DOI 10.1007/s11015-017-0494-9
*Metallurgist, Vol. 61, Nos. 3–4, July, 2017 (Russian Original Nos. 3–4, March–April, 2017)*

# STUDY OF METAL STRAINED STATE DURING WORKPIECE REDUCTION IN A THREE-ROLL SCREW-ROLLING MILL

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UDC 621.774

*Results are given for a study of metal deformation state with screw rolling in a three-roll mill by means of computer modeling. Quantitative characteristics are obtained for the unequal distribution of degree of deformation through a workpiece cross section. Features are established for the use of screw line pitch length, partial reduction, and penetration index for the plastic deformation zone to workpiece axis in relation to screw line pitch number. Recommendations are given according to which in calculating roll calibration the roll profile should be selected so that deformation penetrates the whole workpiece depth over the whole deformation site length.*

***Keywords:*** *screw rolling, finite-element modeling, deformation state.*

The work of S. P. Galkin, V. L. Kolmogorov, A. N. Nikulin, V. Ya. Osadchii, E. I. Panov, B. A. Romantsev, P. K. Teterin, and others is important for developing screw rolling theory. Galkin was concerned with studying metal shape change during screw rolling in a three-roll mill, steel rheology, and also development of rolling regimes and universal calibration of a production tool [1–3]. Panov conducted comparative analysis of the stress-strained state during rolling in two- and three-roll mills using computer modeling in an Ansys program and established that during rolling in a three-roll mill considerable overall plastic deformation is provided and there is more uniform distribution of plastic deformation through a workpiece cross section at the deformation site [4]. Results are given in [5, 6] for a study of the geometry of deformation site, screw rolling kinematics, and also workpiece gripping conditions. Nikulin established [7] that during screw rolling there is shear displacement of metal and localization of plastic in workpiece surface layers, which leads to the formation at the ends of workpieces of axial depressions. Kolmogorov showed that deformation is variable in nature during screw rolling [8, 9].

The deformation process in a three-roll screw-rolling mill is used extensively. For example, in the pipe rolling unit TPA-80 of SinTZ company, a three-roll screw-rolling mill is used for reducing a continuously-cast billet (CCB) 150 and 156 mm in diameter to a diameter of 120 mm before broaching. Use of a CCB has made it possible to increase pipe rolling unit production by 15% and also to reduce pipe cost by 10% [10]. It has also been established that during reduction in a three-roll screw rolling mill there is profound working of the structure as a result of which in pipes from a cast workpiece the grain size is smaller than in pipes of rolled workpieces [11]. In view of, a study of the deformed condition of metal during screw rolling is an important task since this will make it possible to select a rational deformation regime, to work out new tool sizing, to study features of metal flow, and also to provide preparation of an ultrafine grain structure.

The aim set for this work is development of a procedure for studying the deformation conditions and shape change of workpiece metal during screw rolling for planning tool sizing and rational deformation regimes.

*Statement of the computer modeling problem and planning of a calculation experiment.* Modeling of workpiece reduction in Deform 3D was accomplished with a roll feed angle $\beta = 16^o$, rolling angle $\varphi = 12^o$, and roll rotation frequency $n =$ = 80 rpm. Roll diameter in the pinch was 650 mm, and the barrel length was 380 mm. Roll calibration existing in the pipe

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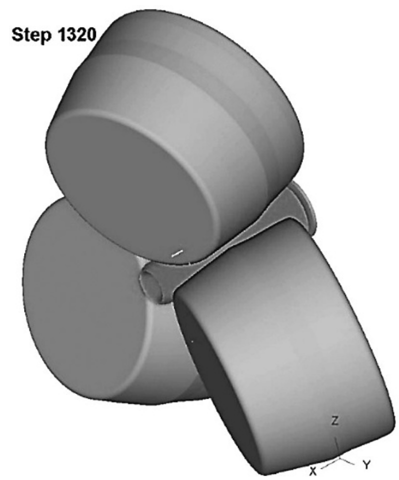


Fig. 1. Workpiece steady-state reduction.

