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ACCOUNTING FOR THE INHOMOGENEITY OF DEFORMATION IN IDENTIFICATION OF MICROSTRUCTURE EVOLUTION MODEL

NIEJEDNORODNOŚĆ ODKSZTAŁCENIA W IDENTYFIKACJI MODELU ROZWOJU MIKROSTRUKTURY

The paper deals with the problem of identification of microstructure evolution model on the basis of two-step compression test. Classical interpretation of this test assumes uniform fields of strains, stresses and temperatures in the deformation zone and calculates the coefficients in the model on the basis of force measurements in the second step. In the present paper the inverse approach was applied. Finite element (FE) simulations of the compression test were performed and local values of microstructural parameters were determined accounting for the inhomogeneity of deformation. Objective function was formulated as the Euclid norm for the error between measured and calculated forces for various interpass times. Coefficients in the microstructure evolution model were determined by searching for the minimum of the objective function. Optimized model was validated in simulations of plane strain compression tests.

W artykule poruszono problem identyfikacji parametrów modelu rozwoju mikrostruktury na podstawie dwuetapowej osiowosymetrycznej próby ściskania. Klasyczna interpretacja wyników tej próby zakłada w strefie odkształcenia jednorodne pole odkształceń, naprężeń oraz temperatury, a parametry modelu są wyznaczane na podstawie pomiarów sił w drugim etapie ściskania. W pracy do oszacowania wartości parametrów zastosowano metodę odwrotną. Wykonano symulacje metodą elementów skończonych oraz wyznaczono lokalne wartości parametrów mikrostruktury uwzględniając nierównomierność odkształcenia. Funkcja celu została zdefiniowana jako odległość Euklidesowa między siłami obliczonymi i zmierzonymi w próbie dwuetapowego ściskania dla różnych długości przerw pomiędzy odkształceniami. Parametry modelu mikrostruktury oszacowano poprzez wyznaczenie minimum funkcji celu. Model z wyznaczonymi parametrami został zweryfikowany w próbie ściskania w płaskim stanie odkształcenia.

1. Introduction

Static recovery and recrystallization play an important role in the design of pass schedules for the controlled rolling, in particular for microalloyed and advanced high strength steels. These softening mechanisms have a significant effect on the final microstructure, and hence the final properties of a hot rolled steel. Beyond this, the grain size at the beginning of microstructure evolution influences their kinetics. In order to optimize the design of controlled rolling schedules, the phenomena of static recovery and recrystallization must be well understood. Numerical modelling is commonly used to support timely and expensive experiments in this research and to design of optimal rolling schedules.

A variety of models dedicated to prediction of microstructure evolution during hot strip rolling were published. Applied solutions vary from fundamental JMAK equation to advanced models, which account explicitly for the material microstructure. Among numerous publications in this field, those based on the fundamental works of Sellars at the University of Sheffield [1,2] should be mentioned in the first group based on JMAK equation. 3-D microstructure evolution model using Representative Volume Element (RVE) and approaches based on the Cellular Automata model [3,4] are examples of the most advanced solutions.

None of these models is general. All models contain coefficients, which have to be determined for each particular material. Whatever the model is used in the analysis, its accuracy and reliability depends on the correctness of determination of these coefficient. This problem has been of interest of scientists for half of the century and various experiments were designed to supply data for identification of the microstructure evolution models.

Two-step compression (often called double hit test) and stress relaxation tests seem to be the most commonly used. The latter method described in [5] is not considered in the present paper. The former seems more frequently used and numerous applications of this method can be found in the

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scientific literature. In 1980-ies several researchers applied this method to develop microstructure evolution model mainly for microalloyed steels. The works of Jonas and his collaborators were particularly valuable [6,7]. During following decades the method was continuously used for identification of microstructure evolution models of new metals and alloys. The most recent applications of this method include steel 300M [8] and steel GCr 15 [9]. Authors of the paper [10] compared stress relaxation and 2 step deformation methods and concluded that stress relaxation tests are less effective in determining the recrystallization behaviour of microalloyed steels. First of all, a very difficult and precise setup and control of the temperature and the deformation system is necessary. This leads to a big difference in recrystallization kinetics when the same test is performed with a different type of equipment. Further, there exists no standard method for analysing relaxation curves that can be used for all types of equipment, at all testing temperatures. Finally, the resulting recrystallization kinetics cannot be compared with results from double deformation. In [10] accelerated kinetics was found when the stress relaxation method was used. Among the several methods developed to determine the fractional softening obtained from double deformation tests, there are two which better separate the effect of recovery and are thus more suitable to describe at an elevated temperature.

