Publishing House
AKAPIT

COMPUTER METHODS IN MATERIALS SCIENCE
Informatyka w Technologii Materiałów

Vol. 7, 2007, No. 2

COMPARISON OF 3D AND 2.5D FINITE ELEMENT SIMULATION PRINCIPLES FOR ROLLING IN GROOVES MODELING

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Abstract

The paper deals with comparison of 3D and 2.5D finite element simulation principles using modeling of round shape billet rolling as an example. The results of simulation based on both methods are presented. The deformation fields as well as calculated geometric parameters of the billet and assessment of error are considered.

Key words: FEM, 3D, 2.5D, rolling, comparison, Forge, SPLEN, mathematic simulation

1. INTRODUCTION

A major term of highly productive functioning of rolling mill is a properly realized roll pas design, which allows to get a finished profile according to required dimensions, surface roughness and uniform mechanical properties along the length and the width of the billet. The objectives of the technology design include implementation of rolling with the least disbursement of rollers and energy, as well as minimal rolling time, elimination of manual labor and make the rolling process automated and mechanized as much as possible. When selecting the approach of forming process simulation it is necessary to take into account the specific character of the concerned problem. This allows minimizing the computing time and computer resource by using some specific mathematic simplifications. So-called 2.5D method allows using several hypotheses to achieve the frequentative reduction of computing costs and, at the same time, to avoid critical sacrifice of accuracy.

2. MATHEMATIC MODEL

The solution of three-dimensional task means that in adjusted boundary conditions in each point of considered body (*x, y, z*) and in each point of time the following velocity vector have to be found:

$$\begin{Bmatrix} v_x(x,y,z) \\ v_y(x,y,z) \\ v_z(x,y,z) \end{Bmatrix}. \tag{1}$$

Full computing realization of three-dimensional velocity field retrieval leads to necessity of a lot of computing operations, which even in modern level of computer engineering development require a lot of time. The 2.5D principle allows to reduce the time of calculation, by specified one of the velocity components in closed form. As applied to rolling process, this implies that following hypothesis should be accepted. Lets in the Cartesian coordinate system *xyz*, with z-direction being the rolling direction, assume that in each section of deformation zone by *z*-orthogonal plane the distribution of strain rate in direction of rolling is constant. This supposition lets us to implement the retrieval of particle transfer velocity in each section in the following form:

$$\begin{Bmatrix} v_x(x,y) \\ v_y(x,y) \\ Cz \end{Bmatrix}, \tag{2}$$

ISSN 1641-8581

where C = Const.

Consequently we able to construct the three-dimensional model of billet deflected mode by joining up the set of 2D solutions in control sections. Detailed consideration of 2.5D principles is presented by the authors in papers [2-4]. Ibidem described the computer software SPLEN(Rolling) developed on the basis of this method. Rolling in grooves is analyzed in the present paper. The comparison of results of simulations obtained from the 2.5D method in the program SPLEN(Rolling) and results of three-dimensional finite element analysis of the same process using Forge 3 code is presented.

3. CONDITIONS OF THE SIMULATION

Investigated process is a final part of the rolling of the round billet in 25 passes. The two last passes (24 and 25) have been simulated. The pause before rolling in 24th pass is large enough to assume that the grain recovery was completely finished and the retained strain in the billet is zero. Input billet shape in 24-th pass is round stock with the diameter of 25 mm. The groove design and stock in both passes are shown in figures 1 and 2.

The following equation has been used for description of material plastic properties:

$$\sigma = A\exp(\alpha_1 T)\varepsilon^{\alpha_2}\dot{\varepsilon}^{\alpha_3}\exp\left(\frac{\alpha_4}{T}\right), \quad (3)$$

where: σ - stress, ε - strain, $\dot{\varepsilon}$ - strain rate, T - temperature; $A = 927.92706$, $a_1 = -0.00234$, $a_2 = -0.12626$, $a_3 = 0.13938$, $a_4 = -0.0477$.

