NUMERICAL MODELLING OF THE TORSION TEST ON THE STD 812 TORSION PLASTOMETER

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Abstract

The paper presents the results of numerical modelling of fixed-end hot torsion testing for conditions characteristic of the STD 812 torsion plastometer. The material used for the tests was a hard deformable aluminium alloy in grade 5019. The FORGE 2011®, a finite element method-relying software program, was used for numerical modelling. The obtained numerical modelling results were compared with results obtained from an actual torsion test using the STD 812 torsion plastometer. The performed numerical analysis enabled the determination of the stress and strain states and the temperature in the investigated aluminium alloy. Numerical modelling of the torsion test carried out in accordance with real experimental testing conditions makes it possible to determine the representative area for possible metallographic examinations.

Keywords: Numerical modelling, hot torsion test, hard deformable aluminium alloy 5019

1. INTRODUCTION

A natural feature of the torsion test is the unevenness of the deformation parameters, strain rate and temperature on the cross-section and longitudinal section of the material under torsion. On the cross-section of the torsion material, all the above-mentioned materials attain the highest values on the surface and decrease towards the sample axis [1]. The effect of this unevenness should be taken into account by calculating the deformation parameters for the so-called representative radius, where the deformation parameter values correspond to the average values on the cross-section [1]. The differentiation of the deformation and strain rate values depending on the analytical relationships used, which relate the effective strain with the redundant strain, may cause the equivalent radii to assume different values [1]. As shown by studies, including references [1÷2], 2/3 r, 0.6 r, 0.724, or 0.75 r is proposed in the technical literature as equivalent radii, where r denotes the radius of the torsion specimen.

Numerical modelling of the torsion test, carried out in accordance with real experimental testing conditions, enables, inter alia, the representative area for possible metallographic examinations to be determined. Based on the obtained results, it is also possible to analyze the strain and stress states within the entire volume of the material. This is particularly important in the case of a complex deformation scheme [3] (e.g. simultaneous torsion with tension or simultaneous torsion with compression). Numerical analysis of the torsion test enables also the determination of the degree of unevenness of deformation parameters for different materials and different dimensions of the working portion of torsion specimens in a wide range of deformation parameters and temperature. The investigation results reported in the paper make an introduction to a further analysis of phenomena occurring in different materials during their deformation in the STD 812 torsion plastometer.

2. THE AIM, SCOPE AND METHODOLOGY OF THE INVESTIGATION

The purpose of the paper was to numerically represent the fixed-end hot torsion test for conditions characteristic of the STD 812 torsion plastometer. Numerical modelling, carried out in accordance with real experimental testing conditions, enables, inter alia, the determination of the representative area for possible metallographic examinations. Based on the obtained results, it is also possible to analyze the strain and stress states within the entire volume of the material.

The investigation described in the paper was carried out for a hard deformable aluminium alloy, grade 5019. The FORGE 2011®, a finite element method-relying software program, was used for numerical modelling [4].

At the first investigation stage, the fixed-end hot torsion test was performed using the STD 812 torsion plastometer. The tests were conducted at a temperature of 480 °C and at a strain rate of 0.25 s^{-1}. The total actual deformation was 5. The dimensions of the specimen working portion were as follows: the diameter, d = 8 mm; and the length, l = 20 mm. The temperature was controlled using a K-type (NiCr-NiAl) thermocouple. The next investigation stage included numerical modelling of the torsion test was performed using the commercial software program Forge 2011®, according to the real testing conditions. At the last investigation stage, the numerical modelling results were compared with the results obtained from the actual torsion test.

3. ANALYSIS OF THE INVESTIGATION RESULTS

The chemical composition of the 5019 grade hard deformable aluminium alloy is given in **Table 1**.

Table 1 Chemical composition of the 5019 aluminium alloy [5]

Constituent contents [%]								
Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.246	0.146	0.004	0.567	5.54	0.002	0.026	0.019	Rest

During testing, the uneven distribution of temperature across the specimen length was taken into account. To accurately determine the temperature distribution, temperature measurements were taken by a contact method using the K-type (NiCr-NiAl) thermocouples (**Figure 1**). The obtained results were taken into account in the proper tests (**Figure 2**).