2. Models

2.1. Rheological model

Three microalloyed steels were investigated but all results are presented for the steel A containing 0.11%C, 1.95%Mn, 0.95%Si, 0.2%Mo, 0.18%Ti. In the two remaining steels lower content of titanium (0.12%Ti in steel B) and addition of niobium (0.035%Ni in steel C) was used. Identification of the microstructure evolution model using two-step tests requires an accurate evaluation of the flow stress in the second step. Therefore, an advanced flow stress model proposed in [11] and published also in [12] was used:

$$\sigma_p = \sigma_0 + \left(\sigma_{ss(e)} - \sigma_0\right)\left[1 - \exp\left(-\frac{\varepsilon}{\varepsilon_r}\right)\right]^{\frac{1}{2}} - R \qquad (1)$$

where:

$$R = \begin{cases} 0 & \varepsilon \le \varepsilon_c \\ \left(\sigma_{ss(e)} - \sigma_{ss}\right)\left[1 - \exp\left(-\left[\dfrac{\varepsilon - \varepsilon_c}{\varepsilon_{xr} - \varepsilon_c}\right]^2\right)\right] & \varepsilon > \varepsilon_c \end{cases}$$

$$\sigma_0 = \frac{1}{\alpha_0}\sinh^{-1}\left(\frac{Z}{A_0}\right)^{\frac{1}{n_0}}, \quad \sigma_{ss} = \frac{1}{\alpha_{ss}}\sinh^{-1}\left(\frac{Z}{A_{ss}}\right)^{\frac{1}{n_{ss}}},$$

$$\sigma_{sse} = \frac{1}{\alpha_{sse}}\sinh^{-1}\left(\frac{Z}{A_{sse}}\right)^{\frac{1}{n_{sse}}}$$

$$Z = \dot{\varepsilon}\exp\left(\frac{Q_{def}}{RT_{def}}\right)$$

$$\varepsilon_r = \frac{1}{3.23}\left[q_1 + q_2\left(\sigma_{ss(e)}\right)^2\right], \quad \varepsilon_{xr} - \varepsilon_c = \frac{\varepsilon_{xs} - \varepsilon_c}{1.98},$$

$$\varepsilon_c = C_c\left(\frac{Z}{\sigma_{ss(e)}^2}\right)^{N_c}, \quad \varepsilon_{xs} - \varepsilon_c = C_x\left(\frac{Z}{\sigma_{ss(e)}^2}\right)^{Nx}$$

The model contains 16 coefficients, which were determined for the three investigated steels. Axisymmetric compression tests were performed in the temperature range 800°C – 1200°C and at strain rates 0.1, 1 and 10 s^{-1}. Inverse algorithm described in [13] was applied for identification and the values of coefficients obtained for the steel A are given in Table 1.

2.2. FE model

Commercial code Larstran developed at the RWTH Aachen was used in simulations of compression tests. This code is based on the rigid-plastic flow rule:

$$\boldsymbol{\sigma} = \frac{2\sigma_p}{3\dot{\varepsilon}_i}\dot{\boldsymbol{\varepsilon}} \qquad (2)$$

where: $\boldsymbol{\sigma}$, $\dot{\boldsymbol{\varepsilon}}$ - stress and strain rate tensors.

FE simulations supplied information concerning inhomogeneity of strains, stresses and temperatures. Accounting for these inhomogeneities is crucial for the accuracy of identification of coefficients in the microstructure evolution model.

2.3. Microstructure evolution model

Microstructure evolution model was implemented into the FE code using the user procedures. The model was based on adaptation of the JMAK equation proposed in [1,2] as follows:

$$X = 1 - \exp\left(\ln\left(0.5\right)\left[\frac{t}{t_{0.5}}\right]^n\right) \qquad (3)$$

where: n – coefficient, $t_{0.5}$ – time for 50% recrystallization calculated from the equation:

TABLE 1

Coefficients in the phase microstructure evolution determined using inverse analysis

α_0	α_{sse}	α_{ss}	n_0	n_{sse}	n_{ss}	A_0	A_{sse}
0.2787×10^{11}	16.72	0.1209	0.671×10^{12}	1.878	0.0304	0.4684×10^{12}	1.889
A_{ss}	q_1	q_2	C_c	N_c	C_x	N_x	Q_{def}
0.0513	1.0335	0	0.00026	0.0268	0.0048	0.2231	398380

$$t_{0.5} = A\varepsilon^{-a_1}\dot{\varepsilon}^{-a_2}D_0^{a_3}\exp\left[\frac{Q_{RX}}{R(T+273)}\right] \tag{4}$$

where: A, a_1, a_2, a_3 – coefficients, Q_{RX} – activation energy for recrystallization.

The grain size after static recrystallization is described by the following equation:

$$D_{RX} = B\varepsilon^{-b_1}\dot{\varepsilon}^{-b_2}D_0^{b_3}\exp\left[\frac{-Q_D}{R(T+273)}\right] \tag{5}$$

where: B, b_1, b_2, b_3 – coefficients, Q_D – activation energy for grain size.

