ARCHIVES OF METALLURGY AND MATERIALS
Volume 50 2005 Issue 2

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MODELING OF THE COLD ROLLING TEXTURE FORMATION IN TWO- PHASE MATERIALS USING THE FINITE ELEMENT METHOD

MODELOWANIE ROZWOJU TEKSTURY W WALCOWANYCH NA ZIMNO MATERIAŁACH DWUFAZOWYCH Z ZASTOSOWANIEM METODY ELEMENTÓW SKOŃCZONYCH

The paper presents the possibility of applying the finite element method to predict the crystallographic texture development in the cold rolled materials. The calculations were carried out using the finite element code Abaqus in conjunction with the user subroutine Vumat. The orientations deviated from positions characteristic for cold rolled FCC and BCC materials were tested. The results for various sample regions are presented as the mean orientations.

Keywords: texture, simulation, FEM, multiphase materials.

W pracy przedstawiono możliwość zastosowania metody elementów skończonych w celu przewidywania rozwoju tekstury krystalograficznej w materiałach poddanych walcowaniu na zimno. Obliczenia wykonano z użyciem pakietu Abaqus w połączeniu z opracowanym podprogramem Vumat. Testowano zmiany orientacji odchylonych od położeń charakterystycznych dla tekstur walcowania na zimno w fazach o sieci RPC i RSC. Wyniki przedstawiono w postaci orientacji średnich z różnych obszarów próbki.

1. Introduction

In the last years one could observe increased interest in the finite element method with respect to using it for crystallographic texture prediction. This follows from its advantages such as: good projection of the stress and strain state (elimination of the simplifications of the Sachs and Taylor models) and assuring of the material continuity (which is very important in multiphase materials modelling). In the publications one can find several proposals of FEM application to texture development modelling

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[1-8]. Most proposals are based on the Taylor model and its further modifications demonstrating good agreement with the experimental data. In this context an attempt to prepare a model based on Leffers and Wierzbanowski model [9, 10, 11] has been made with the aim of texture prediction in the two-phase material.

2. Calculations

The cold rolling process (Fig.1) of a sample with the dimensions 20×25×50mm and composed of four alternately arranged layers, having FCC or BCC structure (Fig.2), was performed using FE-code Abaqus. When considering the symmetry in the rolling and the transverse planes, the modelled sample makes $^1/_4$ of a real rolled billet. The roll was modelled as a rigid body. The assumed parameters of the rolling process are:

- total reduction 30%
- sample velocity 1m/s
- roll velocity 4 rad/s
- roll diameter 500 mm
- friction coefficient 0.25

Using the prepared user subroutine Vumat the crystallographic orientation changes were calculated. It was assumed that one finite element corresponds to one crystallite. Each crystallite of a given phase has the same initial orientation at the start of the process.

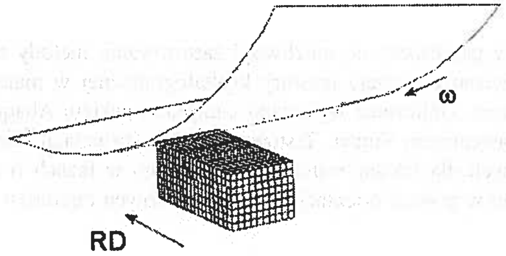

Fig. 1. The sample and the rigid roll

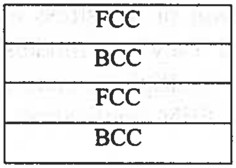

Fig. 2. Distribution of phases in the tested sample

The choice of the active slip system was made on the basis of the maximal shear stress criterion (Schmid-Boas law):

$$\tau_{\mathrm{active}} = \tau_{\max}. \tag{1}$$

The change of orientation was calculated using the well known expressions [12]:

$$\begin{gathered}\Delta\varphi_1 = \frac{\sin\varphi_2}{\sin\Phi}r_1 + \frac{\cos\varphi_2}{\sin\Phi}r_2\\ \Delta\phi = \cos\phi_2 r_1 - \sin\phi_2 r_2\\ \Delta\varphi_2 = \frac{\sin\varphi_2}{\sin\Phi}r_1 + \frac{\cos\varphi_2}{\sin\Phi}r_2 + r_3,\end{gathered} \tag{2}$$

where:

$$r_k = -\frac{1}{2}(e^e_{ij} - e^e_{ji}) \tag{3}$$

are components of the rotation vector r, and:

$$e^c_{ij} = \gamma R_{ij,n}, \tag{4}$$

where: γ — is shear deformation for one slip event [9],
e_{ij} — deformation gradient

$$R_{ij}, n = m^n_i \ p^n_j \tag{5}$$

where: m^n_i and p^n_j are slip direction and slip plane normal of the n-th slip system. The twelve slip systems <110>{111} for the FCC phase and forty eight slip systems: <111>{110},<111>{112} and <111>{123} for the BCC phase were assumed. The isotropy of the material was assumed for the stress calculations (based on the Mises theory)[13].

