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POROUS MATERIAL DEFORMABILITY IN FOUR-ROLL PASS ROLLING

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Rolling in four-roll passes offers a lot of technological and ecological advantages over swaging which is presently used for working of sintered powder rods from tungsten and molybdenum. It explains the necessity of thorough experimental and theoretical investigations of such processes as plastic shaping and compacting of sintered powder materials at the zone of their deformation in rolling with four-side reduction. Authors have carried out numerous experimental investigations of compacting of powder rods in the process of their rolling in four-side passes. There exist several empirical formulae describing rod density change in the process of rolling. The present paper gives complex experimental details and justification of the proposed analytic function allowing the evaluation of powder strip density by measuring its geometric parameters. This analytic function is based on the law of constant rod mass in plastic shaping and compacting.

Keywords: porous material; deformability; four-roll pass; density; experimental investigation; template.

Introduction

It is mostly imperative for modern material swaging theory to develop mathematical models and matching methods of calculation of plastic shaping and compacting parameters. This is entirely true for new technique of sintered powder rod rolling in four-roll passes. Presently, such rods made of tungsten and molybdenum powders by their pressing and two-stage sintering are treated basically by swaging. But experimental investigations and commercial production practice evidently show technological and ecological advantages of four-roll pass rolling technique over swaging. Owing to such a situation, there is an urgent need for thorough experimental and theoretical investigations of plastic shaping and sintered powder material compacting at the zone of deformation during the rolling with four-side reduction. Besides, such investigations would be critical for improving existing technologies and developing up-to-date methods of rod rolling with four-side reduction of the rod at the zone of deformation.

Model of powder rod compacting in rolling

Basing on previous experimental data concerning the nature of powder sintered rod compacting at the zone of deformation during the process of four-roll rolling, authors have proposed the following analytic functions describing density changes in a powder strip along the entire length of its deformation zone [1]:

$$\rho(x) = (\rho_0 - \rho_1)\left(-\frac{x}{l}\right)^k + \rho_1, \qquad (1)$$

where ρ_0, ρ_1 are rod densities before and after the rolling, respectively,

l is the length of deformation zone,

k is the parameter of deformation degree, its values being set as follows: $k = 0$ if $\rho = \text{const}$, $k = 1$ if the degree of deformation ε is less than 40 %, and $k = 2$ if ε is greater than 40 %.

Another analytic function [2] is expressed as:

$$\rho(x) = \rho_0 \sqrt[n]{\left(\frac{\rho_1}{\rho_0}\right)^n + \left[1 - \left(\frac{\rho_1}{\rho_0}\right)^n\right]\frac{x}{l}}, \qquad (2)$$

where n is the parameter characterizing the rate of powder rod compacting in the direction of rolling; this rate being inversely proportional to rod density at the given profile of deformation zone.

However, the latest complex experimental investigations of plastic shaping character and powder rod compacting at the zone of deformation in the process of rolling with four-side reduction have revealed that the proposed functions (1) and (2) fail to describe properly the real nature of changes in sintered powder rod density along the entire length of deformation zone. The above functions just set a trend for possible monotonic changing in rod density and leave the question of what degrees of that monotony would be at each separate point of the entire length of deformation zone.

The goal was to obtain a more accurate expression for density distribution in sintered powder rod along the length of deformation zone. The experimental investigations have been carried out to solve the problem using underrolled molybdenum powder rods obtained by rolling in four-roll passes. During the experiment, the character of step-by-step changing in cross-section area was also observed.

Industrial tests of the following technique were also carried out. There were selected the samples from the batch of sintered pure molybdenum powder rods with 18×18 mm cross-section area and 600 mm length having the smallest differences in densities of the material far and wide. The selection of samples was carried out in two ways: by hydroweighing and radioisotopic density measuring with the help of special device [3], permitting to measure density characteristics in powder sintered rods so as to gain information about the average density in the rod at a definite cross-section area as well as density distribution over that area or lengthwise. The above device utilizes gamma-radiation source, its principle of operation basing on registration of changes in collimated gamma-ray beam passing through gamma absorber, e.g. sintered powder rod. The device offers ±0.1 g/cm^3 accuracy of density measurements.

From the selected powder rods underrolled rods were produced by rolling on four-roll pass industrial mill MK-210×4, at the UZBEK Refractory Metals Combine. The underrolled rods were subjected to different degrees of deformation, namely, 25 %, 30 %, 33 % and 36 % [1] and edge reduction. Special guides held the rods oh their edges during the reduction. The underrolled sintered powder rods were cut into cross 1 and longitudinal 2 templates (Fig. 1) to study their macro- and microstructures and to measure the density of rod material along the entire length of deformation zone.

The changes in material density values along the zone of sintered powder rod deformation were measured by hydroweighing of cross templates, and the changes in rod cross-section area magnitudes along the length of deformation zone were observed by BMI-1 microscope. The character of density distribution $\rho(x)$, over the material, and rod cross-section areas $S(x)$ along the length of deformation zone were approximated by the following analytic functions:

$$\rho(x) = \rho_0 \left[1 + A(1 - \tfrac{x}{l})^n \cdot \exp\left(\tfrac{nx}{l}\right)\right], \quad (3)$$

$$S(x) = S_0 \left[1 - B\left(1 - \tfrac{x}{l}\right)^m \cdot \exp\left(\tfrac{mx}{l}\right)\right], \quad (4)$$

where n and m are exactly the parameters whose values are found as a result of data processing by least square method.