Microstructure evolution model contains several coefficients, which are identified on the basis of experimental tests. Stress relaxation tests and two step compression tests are most commonly used for that purpose. In the present paper the latter tests were used to determine coefficients in the microstructure evolution model.

3. Experiments

It is well known that compression tests involve strong inhomogeneities of strains, stresses and temperatures. These inhomogeneities make interpretation of the tests and identification of the flow stress and microstructure evolution models a difficult problem. In the former case inverse analysis was applied to eliminate the effect of inhomogeneities and good results were obtained [13,15]. In the latter case researchers are trying to define the representative area in the sample where strains and temperatures are close to the nominal values for the test. The nominal strain is defined as $\ln(h/h_0)$, where h and h_0 are current and initial height of the sample, respectively. The objective of the present work is to apply inverse analysis to the two step compression tests and to eliminate the influence of inhomogeneities in the sample. Two-step tests for axisymmetrical and plane strain samples were considered.

3.1. Plane stain compression tests (PSC)

Character of distributions of strains, stresses and temperatures in axisymmetric samples is well known and is not discusses in this paper. Plane strain compression (PSC) is one of the plastometric tests, which is used for physical simulations of rolling processes. In this test a cuboid sample is compressed between two flat dies [14]. The PSC test allows large plastic deformation and the state of strains is similar to that, which occurs in the flat rolling process. The plane strain state is obtained due to two factors. The low width of the sample–to width of the die ratio prevents flow of the material in the width direction [14]. It is similar to the flat rolling, where low length of contact–to–width of the strip ratio fosters elongation and prevents spread. Influence of the rigid ends is another factor, which constrains spread and involves plane strain state. Rigid ends are the parts of the sample beyond the area under the die. These parts are not compressed, therefore, they do not have tendency to spread. Moreover, when the samples are heated by resistance heating (e.g. on Gleeble 3800) these parts are at lower temperature than the area under the dies and their

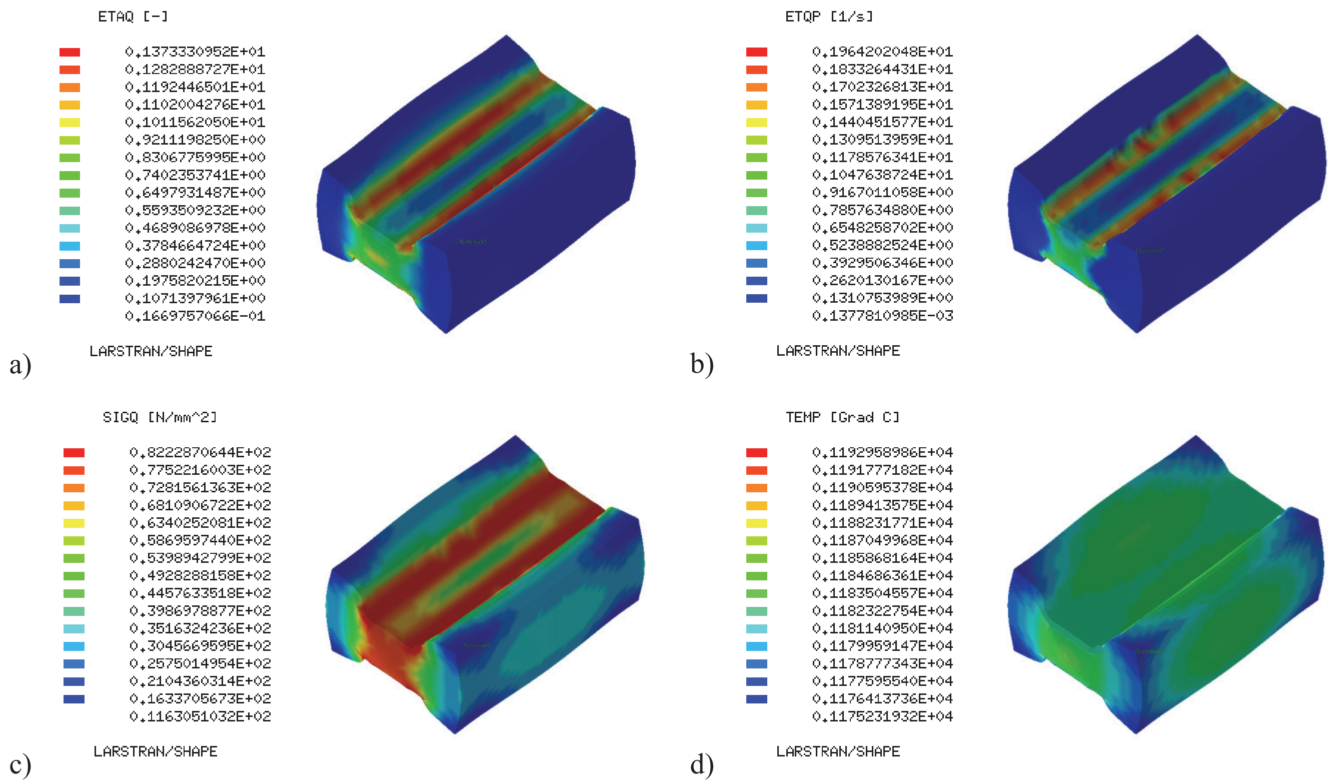


Fig. 1. Selected examples of distribution of strains (a) strain rates (b), stresses (c) and temperatures (d) calculated by the Larstran code in the PSC test.