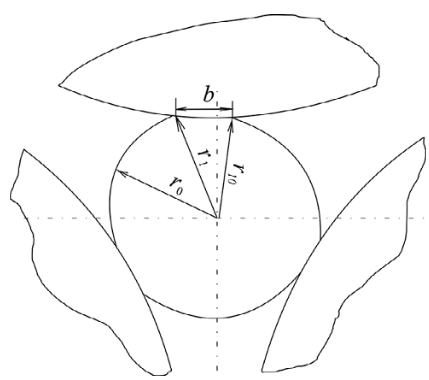


Fig. 2. Diagram of change in contact surface width: $r_0$ is workpiece radius before lap formation; $r_1$ is workpiece radius before entry to deformation site; $r_{10}$ is workpiece radius before reduction by roll.

rolling unit TPA-80 of SinTZ was used, and workpiece diameter was 150 mm. Roll convergence was provided in order that at the outlet from the mill a workpiece 120 mm in diameter was prepared (reduction coefficient $\lambda = 1.56$). From the list of materials in Deform-3D program for workpieces steel AISI 1045 was selected, similar to steel St45 according to the Russian standard. Workpiece heating temperature was taken as 1200ºC, and tool temperature of 150ºC. Workpiece $l_w = 400$ mm was taken as a minimum, but adequate for forming an overall deformation site. The typical size of an element in a grid was taken as equal to 3 mm; Siebel friction index determined from the expression $\tau = \psi\tau_s$ ($\tau$ is friction stress, $\tau_s$ is shear deformation resistance) was taken as equal to $\psi = 1$ [12, 13].

A three-dimensional model of the rolling process in a three-roll reducing mill is given in Fig. 1. Efficiency functions of the computational experiment were: value of accumulated degree of deformation $\varepsilon_u$, screw line pitch length $l_s$, relative change in workpiece radius $(r_1 - r_{10})/r_0 = \Delta r/r_0$ (Fig. 2), and ratio of workpiece radius to width of contact surface $r_0/b$ over the deformation site length. Measurement and calculation of parameters $\varepsilon_u$, $l_s$ was carried out along the trajectory for movement of five points of different radial coordinate, and parameters $\Delta r/r_0$ and $r_0/b$ were determined at point 5, which is at the workpiece surface (Fig. 3).

With screw rolling, in a section with formation at a workpiece surface over the path of a point (see Fig. 3), a lap is formed ahead of the deformation site and this is caused by an increase in workpiece radius from $r_0$ to $r_1$ (see Fig. 2). Results

TABLE 1. Values of Parameters along Deformation Site

| Screw line pitch number at deformation site | Point 1 | Point 2 | Point 3 | Point 4 | Point 5 |
|---|---|---|---|---|---|
| *Degree of deformation for workpiece cross section* $\varepsilon_u$ | | | | | |
| 1 | 0.02 | 0.02 | 0.04 | 0.04 | 0.04 |
| 2 | 0.05 | 0.08 | 0.15 | 0.33 | 0.79 |
| 3 | 0.18 | 0.25 | 0.43 | 0.92 | 1.80 |
| 4 | 0.36 | 0.45 | 0.77 | 1.55 | 3.08 |
| 5 | 0.47 | 0.57 | 0.95 | 1.87 | 3.78 |
| 6 | 0.50 | 0.60 | 1.00 | 1.98 | 4.24 |
| 7 | 0.51 | 0.61 | 1.02 | 2.06 | 4.66 |
| 8 | 0.51 | 0.62 | 1.03 | 2.09 | 4.72 |
| *Screw line pitch length* $l_s$, *mm* | | | | | |
| 1 | 0 | 0 | 0 | 0 | 0 |
| 2 | 24.1514 | 24.3916 | 24.5075 | 24.4365 | 25.8789 |
| 3 | 23.7833 | 24.1875 | 24.4984 | 25.25 | 27.6609 |
| 4 | 26.6508 | 26.8937 | 27.1066 | 28.0981 | 31.0543 |
| 5 | 29.8559 | 29.8938 | 29.9621 | 30.3312 | 31.6058 |
| 6 | 31.2945 | 31.2376 | 31.1479 | 31.0997 | 31.5581 |
| 7 | 27.7096 | 31.6293 | 31.628 | 31.6511 | 32.061 |
| 8 | 31.2603 | 31.2287 | 31.3032 | 31.4104 | 31.6027 |