3. Results

The stress and strain distributions (Fig.3, 4) and the orientations in a rolled sample were obtained . The results are presented as the mean orientation in the "fibres" containing 20 finite elements. Positions of the "fibres" are shown in Fig 5. Because the sample makes $^1/_4$ of a real billet, the "fibres" numbered 5,6,7 and 8 represent the central area of the billet, "fibres" numbered 1,2,3 and 4 represent the flank of the billet.

Table 1 shows the calculated mean orientations for the FCC phase.

The calculated mean orientations for the BCC phase are shown in table 2.

In order to reveal the influence of the neighbourhood on the orientation changes an additional test was performed. Two cases for both the FCC ("fibre" No 3, Fig.5) and the BCC ("fibre" No 2, Fig.5) phases were analysed:

a) the neighbour is the same phase,

b) the neighbour is a different phase. The results of the test are given in tables 3 and 4.

TABLE 1

Orientations for the FCC phase (see Fig. 5)

Tested orientation (hkl)[uvw] $\{\varphi_1\ \phi\ \varphi_2\}$	Initial orientation, (in Euler angles),[°]	Final mean orientation, (in Euler angles),[°]	No. of el. set (Fig.5)	Position of the tested region in the sample	
$(011)[2\bar{1}1]$ $\{35\ 45\ 0\}$	30 40 5	35.7 42.1 - 4.8	1	surface	flank
		35 38 0.2	3	middle	
		34.3 41 0.2	5	surface	center
		34.7 42.7 -4.9	7	middle	
$(110)[001]$ $\{90\ 90\ 45\}$	85 85 40	86.4 90 42.2	1	surface	flank
		85.7 88 41.3	3	middle	
		85.9 88.6 41.4	5	surface	center
		86.2 89.3 41.8	7	middle	
$(112)[\bar{1}\bar{1}1]$ $\{90\ 35\ 45\}$	95 30 50	89.1 33.3 49	1	surface	flank
		91 32.1 45.7	3	middle	
		90.5 33.2 48	5	surface	center
		88 32.2 50.2	7	middle	
$(213)[\bar{3}\bar{6}4]$ $\{59\ 37\ 63\}$	54 32 58	57.5 36.1 58.2	1	surface	flank
		56.4 35.8 57.8	3	middle	
		57.2 36.4 57.9	5	surface	center
		56.8 35.2 58.4	7	middle	

TABLE 2

Orientations for the BCC phase

Tested orientation (hkl)[uvw] $\{\varphi_1\ \phi\ \varphi_2\}$	Initial orientation, (in Euler angles),[°]	Final mean orientation, (in Euler angles),[°]	No. of el. set (Fig.5)	Position of the tested region in the sample	
$(001)[1\bar{1}0]$ $\{0\ 0\ 45\}$	10 15 35	-2.9 14.7 51	2	near surface	flank
		0.7 14.9 47	4	middle	
		-5 14.7 47.3	6	near surface	center
		-4.2 14.8 47.5	8	middle	
$(112)[1\bar{1}0]$ $\{0\ 35\ 45\}$	10 30 35	3.2 29.5 45.4	2	near surface	flank
		5.1 29.8 42.5	4	middle	
		1.9 29.7 46.7	6	surface	center
		1.5 29.9 46.7	8	middle	
$(111)[\bar{1}\bar{1}0]$ $\{0\ 55\ 45\}$	10 45 35	5.1 44.6 44.7	2	near surface	flank
		6.3 44.7 43.9	4	middle	
		3.7 44.6 45.4	6	near surface	center
		3.5 44.8 46.2	8	middle	

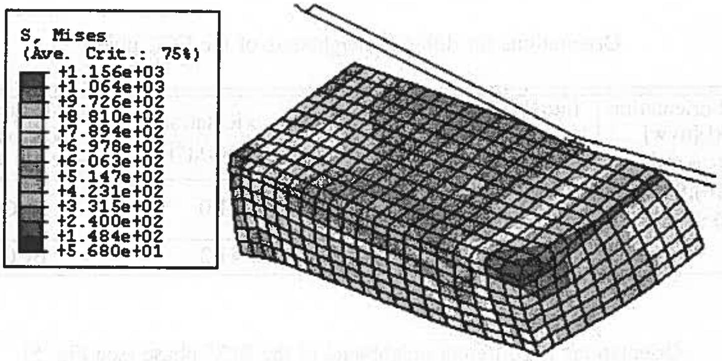

Fig. 3. Mean stress distribution [MPa]