resistance to deformation is higher. Good practice guide for performing PSC tests is given in [18]. Figure 1 shows selected examples of distribution of strains (a) strain rates (b), stresses (c) and temperatures (d) in the PSC test calculated by the Larstran code. The sample dimensions were 15×20×35 mm and the width of the die was 10 mm. The conditions of the simulated test were temperature 1000°C and strain rate 1 s^{-1}. The plots in Figure 1 confirm that PSC tests are characterized by strong inhomogeneity of all parameters.

3.2. Two stage compression tests

Two stage compression tests were performed. In the first set of experiments axisymmetrical samples measuring ϕ10×12 were compressed with different strains in the first deformation and with different time intervals between the deformations. The first time interval was always the minimum which arise sfrom limitations of the servohydraulic system in particular conditions. Selected plots of forces monitored during the axisymmetrical tests are shown in Figure 2.

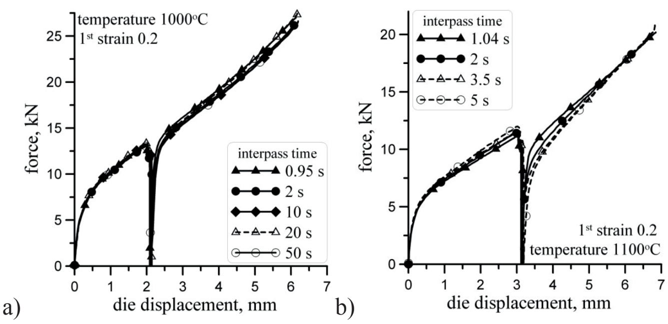


Fig. 2. Selected examples of forces recorded during the 2-step axisymmetrical compression tests for the nominal strain 0.2 in the first step.

Despite the high deformation temperatures, the results presented in Figure 2 show that the deformed material recrystallizes slowly after the deformation. This is caused by the presence of TiN and dynamic precipitation of TiC particles due to the high Ti content in experimental steels.

4. Identification of the microstructure evolution model

4.1. Problem definition

As it has been mentioned, researchers for years have used the procedure, in which representative area for microstructure analysis was selected at the cross section of the sample. Since finite element method enables calculation of local values of strains, stresses and temperatures, this information has been combined with microstructure measurements and identification of microstructure models became more efficient. Compression of cylindrical samples along their diameter is an example of such approach [16]. This test involved strong inhomogeneity of deformation as shown in Figure 3. The samples with the diameter of 4 mm were compressed along their diameter. Due to two axes of symmetry, only a quarter of the deformation zone is shown in Figure 3. It is seen that strains at the cross section vary from zero to maximum strain of about 0.7. Samples were quenched directly after the deformation and the grain size was measured at several locations at the cross section. The recrystallized volume fraction was evaluated on the basis of measurement of recrystallized and nonrecrystallized grains. In consequence one sample supplied several measurement points, at which local values of strains and temperatures were calculated by the FE model.

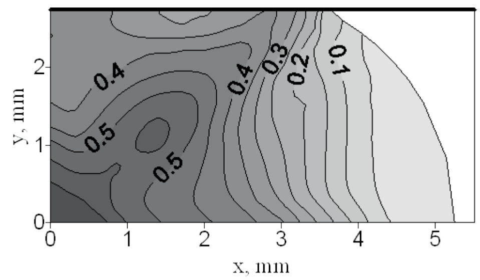


Fig. 3. Effective strain distribution at the cross section of the sample compressed along its diameter.

Described method allowed to decrease noticeably the costs of identification of the microstructure evolution model. The solution proposed in the present paper takes advantage from much larger power of today computers and it uses the inverse solution for the two stage compression tests.

