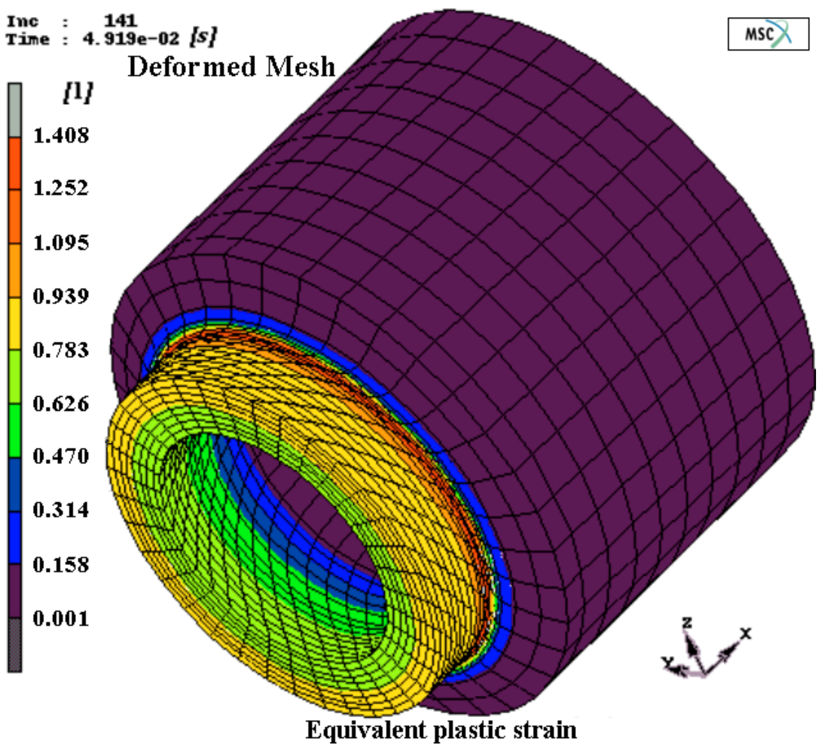

Fig.9 The plastic strain intensity values at time t=4.919×10^{-2} *s* (solution with reduced length, MSC.MARC/MENTAT software).

Figure 9 shows distribution of equivalent plastic strain at time t = 4.919×10^{-2} s (solution with reduced length and without mechanical contact, MSC.MARC/MENTAT software).