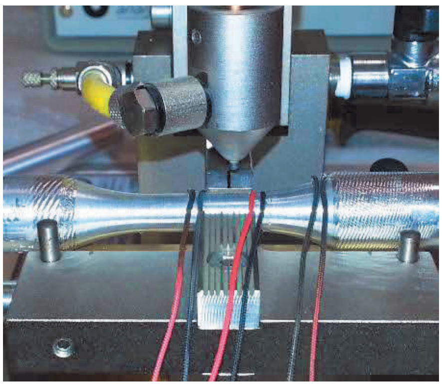

Figure 1 A 5019 aluminium alloy specimen in a thermocouple welding machine

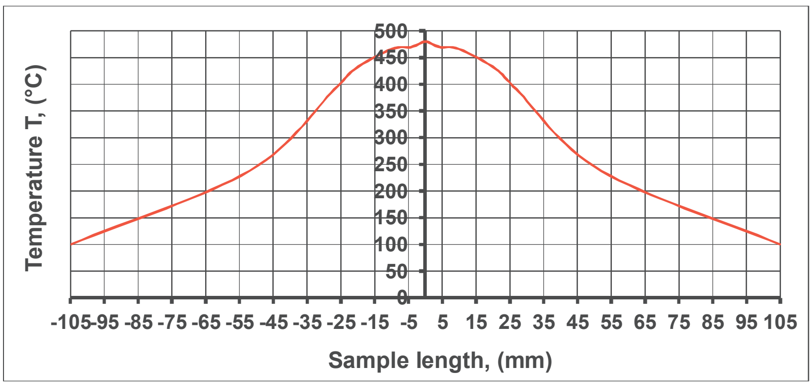

Figure 2 The actual distribution of temperature across the length of the 5019 aluminium alloy specimen, as determined by the contact method

The actual rotational speed during the torsion test as a function of time is represented in **Figure 3**. For the specimen dimensions under analysis and in the examined range of strain rates and strain magnitudes, the rotational speed was 20.5 rpm.

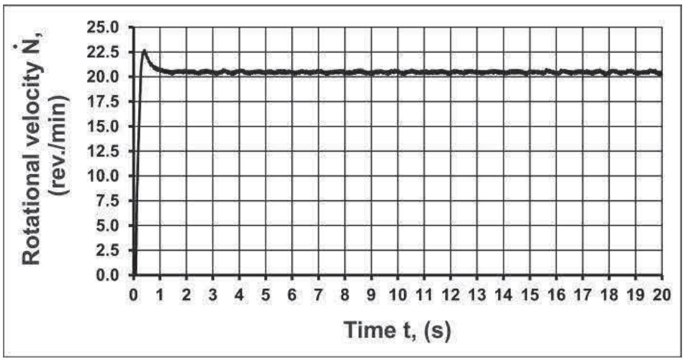

Figure 3 Variations in the rotational speed of the STD 812 torsion plastometer motor during the torsion of 5019 aluminium alloy specimens

In order to numerically represent the torsion test it was necessary to determine the rheological properties of the examined alloy, which were published in work [5]. To implement these properties in the material database of the Forge 2011® program, the experimental testing results were approximated with Equation (1) [6]. The coefficients of this equation are given in **Table 2**. A sample diagram representing the stress variation as a function of strain within the examined deformation parameter range and temperature is shown in **Figure 4**. From the obtained results it was found that that the values resulted from the approximation corresponded with high accuracy to the actual stress values determined in the torsion test experiment. The numerical modelling was performed in accordance with the experimental testing conditions, at a constant temperature.

$$\sigma_p = A \cdot e^{m_1 \cdot T} \cdot t^{m_9} \cdot \varepsilon^{m_2} \cdot e^{\frac{m_4}{\varepsilon}} \cdot (1+\varepsilon)^{m_5 \cdot T} \cdot e^{m_7 \cdot \varepsilon} \cdot \dot{\varepsilon}^{m_3} \cdot \dot{\varepsilon}^{m_8 \cdot T} \tag{1}$$

where:

σ_p - flow stress [MPa], T - temperature [ºC], ε - actual strain, $\dot{\varepsilon}$ - strain rate [s^{-1}], A, $m_1 \div m_9$ - coefficients.