4.2. Inverse problem

The problem of identification is the classical inverse task. The basis of ill-posed inverse problems and regularization for modelling of thermomechanical plastic processes are presented in [17]. The mathematical model describing microstructure evolution presented in the section 2.3 was included in the Larstran FE code in each Gauss point. The macro parameters, strain and temperature, were transferred to micro model to calculate microstructure evolution. Strain corrected according to the value of recrystallized volume fracture is returned in the reverse direction. Thus, the direct model of the two-step compression experiment consists of thermomechanical, thermal and once again thermomechanical FE models. To estimate the microstructure parameters: n, A, a_1, a_2, a_3, Q_{RX}, the experiments were performed for various temperatures, strain rates and times between compression stages. Due to complex mathematical model of the test and ill-posedness if the inverse identification problem, the problem was transformed to optimization task and the objective function was defined as:

$$\Phi(\mathbf{x}) = \sqrt{\sum_{i=1}^{N}\sum_{j=1}^{M_i} \omega_{ij}\left[F_{ij}^{c}(\mathbf{x}) - F_{ij}^{m}\right]^2} \qquad (6)$$

where: $\mathbf{x} = [n, A, a_1, a_2, a_3, Q_{RX}]^T$ is the vector of optimized parameters, F_{ij}^{c}, F_{ij}^{m} are the calculated (index c) and measured (index m) loads in the i^{th} test at the j^{th} test time step, ω_{ij} are weighted coefficients, N is the number of tests, M_i is the number of sampling points in the i^{th} test.

Forces in the second pass only are considered in function (6). To identify components of the **x** vector, the function (6) is minimized.

4.3. Sensitivity analysis

Sensitivity analysis was performed to estimate how the variation of the coefficients in the microstructure evolution model influence the objective function (6) defined in the inverse problem and to support the efficiency of the minimization procedure. The local sensitivity index ξ_i, $i \in \{n, A, a_1, a_2, a_3, Q_{RX}\}$ for each parameter was defined as follows:

$$\xi_i = \frac{\left|\Phi(\mathbf{x}+\Delta_i) - \Phi(\mathbf{x})\right|}{\Phi(\mathbf{x})} \tag{7}$$

where: $\Phi(\mathbf{x})$ is the objective function (6) calculated for selected microstructure model parameters gather in vector **x**, $\Phi(\mathbf{x}+\Delta_i)$ is the objective function calculated for the ith disturbed parameter.

The calculation of ξ_i were carried out for vector **x** generated with Latin hyper cube procedure and for various values of Δ_i. To compare indexes ξ_i for all microstructure model parameters they were normalized $\tilde{\xi}_i = \xi_i / \|\boldsymbol{\xi}\|$, where the components of vector $\boldsymbol{\xi}$ are ξ_i. The results of the analysis, mean local sensitivity indexes for all parameters, are presented in Figure 4.

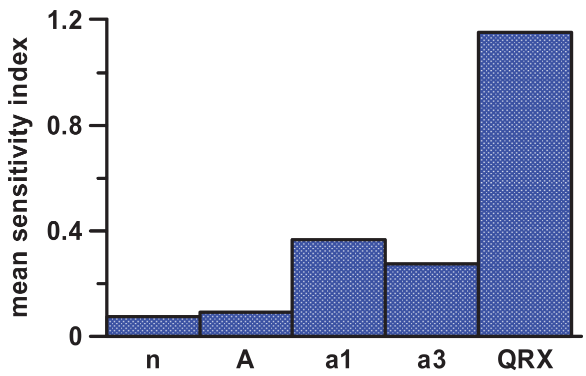


Fig. 4. Mean sensitivity indexes of the objective function (6) with respect to parameters in the microstructure evolution model.

The parameter Q_{RX}, which is the activation energy for recrystallization, influences the objective function (6) the most. It means that the loads measured during the multistage compression test are the most dependent on Q_{RX}. Parameters a_1 and a_3, which are exponents at strain and initial grain size are the other crucial parameters. Contribution of remaining parameters to control of the objective function in smaller.

4.4. Conventional approach to identification of the microstructure evolution model

There are few conventional techniques used to evaluate the rate of softening. The offset method employs the following definition:

$$X = \frac{\sigma_m - \sigma_2}{\sigma_m - \sigma_1} \tag{8}$$

where: σ_m - the flow stress corresponding to the unloading strain in the first hit (Figure 5), σ_1, σ_2 - the offset yield stresses in the first and second hits, respectively.

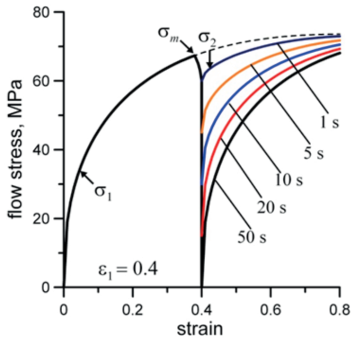


Fig. 5. Typical true stress-true strain curves in the two-step compression for different interpass times.

The following definition of the softening is used for the back extrapolation method:

$$X = \frac{\sigma_m - \sigma_{BE}}{\sigma_m - \sigma_1} \tag{9}$$

where: σ - value of stress for which average value is calculated, σ_{BE} - stress corresponding to the intersection of the vertical or loading line with the prestraining curve after it has been superimposed on the reloading curve, ε_1, ε_2 – strains between which the average stress is calculated.