Setting x equal to zero one can find density values ρ_1 and cross-section area magnitudes S_1 at the outlet of rod deformation zone:

$$\rho_1 = \rho(0) = \rho_0(1 + A), \quad (5)$$

$$S_1 = S(0) = S_0(1 - B). \quad (6)$$

Introducing δ_ρ as relative rod compactness after rolling:

$$\delta_\rho = \frac{\rho_1 - \rho_0}{\rho_0}, \quad (7)$$

and δ_S as relative reduction of rod cross-section area:

$$\delta_S = \frac{S_0 - S_1}{S_0}, \quad (8)$$

one can rewrite functions (3) and (4) with respect of (5), (6), (7) and (8) equations as follows:

$$\rho(x) = \rho_0 \left[1 + \delta_\rho(1 - \tfrac{x}{l})^n \exp\left(\tfrac{nx}{l}\right)\right], \quad (9)$$

$$S(x) = S_0 \left[1 - \delta_S(1 - \tfrac{x}{l})^m \exp\left(\tfrac{mx}{l}\right)\right]. \quad (10)$$

With regard to the law of constant mass of the material under plastic shaping and compacting, one can find the relationship between parameters of original rod and rolled strip:

$$(1 - \delta_S)\lambda_\rho(1 + \delta_\rho) = 1, \quad (11)$$

where $\lambda_\rho = \frac{L_1}{L_0}$ is the strip elongation in one pass,

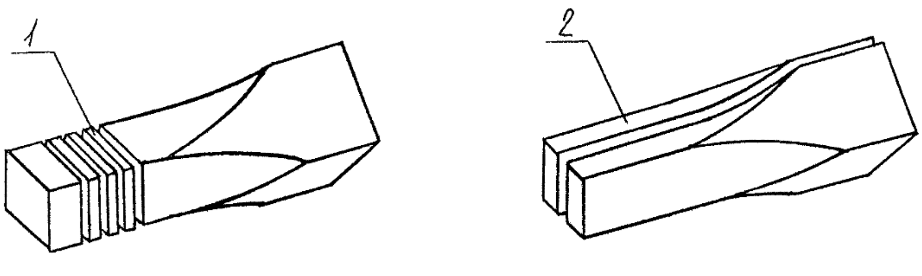

Fig. 1. Cross 1 and longitudinal 2 underrolled rod templates

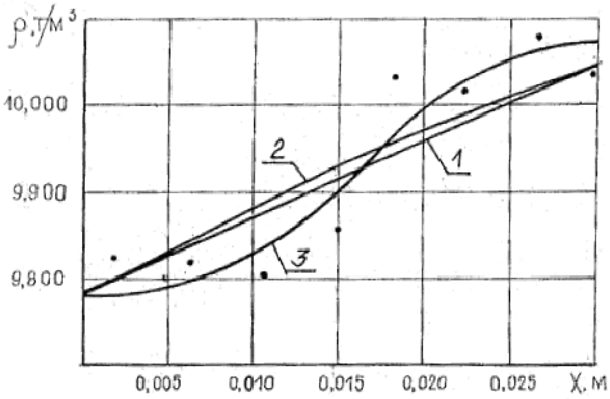

Fig. 2. Powder rod compacting curves. Data taken along the entire length of deformation zone in the process of rod rolling. Straight line 1 is the plot of function (12); Curve 2 is the plot of function (2) when *n* = 20; Curve 3 is the plot of function (9); (•) are experimental points

L_0 and L_1 are rod lengths before and after the rolling, respectively.

With respect to the relative compactness δ_ρ, formula (11) can be expressed as:

$$\delta_\rho = \frac{1}{(1-\delta_S)\lambda_\rho} - 1. \tag{12}$$

Formula (12) clearly shows that deformation parameters are interrelated, i.e. knowing the values of any two of them one can easily find the third one from (12). For instance, as geometrical parameters δ_S and λ_ρ can be directly found from the experiment, then the value of parameter δ_ρ is obtained from formula (12), thus avoiding labour-consuming experiment for determination of the character of density distribution in powder rod along the length of its deformation zone.

Basing on experimental data obtained the values of n and m parameters in equations (9) and (10) were calculated according to the standard computer approximation program by method of the least squares. Calculation results and experimental data are plotted in Fig. 2.

Thorough analysis of curves behavior in Fig. 2, which are plotted according to the above functions (12), (2) and (9) against experimental data points, reveals function (9) to be the most real description of powder compacting character along the length of deformation zone, while functions (12) and (2) show just a qualitatively monotonic character of compacting. This provides for a further application of function (9) to powder material plastic compacting at the zone of its deformation in rolling with four-side reduction.

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ДЕФОРМИРУЕМОСТЬ ПОРИСТОГО МАТЕРИАЛА ПРИ ПРОКАТКЕ В ЧЕТЫРЕХВАЛКОВОМ КАЛИБРЕ

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Прокатка в четырехвалковом калибре предлагает множество технологических и экологических преимуществ по сравнению с обжимом, который в настоящее время используется для обработки спеченных прутков из порошков вольфрама и молибдена. Это объясняет необходимость тщательных экспериментальных и теоретических исследований таких процессов, как пластическая деформация и прессование спеченных порошковых материалов в зоне их деформации при прокатке с четырехсторонним обжатием. Авторы провели многочисленные экспериментальные исследования прокатки порошковых заготовок в четырехвалковых калибрах. Известны эмпирические формулы, описывающие изменение плотности заготовок в процессе их прокатки. В настоящей статье приведены результаты комплексных экспериментальных исследований и дано обоснование предлагаемой аналитической функции, позволяющей дать оценку плотности заготовки путем измерения ее геометрических параметров в процессе прокатки. Эта аналитическая функция основана на законе постоянства массы прутка при пластической деформации и прессовании.

Ключевые слова: пористый материал; деформируемость; четырехвалковый калибр; плотность; экспериментальное исследование; темплет.

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