TABLE 2. Values of Parameters at Point 5 along Deformation Site

| Screw line pitch number at deformation site | $\Delta r/r_0$ | $b$ | $r_0$ | $r_0/b$ |
|---|---|---|---|---|
| 1 | 0.07 | 20.70 | 76.77 | 3.71 |
| 2 | 0.11 | 25.85 | 71.50 | 2.77 |
| 3 | 0.08 | 24.15 | 64.68 | 2.68 |
| 4 | 0.02 | 15.66 | 60.83 | 3.89 |
| 5 | 0.01 | 9.14 | 60.28 | 6.59 |
| 6 | 0.01 | 8.38 | 60.13 | 7.17 |
| 7 | 0.01 | 7.52 | 60.27 | 8.01 |
| 8 | 0.01 | 7.43 | 60.15 | 8.10 |

of measurement and calculation of parameters $\varepsilon_u$, $l_s$, $\Delta r/r_0$, and $r_0/b$ are provided in Tables 1 and 2, respectively, and curves (Figs. 4–7) were constructed from tabulated data. All the values of radius were measured at point 5 along the screw trajectory at a local deformation site. Parameter $r/b$ specifies the depth of penetration of plastic deformation in a transverse section: with $r/b > 4.37$, deformation is localized within the surface layer.

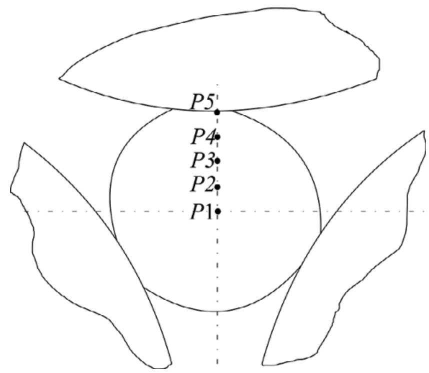


Fig. 3. Points (*P1–P5*) for measurement of parameters $\varepsilon_u$, $l_s$, and *b*.

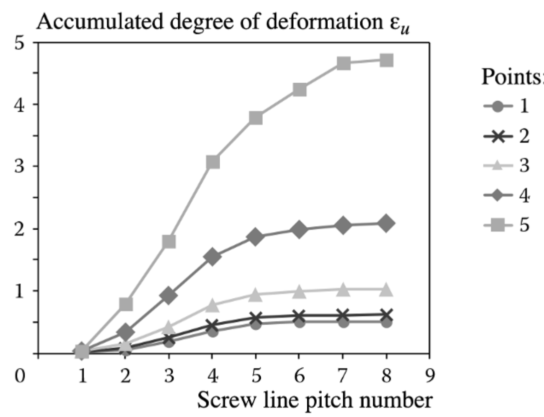


Fig. 4. Change in degree of deformation $\varepsilon_u$ accumulated at five points along deformation site.

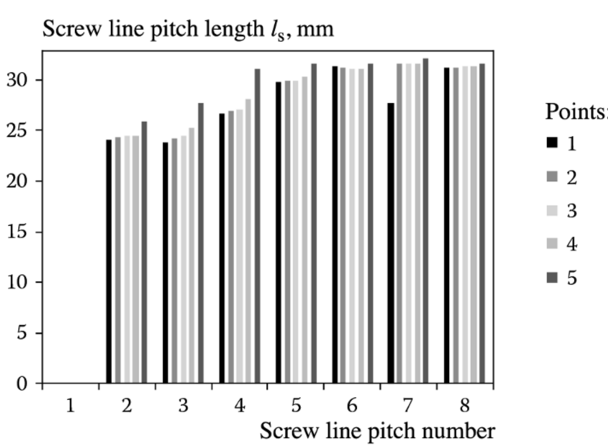


Fig. 5. Screw line pitch length along deformation site.

It is seen from Fig. 4 that the degree of deformation is not uniformly distributed through a workpiece cross section. The value of accumulated degree of deformation increases from the workpiece surface to its axis. The maximum degree of

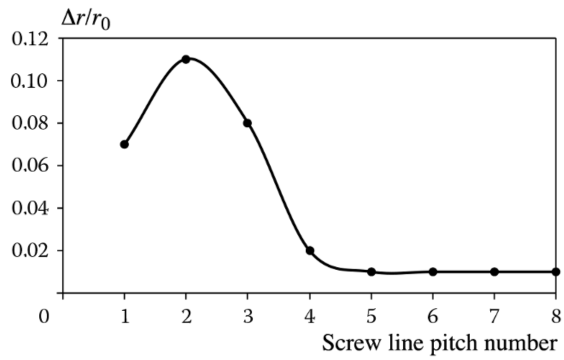


Fig. 6. Change in relative reduction $\Delta r/r_0$ along deformation site.