Calculation of the softening fraction is made using the following formula:

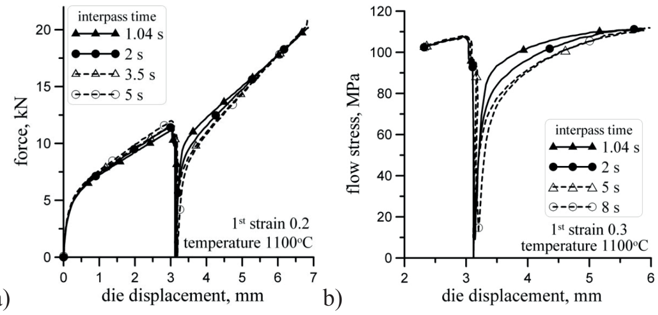
$$X = \frac{\overline{\sigma}_m - \overline{\sigma}}{\overline{\sigma}_m - \overline{\sigma}_0} \tag{10}$$

where: $\overline{\sigma}_m$ - value of average stress for curve continuation to the second deformation (dotted line in Figure 5), $\overline{\sigma}_m, \overline{\sigma}_0$ - value of average stress for curves in the first and the second deformation.

Data needed for calculation of the softening parameter using the offset method and the back extrapolation method, based on equations (8) and (9), respectively, can be easily acquired from the recorded stress-strain data. Contrary, the data from the stress-strain curves needed for the evaluation of the softening parameter on the basis of the overall level of the flow curve, equation (10), requires average values of stresses. Maximum mean stress in the second hit, which is proportional to the area under the dotted line in Figure 5 for the strain above $\varepsilon_1 = 0.4$, is needed. Similarly, values of the average stress for curves in the first and the second deformation, require calculation of the area under the stress-strain curve in relevant intervals of strains 0 – 0.4 and 0.4 – 0.8. Thus, numerical integration of the stress-strain curves is needed to calculate the softening parameter from equation (10). Whatever the method of calculation of the softening parameter is used, it does not account for the inhomogeneity of deformation and for the local influence of the recovery. Therefore, the inverse method was applied in the present paper.

4.5. Inverse approach to identification of the microstructure evolution model

Identification of the microstructure evolution model using inverse method was carried out in two steps. In the first step identification of the flow stress was performed using the inverse algorithm described in [13]. Figure 6 shows flow stress as a function of strain obtained from the inverse analysis for the two-step axisymmetric compression.



a) b)

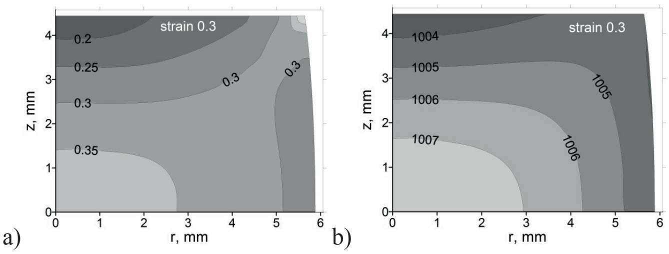
Fig. 6. Flow stress in the two-step compression obtained from the inverse analysis of the tests

Coefficients in the microstructure evolution model determined using inverse analysis are given in Table 2. To validate the model simulations of the two-step compression were performed using FE code with the attached microstructure evolution model. Kinetics of recrystallization during the interpass time was calculated in each Gauss integration point and the strain at the beginning of the second step was calculated on the basis of the current, local value of the recrystallized volume fraction:

$$\varepsilon_r = \varepsilon A_r \left(1 - X\right) \tag{11}$$

where: A_r – coefficient accounting for the effect of the recovery, which in the present work was assumed 1, ε - local effective strain at the end of the first step, ε_r - local effective strain at the beginning of the second step, X - local recrystallized volume fraction.

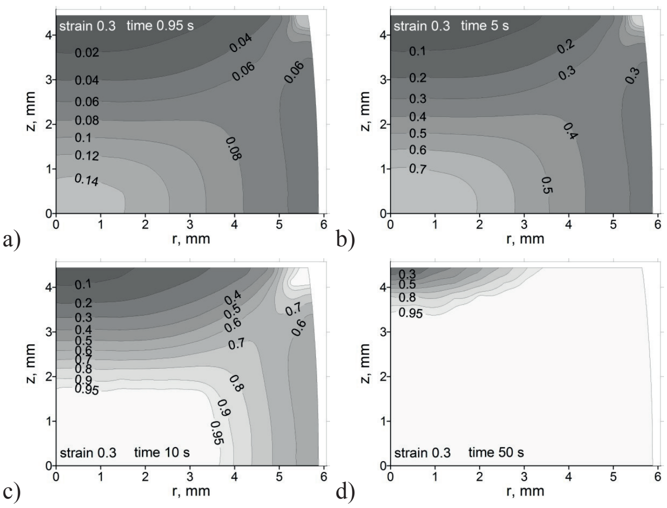
The inverse approach allows to account for the inhomogeneity of deformation and temperature (Figure 7), which results in the inhomogeneity of the kinetics of recrystallization in the volume of the sample. The nominal temperature is the uniform temperature to which the sample is heated before the test. Coefficients in the microstructure evolution model obtained by searching for the minimum of the objective function are given in the first row of Table 2. Values of these coefficients determined using offset method are given in the second row of this table. Different values were obtained for the coefficients n, A, a_1, and Q_{RX}. Negligible difference was obtained for the coefficients a_2 and a_2, which was due to lack of experimental data in a wide range of the strain rate and the grain size.