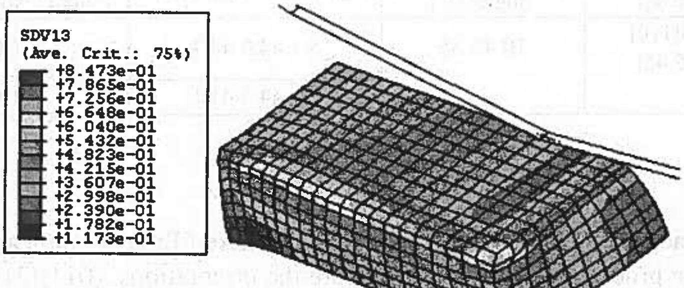

Fig. 4. Equivalent plastic strain distribution

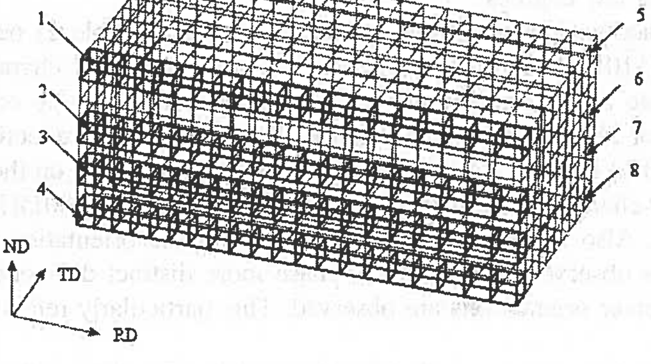

Fig. 5. Positions of the tested "element fibres"

TABLE 3

Orientations for different neighbours of the FCC phase

Tested orientation (hkl)[uvw] $\{\varphi_1\ \phi\ \varphi_2\}$	Initial orientation, (in Euler angles),[°]	Final mean orientation, (in Euler angles),[°]	Neighbourhood of FCC phase ("fibre" No 3, Fig. 5)
(110)[001] {90 90 45}	85 85 40	85.7 87.5 41.0	FCC
		85.7 88.0 41.3	BCC

TABLE 4

Orientations for different neighbours of the BCC phase (see Fig. 5)

Tested orientation (hkl)[uvw] $\{\varphi_1\ \phi\ \varphi_2\}$	Initial orientation, (in Euler angles),[°]	Final mean orientation, (in Euler angles),[°]	Neighbourhood of FCC phase ("fibre" No 2, Fig. 5)
$(111)[1\bar{1}0]$ {0 55 45}	10 45 35	5.1 44.6 44.7	FCC
		5.1 44.5 41.1	BCC

4. Discusion

Four characteristic orientations for the FCC phase (Table 1) indicated as stable in the cold rolling process were tested. These are the orientations: $(011)[2\bar{1}1]$, $(110)[001]$, $(112)[\bar{1}\ \bar{1}1]$ and $(213)[\bar{3}\ \bar{6}4]$.

The direction of changes of the deviated orientations is in agreement with the predictions. The dependence of orientation on the position in the sample is observed. Small differences between the flank and the center orientations are visible. The calculated orientations fluctuate arround the stable positions with small deviations. Only in some cases the deviated orientations do not attain the stable positions or deviate behind it up to a few degrees.

Three characteristic orientations for the BCC phase (Table 2) occuring in α_{BCC} — fibre: $(001)[1\bar{1}0]$, $(112)[1\bar{1}0]$ and $(111)[1\bar{1}0]$ were tested. A characteristic feature of changes in the tested orientations is their tendency towards the orientations from α_{BCC} — fibre, at almost unchanged ϕ angle. With the rolling reduction greater than the assumed (30%) one can expect that after attaining a position on the α_{BCC} — fibre, there will occur changes towards its distinguished orientations: $(001)[1\bar{1}0]$, $(112)[1\bar{1}0]$ and $(111)[1\bar{1}0]$. Also in this case the dependence of the orientation on the position in the sample is observed. For the BCC phase more distinct differences between the flank and the center orientations are observed. This particularly refers to the φ_1 angle (Table 2).

The additional tests have revealed that the neighbourhood has influence on the final texture (Tables 3, 4). A change of the neighbour phase (which has different mechanical properties) has also influence on the stress and strain distribution. As a result the final orientation is also changed.

5. Conclusions

The possibility of applying the finite element method to predict texture development in two-phase materials is presented.

FE–code program Abaqus with the user subroutine Vumat (which introduces the deformation model and calculates the orientation changes) was used in the investigations. The advantages of the application of the Abaqus code are as follows:

1) the phases having different mechanical properties can be arranged arbitrarily inside the tested sample,

2) possibility of analysis of the properties changes (including the orientations changes) depending on the position in the sample,

3) preservation of the material continuity in the sample volume allows to consider the influence of the neighbourhood on the investigated area (which is very important in multiphase materials).

The proper tendency of the orientation changes towards the characteristic stable orientations in the cold rolling process was observed.

The influence of the neighbourhood (changes in the neighbourhood of FCC and BCC phases) on the final orientation was found. This influence is small, but a rolling reduction of the sample is only 30% and the tested two-phase material model is simplified.

The final orientation dependence on the position of the "fibre" in the sample was observed. The orientation differences occur depending on the distance from the rolling plane and between the flank and the center of the tested sample.

The results of investigations indicate that FEM can be succesfully used to tracking the orientation changes during plastic deformation of multiphase materials.

The calculations were made in ACK Cyfronet AGH (KBN/SGI2800/WSP/037/2002)

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Received: 21 March 2005.