Table 2 The values of parameters A and $m_1 \div m_9$ used for the determination of the value of σ_p of the 5019 aluminium alloy

A	m1	m2	m3	m4
0.2715530	-0.0095775	-0.0823773	-0.2465	-0.002
m5	m7	m8	m9	
0.0001	-0.032	0.0010150	1.6514300	

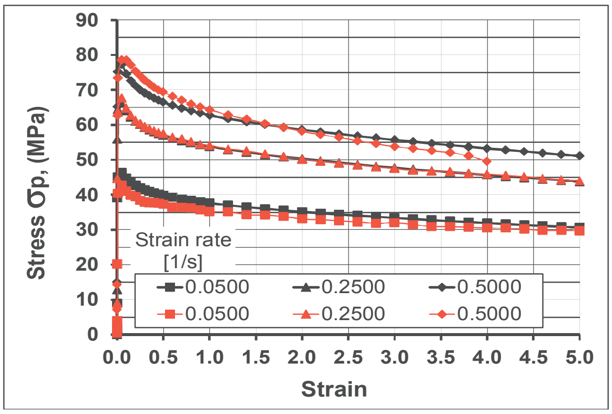

Figure 4 The aluminium alloy flow curves: temperature, 4800 °C; red colour - plastometric test results; black colour - results after approximation

The variations in torsional moment obtained in hot torsion of the 5019 aluminium alloy in the torsion plastometer and from numerical computations, respectively, are shown in **Figure 5**, while The flow stress value was determined based on the numerically determined torsional moment according to relationship (2) [5].

$$\sigma_p = \frac{\sqrt{3}\cdot 3M}{2\pi r^3} \tag{2}$$

where: r - specimen radius, M - torsional moment.

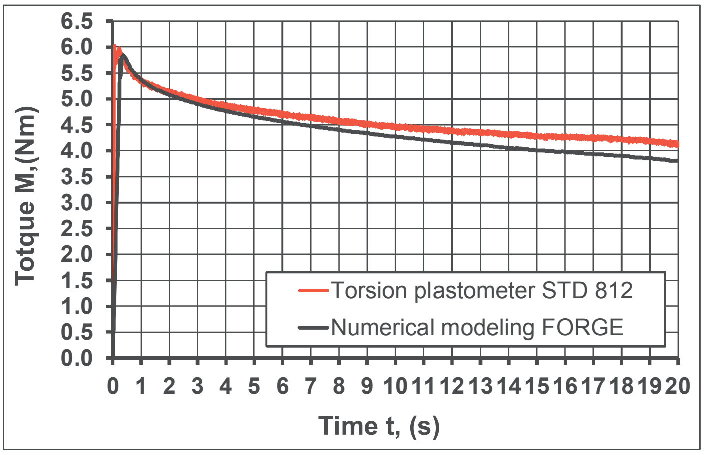

Figure 5 The torsional moment in the torsion of the 5019 aluminium alloy in the STD 812 torsion plastometer and the torsional moment determined numerically using the Forge 2011® program

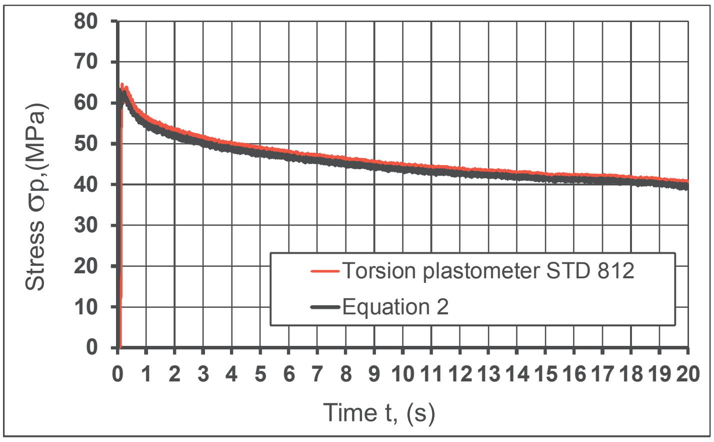

Figure 6 The flow stress in the torsion of the 5019 aluminium alloy in the STD 812 torsion plastometer and the flow stress determined from Equation (2)