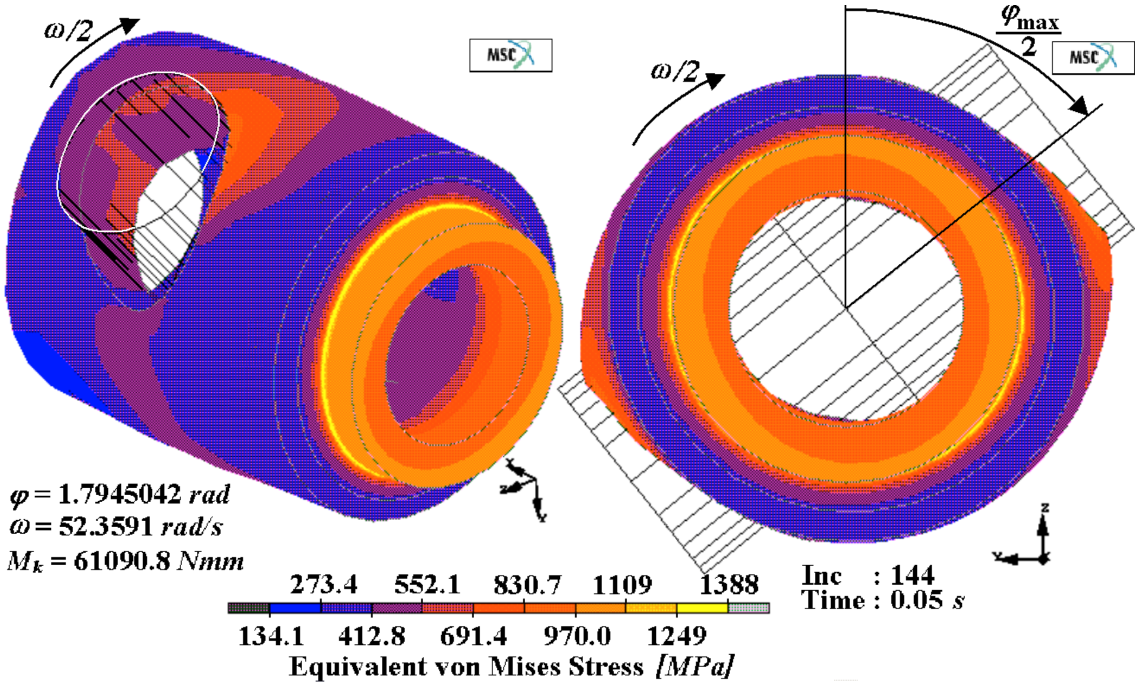

Fig.10 The values of S_σ at time t = 5×10^{-2} s (model with total length and mechanical contact, MSC.MARC/MENTAT software).

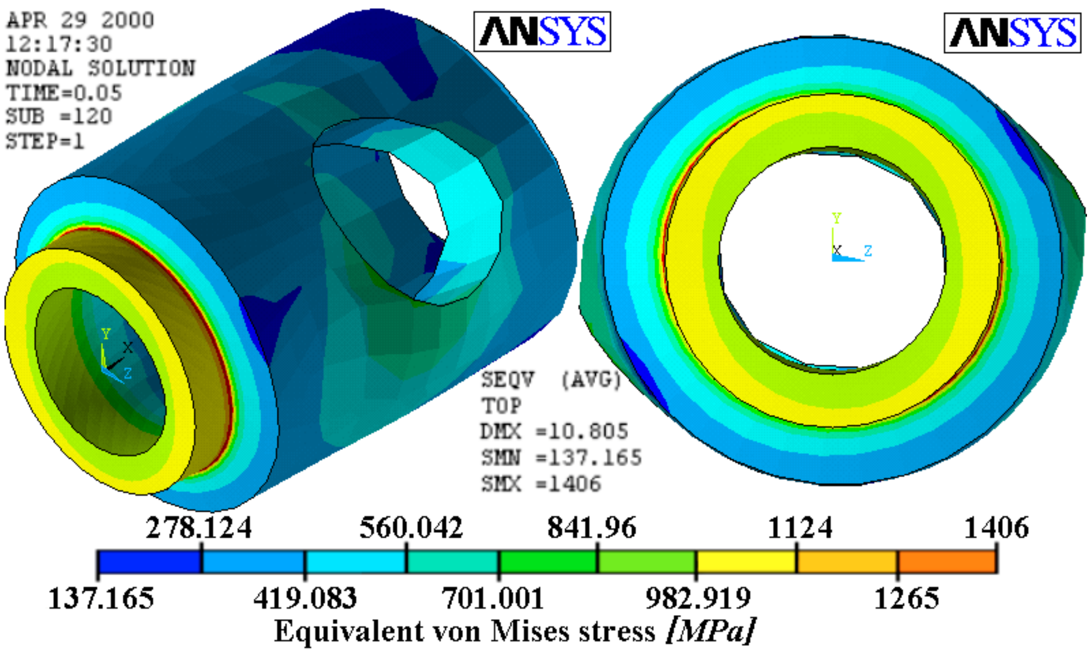

Fig.11 The values of S_σ at time t = 5×10^{-2} s (model with total length and mechanical contact, ANSYS software).

The distribution of stress intensity at time t = 5×10^{-2} *s* is visualised in fig.10 (software MSC.MARC/MENTAT) and fig.11 (software ANSYS). The maximum values (S_σ = 1388 *MPa*, Fig.10) or (S_σ = 1406 *MPa*, Fig.11) are in the neck notch radii (R=0.1 *mm*) of the specimen. Figure 10 and 11 show non-uniform stress distributions through the neck cross-section in symmetry plain YZ. They also show the shape buckling due to excessive plastic strains and also the material accumulation in the contact locality of joint.

4. CONCLUSIONS

The torsion tests modeled by the FEM (MSC.MARC/MENTAT and ANSYS software) together with consideration of fixation effects in the joints of specimen are sufficiently simulated and also agree with the measured experimental results. The torsion tests were solved by a new approach using large non-linearities (large plastic strains, shape buckling and mechanical contact with friction). Performing this tests along with some other material tests [5] and [8] can provide the basic informations about material behaviour.

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