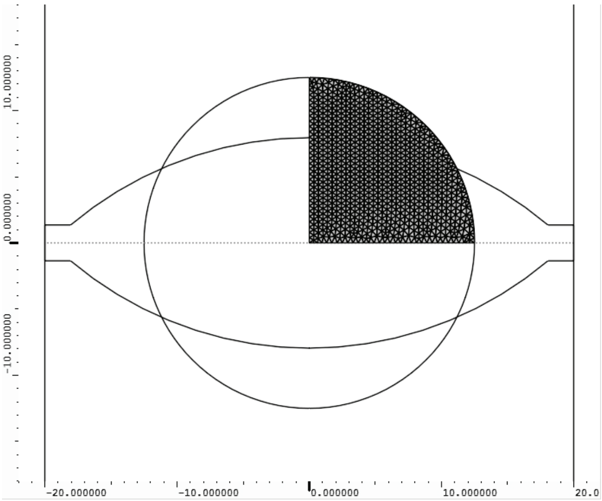


***Fig. 1.** The initial billet section and roller profile for 24th pass.*

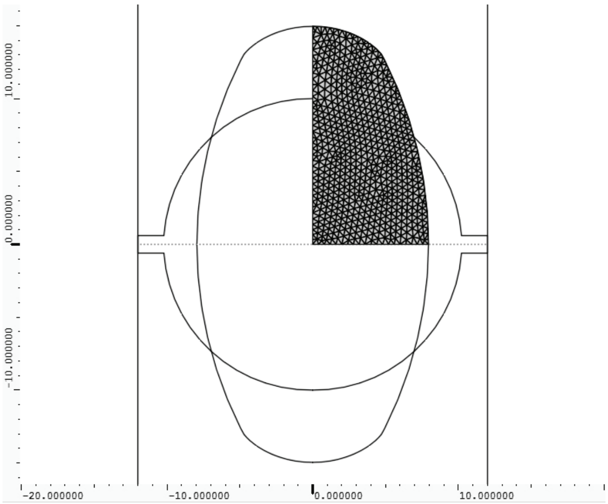


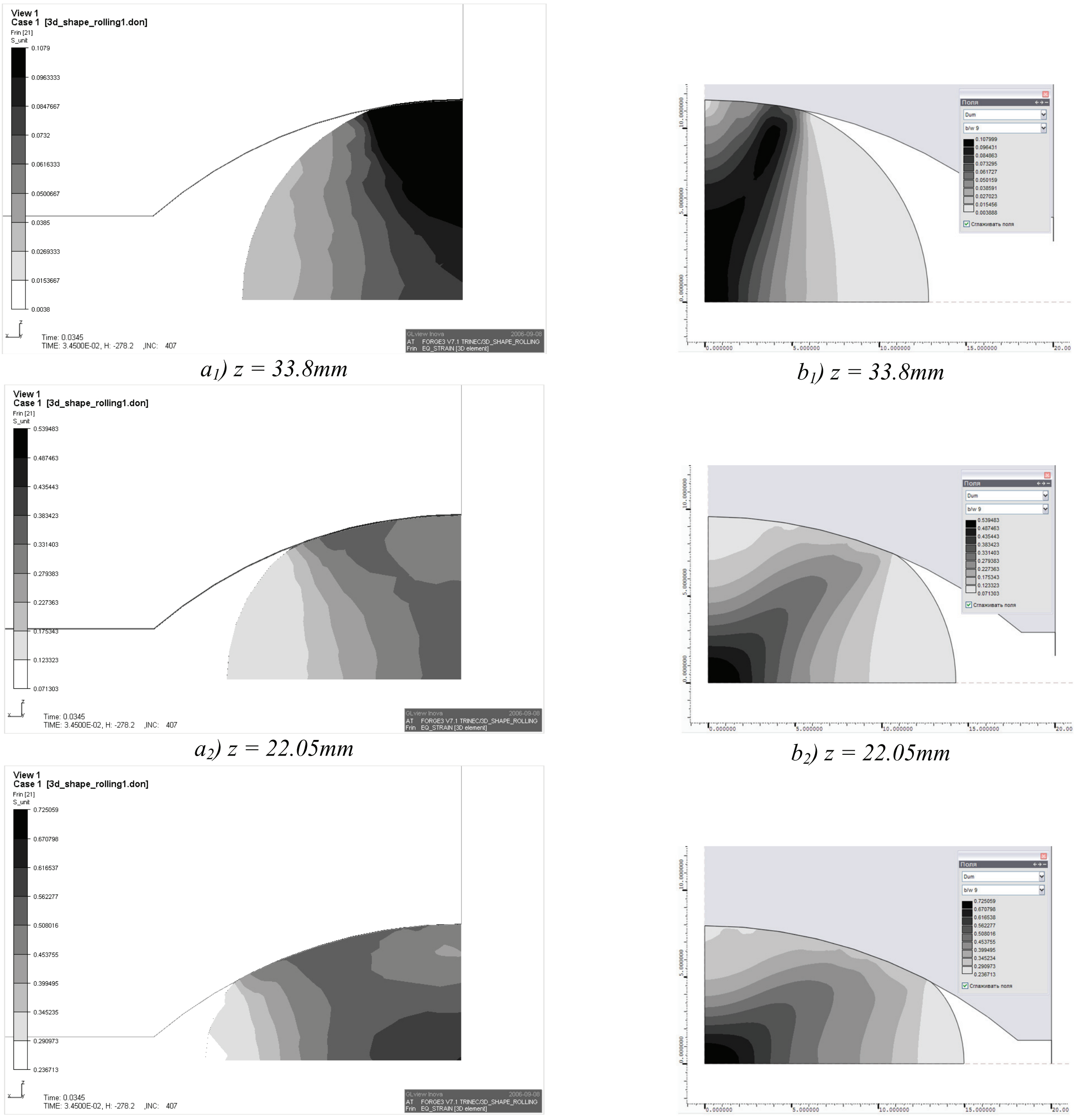
***Fig. 2.** The initial billet section and roller profile for 25th pass.*