a) b)

Fig. 7. Distribution of strains (a) and temperature (b) for the nominal strain of 0.3 and the nominal temperature of 1000°C

Inhomogeneity of the kinetics of recrystallization is well seen in Figure 8 where distribution of the recrystallized volume fraction after different time intervals are shown. Due to two axes of symmetry only a quarter of the cross section of the sample is presented in Figure 7 and Figure 8. The results in these figures were obtained for the nominal temperature of 1000°C and the nominal strain in the first step of 0.3. Similar inhomogeneity was observed in simulations of the all remaining tests.



a) b) c) d)

Fig. 8. Distribution of the recrystallized volume fraction at the cross section of the sample after different interpass times (r, z – cylindrical coordinates)

5. Verification and validation of the model

To verify the model the forces calculated for the second step were compared with the measurements in the experiments. Selected examples of this comparison are shown in Figure 9 and Figure 10. Local softening of the material during the interpass time was accounted for by calculation of strain at the beginning of the second step using equation [11].

TABLE 2

Coefficients in the microstructure evolution model determined using inverse analysis

Method	n	A	a_1	a_2	a_3	Q_{RX}
inverse	1.87	1.903×10^{-11}	-3.597	-0.3	0.7075	206000
offset	1.7	1.738×10^{-11}	-3.269	-0.3	0.7075	207200

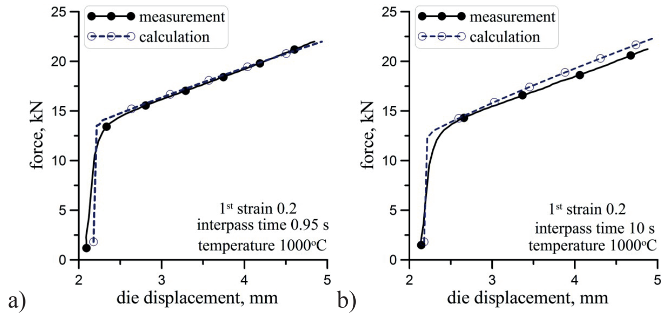


Fig. 9. Selected examples of comparison of forces in the second step measured in the experiment (filled symbols) and calculated using microstructure evolution model (open symbols) with coefficients in Table 2 – nominal temperature of the test 1000°C

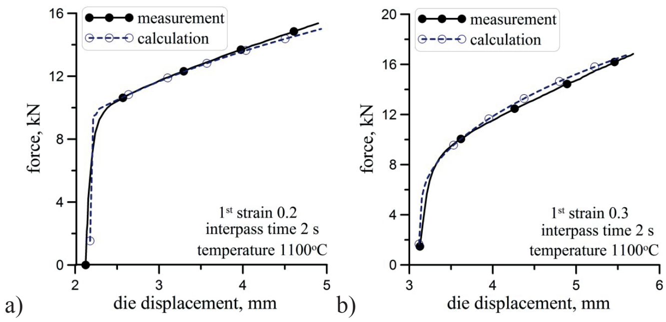


Fig. 10. Selected examples of comparison of forces in the second step measured in the experiment (filled symbols) and calculated using microstructure evolution model (open symbols) with coefficients in Table 2 – nominal temperature of the test 1100°C

Simulations of the multistep PSC test were performed to validate the model and to evaluate its performance in extremely non uniform conditions. The samples measuring 15×20×35 mm were compressed in a die with the width of 10 mm. Results of calculations are presented at the cross section of the sample after the first pass. Figure 11 shows distribution of strains and temperatures at the end of the first pass. Figure 12 shows distribution of the recrystallized volume fraction at the cross section of the PSC sample after various interpass times. Due to two axes of symmetry only a quarter of the cross section is shown in this figure.

Analysis of results in Figure 11 and Figure 12 shows that deformation is much more inhomogeneous that it was seen in the axisymmetric test. Even after the interpass time of 50 s large not recrystallized areas are seen, not only in the rigid ends what is obvious but also under the die. It means that this test should be always used in connection with the FE simulation.