When examining the data in **Figure 5**, one can observe a characteristic peak of torsional moment value at the beginning of the torsion process, followed by a steady decrease in torsional moment value with the increase in deformation. By comparing the torsion moment values obtained during experimental tests with those determined numerically, a good agreement between the the obtained results can be found. Slight differences that occurred after a deformation time of 6 s and grew as the deformation increased, did not exceed 8%. As can be seen from the data in **Figure 6**, they did not affect the high consistence of the flow stress determined from Equation (2) based on the numerically computed torsional moment.

Figure 7 shows the numerically determined distribution of temperature in the examined aluminium alloy 5019.

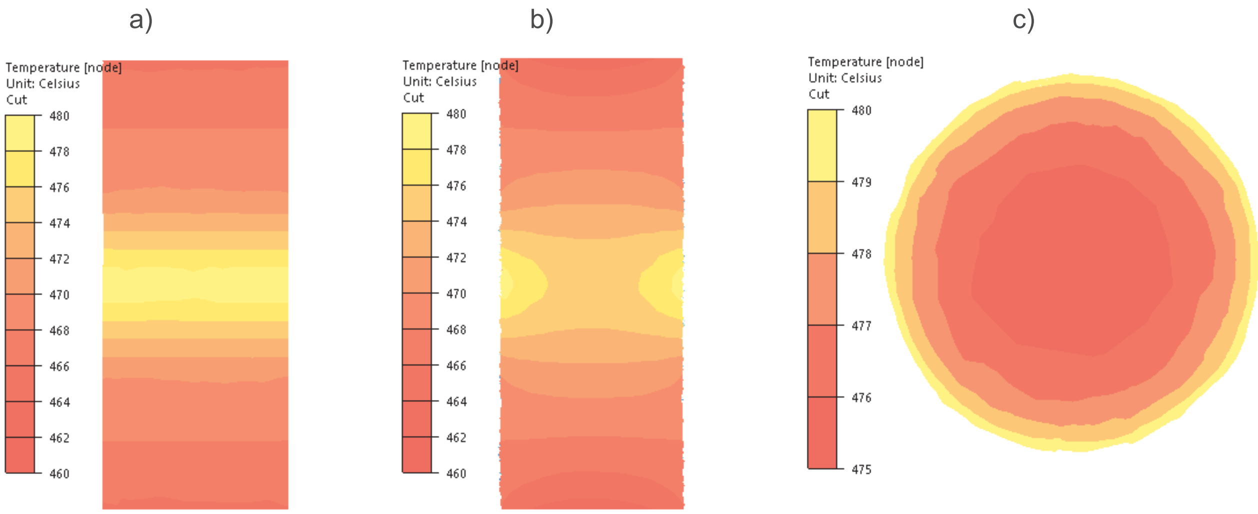

Figure 7 Distribution of the temperature of aluminium alloy 5019 during hot torsion - temperature 480 °C; strain rate, 0.25 s^{-1}: a) temperature distribution at the beginning of torsion - the longitudinal section; b) temperature distribution at the end of torsion - the longitudinal section; c) temperature distribution and the end of torsion - the cross-section in the middle of the specimen working portion

By examining the data in **Figure 7** it was found that the initial 5019 aluminium alloy specimen temperature distribution set at the beginning of the torsion test (**Figure 7a**) did not change throughout the hot torsion process (**Figure 7b**). In the case under examination, the temperature difference along the specimen working portion with a length of l=20 mm and a diameter of d=8 mm amounted to 20 °C. The highest temperature values across the examined specimen length occurred in the middle part of the specimen. When analyzing the temperature distribution on the cross-section in the central part of the specimen (**Figure 7c**), the highest temperature values were found to occur at the surface. In the examined case, the temperature difference on the cross-section of the investigated alloy was 5 °C.