Previous investigations [1] show that influence of temperature distribution on forming parameters in this process is sufficiently small so we could neglect it. Since the main objective of this work is a comparison of predictions of billet geometrical parameters evolution during the rolling, the temperature distribution have been not accounted for. The temperature of the billet was considered constant equal to 850°C.

4. THE RESULTS OF CALCULATION

Predictions of billet forming, as well as deformation and stress fields of stock and torque power limit, have been received as a result of modeling. It is significant that the computation time of this task by using 3D finite-element model was mach longer (20 times more) than the time required to simulate the process using 2.5D method.

The fields of effective strain distribution obtained using both methods for the 24th pass were considered for further comparison. The effective strain fields in the three sections of deformation zone in the 24-th pass are presented in figure 3. As a result of comparison it is obvious that received values of the effective strain at the cross sections are in agreement with each other by absolute values. At the same time nevertheless we could see sum differences in the characteristics of distribution, in particular the field calculated using 3D finite element method is more uniform. Values of the effective strain in the centre of the billet obtained by the 3D simulation are smaller than respective values obtained from the 2.5D method. On the other hand, an opposite effect is observed in contact zones – the values of the 3D model are higher than those of the 2.5D model. This feature can bee explained by specific feature of the 2.5D method, namely, the assumption of constant distribution of strain rate in direction of rolling at cross sections. This assumption is a basis of the 2.5D method. The errors due to this approach are usually important at early stages of the pass, when the contact zone is relatively small.



a₁) z = 33.8mm   *b₁) z = 33.8mm*

a₂) z = 22.05mm   *b₂) z = 22.05mm*

a₃) z = 0.0mm   *b₃) z = 0.0mm*

Fig. 3. *The intensity of deformation field in different sections of the 24th pass deformation zone obtained from the 3D finite element model (a) and from the 2.5D method (b).*

The plot of the billet width along the *z* coordinate in deformation zone obtained calculated by both methods are considered for comparison of geometrical parameters. Graphs representing billet spread obtained for 24th and 25th passes are shown in figures 4 and 5, respectively.

The analysis of the results shows that the width of the billet at the point of contact between the billet and the roll received from the 2.5D model is smaller than respective value from the 3D finite element analysis. This is explained by the fact that deformation of the billet begins even before it enters into roll gap. Due to its specific character the 2.5D method does not account for this effect. However, the errors caused by this fact do not exceed 0.25 mm. At the same time, the maximum difference between the results do not exceed 0.5 mm.

The billet velocity in the direction of rolling, as well as velocity of rollers for 24th and 25th passes, are presented in figures 6 and 7, respectively. The graphs designated as "3D a)" and "3D b)" illustrate respectively the metal flow velocity in the center and at the surface of billet. These are values obtained from the 3D finite element model. The curve designated as "2.5D" shows the metal flow velocity calculated by the 2.5D method. The curve designated as "Roller" shows the velocity of the roll.