Calculation time for one two-step experiment for axisymmetric test (2D model) using in-house FE code lasted 3 minutes and it was much shorter than for the PSC test (3D model) using Larstran software, which took 10 minutes. Computations were performed on the computer with Intel® Core™ i7-4770 CPU and 16 Gb of RAM. Determination of one value of the objective function (6) for the experiments investigated in the present paper required 36 runs of the FE code. It means that using PSC test combined with the inverse analysis would require unacceptably long computing time. Thus, axisymmetric test is recommended for identification of the microstructure evolution model and PSC test is recommended for the physical simulation of multi-pass industrial processes.

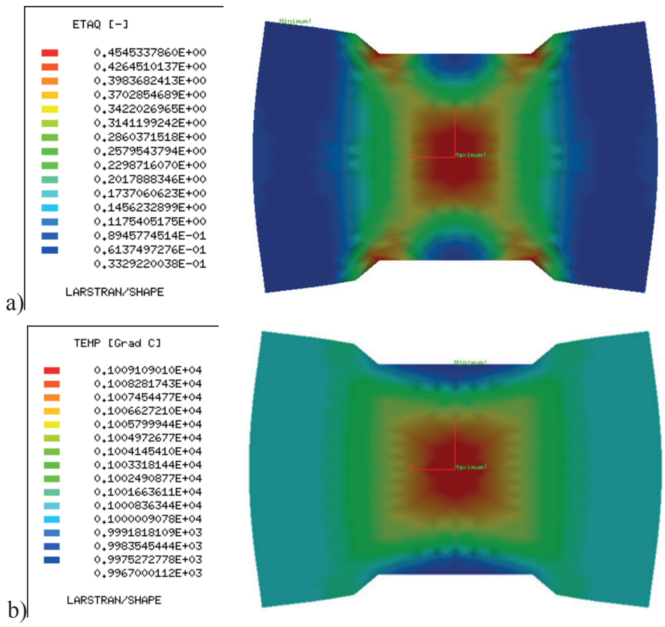


Fig. 11. Distribution of effective strains (a) and temperatures (b) at the end of the first pass.

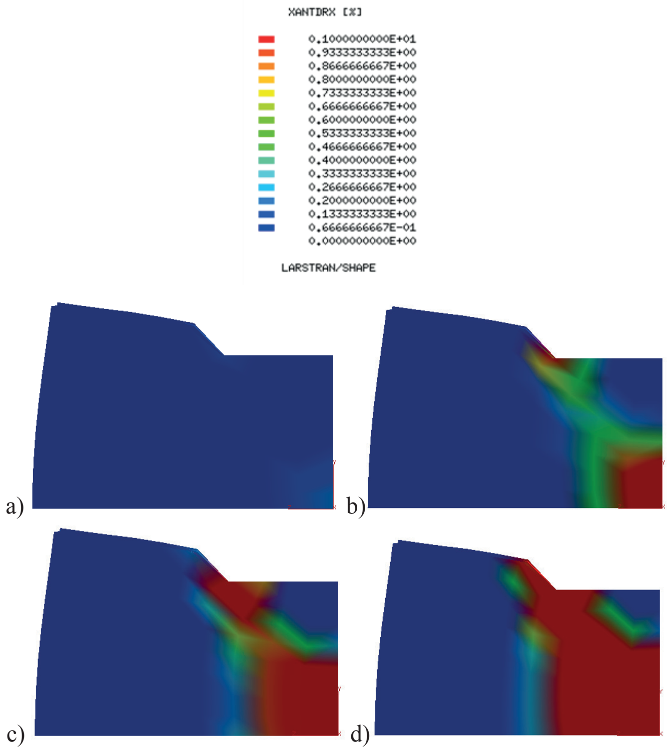


Fig. 12. Distribution of the recrystallized volume fraction at the cross section of the PSC sample after the interpass time of 0.95 s (a), 5 s (b), 10 s (c) and 50 s (d)

6. Conclusions

Identification of microstructure evolution models is a difficult task, which requires costly experiments. Beyond this, interpretation of these experiments is difficult. In the case of the two-step test classical methods of interpretation are based on the analysis of the flow stress in the second step. This requires calculation of the flow stress from the measured loads. There are many sources of errors in this technique. Inhomogeneity of deformation is the main source. Determination of characteristic points from the experimental curves is another reason of errors. Therefore, a new technique based on the inverse analysis was proposed in the paper. Performed analysis and numerical tests allowed to draw the following conclusions:

- The inverse method is insensitive to inhomogeneity of strains, stresses and temperature.
- Simulations have shown that kinetics of the recrystallization may vary significantly in the volume of the sample.
- Numerical tests confirmed good accuracy of the proposed method.
- Sensitivity analysis has shown that activation energy of recrystallization is a crucial parameter of the microstructure evolution model and it has large impact on loads observed at a multistage compression test.
- Due to much shorter computing times, axisymmetric test is recommended for identification of the microstructure evolution model. PSC test requires much longer computing times and it is recommended for the physical simulation of multi-pass industrial processes.
- The number of experimental tests needed to determine coefficients in the model is the same in the inverse analysis as in the classical methods.

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