The distribution of strain intensity, strain rate intensity and stress intensity within the entire volume of the working portion of the investigated material is illustrated in **Figures 8÷10**.

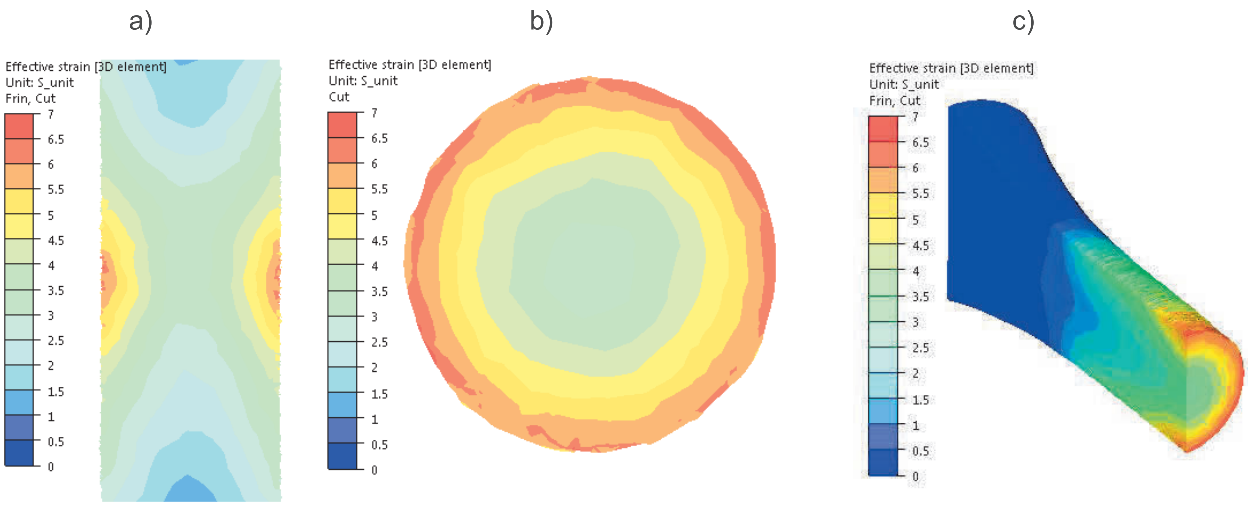

Figure 8 Distribution of the strain intensity of aluminium alloy 5019 during hot torsion - temperature, 480 °C; strain rate, 0.25 s^{-1}: a) longitudinal section; b) cross-section - the middle of the working portion; c) perspective