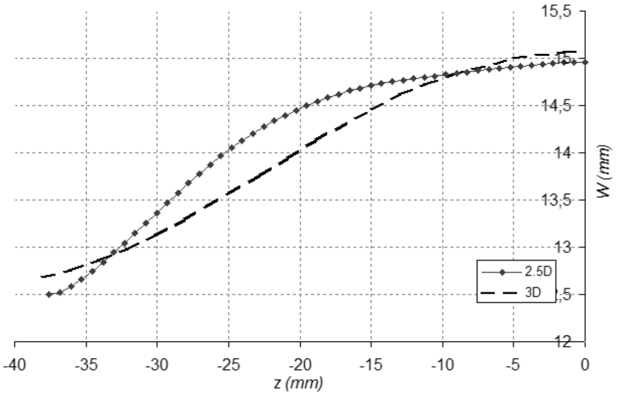


Fig. 4. *Billet spread diagram for 24th pass.*

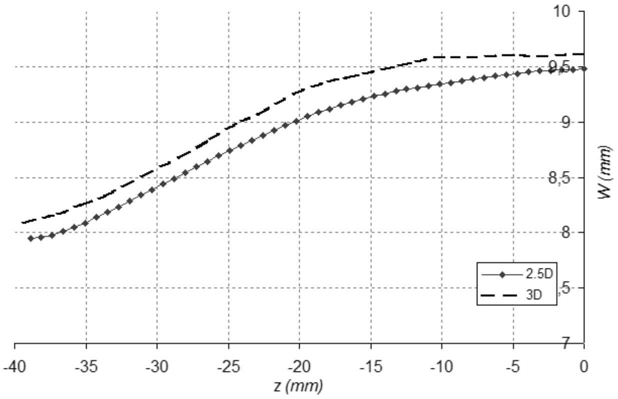


Fig. 5. *Billet spread diagram for 25th pass.*

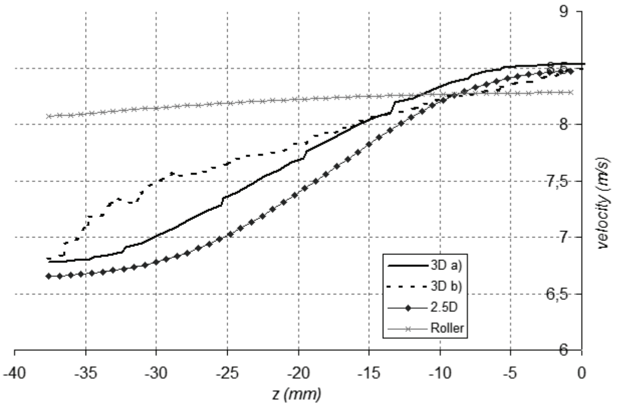


Fig. 6. *The graph of metal flow velocity in direction of rolling in 24th pass.*

This findings show that values of the velocity illustrated by graphs "3D a)" and "2.5D" are in good agreement. At the same time the difference between curves "3D b)" and "2.5D" is more significant. But one should notice that the points of the billet, which conform to this curve, belong to relatively small contact zone and that in spite of curves character, difference between the absolute values of start and final velocities do not exceed 0.3 m/s.

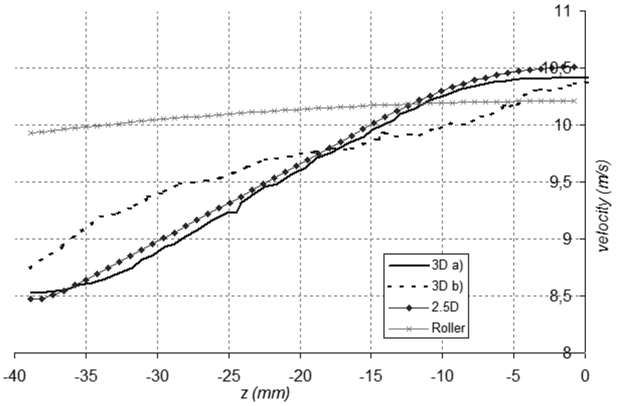


Fig. 7. *The graph of metal flow velocity in direction of rolling in 25th pass.*

5. CONCLUSION

The obtained results show that full three-dimensional finite element approach to modeling of rolling in grooves gives more accurate predictions of character of metal flow in deformation zone. Beyond this, it allows to take into account several features of the process, which have to be neglected in the 2.5D method. Nevertheless, predictions of main rolling parameters and characteristics obtained from the 2.5D approach are in good correspondence with 3D simulation results.

The main advantage of the 2.5D method, and developed on the basis of this method software SPLEN(Rolling), is short time of calculations and building of deflected mode model. The efficiency makes this method a useful tool for fast analyses of rolling parameters at the stage of development and optimization of rolling technology.

Acknowledgments. The authors are indebted to Czech Science Foundation for the financial support of this research (projects 106/04/1452 and 106/04/0601) and also to Ministry of Education, Youth and Sports of Czech Republic for the material support (research plan 61989115).

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PORÓWNANIE WYNIKÓW SYMULACJI 3D I 2.5D PROCESU WALCOWANIA W WYKROJACH

Streszczenie

Dyskusja symulacji z wykorzystaniem metody elementów skończonych 3D i 2.5D procesu walcowania okrągłego wsadu w wykrojach jest tematem niniejszej pracy. Wyniki uzyskane z dwóch zastosowanych modeli obejmujące rozkład pól odkształceń, rozkład parametrów geometrycznych wsadu czy też ocena błędu rozwiązania są zaprezentowane w artykule.

Submitted: October 9, 2006
Submitted in a revised form: October 31, 2006
Accepted: November 3, 2006