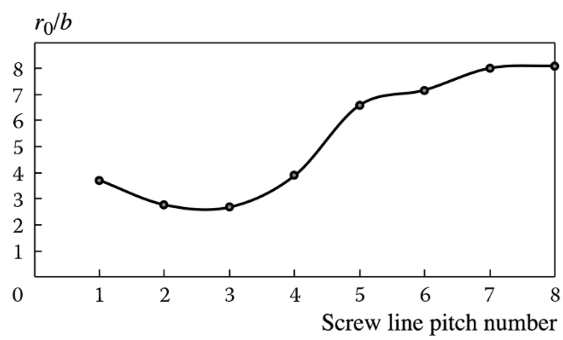


Fig. 7. Change in parameter $r_0/b$ along deformation site.

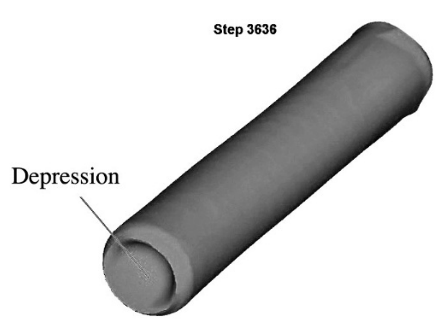


Fig. 8. Spread at workpiece rear end.

deformation is achieved at point 5, located at the workpiece contact surface ($\varepsilon_u = 4.72$), and the minimum degree of deformation occurs at point 1 ($\varepsilon_u = 0.51$). The dependence obtained for distribution of the degree of deformation through a workpiece cross section agrees with the results of studies by Galkin [3] and Nikulin [7].

It is seen from Fig. 5 that displacement of metal particles with a different radial coordinate along the rolling axis is not the same, i.e., point 5 outstrips other points. The rest of the points also shift along the deformation axis to different distances.

Analysis of results given in Table 2 and Fig. 6 showed that the greatest relative reduction is observed in the second step of the screw line and in sections of roll constriction. Then, as there is an increase in the number of screw line pitch, relative reduction decreases. From the fifth to the eighth step of the screw line, relative reduction over the workpiece radius $\Delta r/r_0$ remains almost unchanged. For these steps, workpiece calibration is provided with respect to diameter.

It is well known [14] that expansion of the contact surface leads to an increase in plastic deformation penetration depth, and nonuniformity of deformation through a workpiece section decreases. In order to estimate the width of the contact surface over the length of a deformation zone, a dimensionless parameter $r_0/b$ was introduced. It is seen from Fig. 7 that the least value of ratio of workpiece radius to contact surface width ($r_0/b$) occurs in a pinching section, since the width of the contact surface in this section is at a maximum. In subsequent calculation steps, there is a reduction in relative reduction of a workpiece and width of contact surface (see Table 2). In studying the broaching process, Kolmogorov established that with $r_0/b \geq 4.37$ deformation is localized at a workpiece surface and does not reach its axis [8, 9]. It is seen from Fig. 7 that starting from the fifth step, when there is calibration of a workpiece with respect to diameter, deformation is localized within the contact layer of a workpiece and rolls, which leads to the formation of a depression at the ends of a workpiece (Fig. 8). A depression in the rear end of a workpiece leads to the formation of circular delamination during broaching, with whose separation there is an increase in scrap for pipe surface defects [15]. Therefore, it may be concluded that it is necessary to change calibration in pipe rolling unit TPA-80 of SinTZ in order that the whole of the deformation site penetrates into the whole depth of a workpiece.

**Conclusions**. A procedure has been developed for studying deformation conditions during screw rolling. In the course of research, it has been established that the degree of deformation through a workpiece cross section is not distributed uniformly. The value of accumulated degree of deformation decreases from a workpiece surface towards the axis. The greatest relative reduction of a workpiece at a local deformation site is observed in the pinching section. In this section, the width of the contact surface and penetration depth of plastic deformation is at a maximum. Starting from the fifth step of the screw line, deformation is localized at a workpiece surface, which leads to the formation of a depression in the workpiece end, causing separation of circular separations during broaching and an increase in the amount of scrap for pipe surface defects.

Consequently, in calculating roll calibration the profile should be selected so that deformation propagates into the whole workpiece cross section over the whole deformation site length.

The work was supported by the RF President grant MK-3011.2017.8 and Decree No. 211 of RF Government (Contact No. 02.A03.21.0006) and was carried within the framework of the project part of State Assignment No. 11.9538.2017/VR.

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