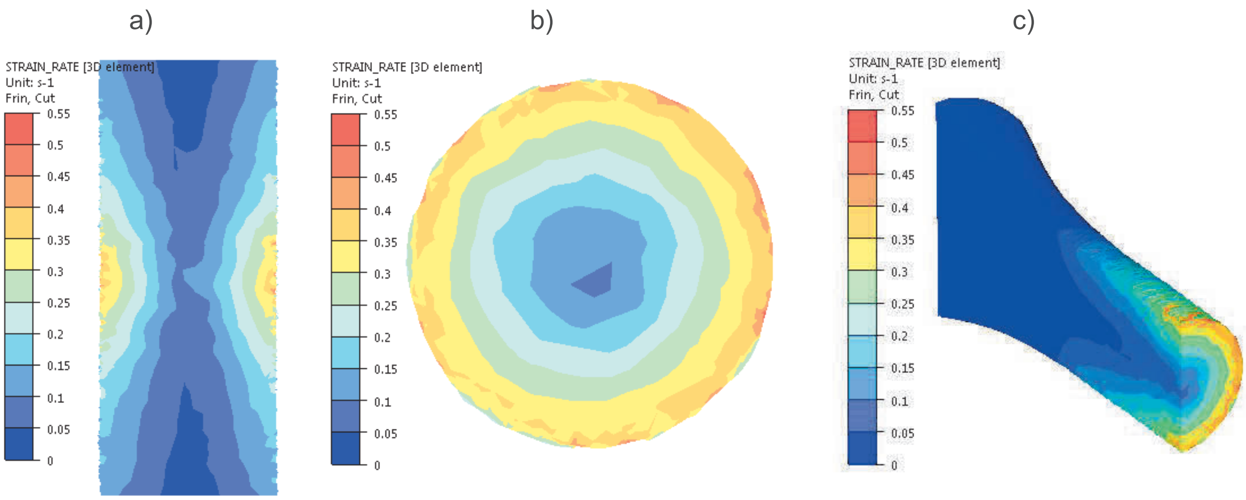

Figure 9 Distribution of the strain rate intensity of aluminium alloy 5019 during hot torsion - temperature, 480 °C; strain rate, 0.25 s^{-1}: a) longitudinal section; b) cross-section - the middle of the working portion; c) perspective

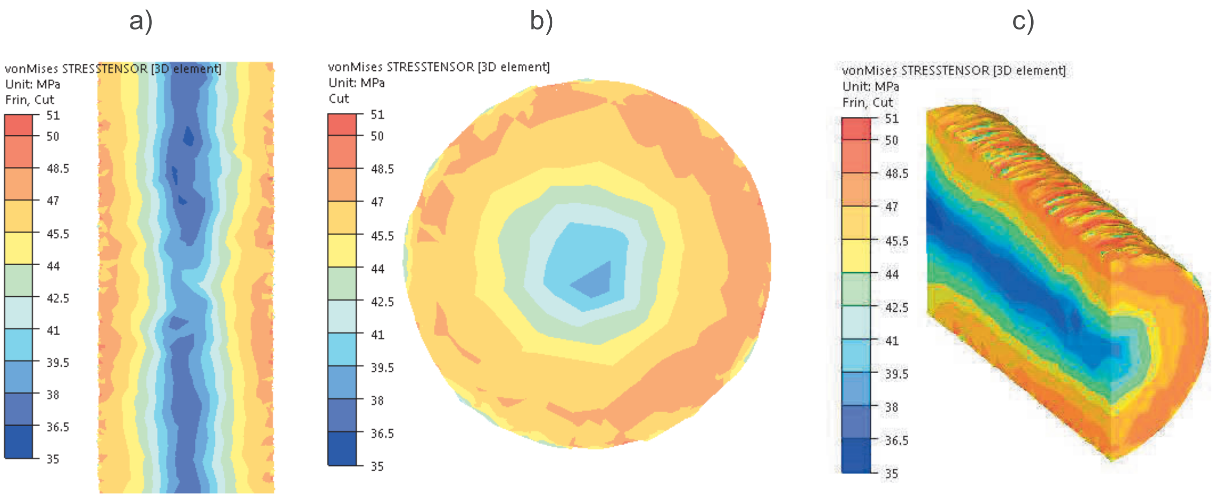

Figure 10 Distribution of the stress intensity of aluminium alloy 5019 during hot torsion - temperature, 480 °C; strain rate, 0.25 s^{-1}: a) longitudinal section; b) cross-section - the middle of the working portion; c) perspective

Based on the analysis of the data in **Figures 8÷10**, an unevenness of the examined parameters can be observed both on the cross-section and on the longitudinal section. The smallest cross-sectional unevenness was observed for stress intensity. For the examined 5019 grade aluminium alloy specimens with working portion dimensions of l=20 mm and d=8 mm in the examined range of strain parameters and temperature, the representative area (radius) is the 2/3 of the specimen radius.

4. CONCLUSIONS

Based on the numerical analysis of the torsion test in the STD 812 torsional plastometer, the following conclusions have been drawn:

- the torsional moment values for aluminium alloy 5019, as determined numerically, are close to the values measured in the hot torsion test using the STD 812 torsional plastometer;

- the computed values of the flow stress of the investigated material correspond with a high accuracy to the experimentally determined values;
- the boundary conditions adopted for numerical modelling were defined correctly; and
- the numerical analysis of the hot torsion test enabled the determination of, inter alia, the strain and stress states and the temperature within the entire volume of the material under torsion.

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