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Identification of Possibilities of Controlling Plastic Processing Processes in Conditions of Complex Loading

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Abstract: The combination of different loads in the process of plastic deformation makes it possible to find sufficiently effective technological modes of deformation associated with the control of plastic shaping of the deformable metal. These approaches are manifested in the fact that it is possible to reduce the force load on the deformation site, or the implementation of processing in which it is possible to improve the quality of finished products, mill productivity. Therefore, the task of finding process parameters that allow you to control and influence the deformation center during rolling in a special way becomes urgent. The analysis of scientific and technical literature shows that such parameters can be impacts that, according to deformation and force loading, should not be comparable with the main load, due to which the process of plastic deformation is realized. In this case, the factor of unevenness of plastic deformation can be controlling if its loading on the deformation site is less than the main one. This work, carried out within the framework of grant № AP23488953, funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan, presents experimental studies of the effect of asymmetric unevenness of plastic processing along the width of the deformation zone during rolling on the conditions of rectilinear movement of the strip in the deformation zone and the force characteristics of ensuring this movement. Experimental data show that the force effect on the deformation site from the unevenness of compression is significantly less than the main load, which gives reason to consider this type of loading as controlling. The imposition of unevenness of plastic deformation on the plastic treatment zone causes the appearance of additional regulatory stresses, which significantly affect the stress state of the deformation site as a whole.

Keywords: Plastic deformation, Rolling, Deformation zone, Unevenness of deformation, Complex loading

Introduction

The combination of different loads in the plastic deformation makes it possible to find sufficiently effective processing modes related to the control of plastic shaping. These approaches are manifested in the fact that it is possible to reduce the force load on the deformation zone, or to implement processing modes while improving the

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quality of the finished product and mill productivity. In this regard, it becomes important to find the process parameters that allow to control and influence the deformation zone in a special way.

The combination of different pressure treatment operations in the deformation zone is presented as primary and auxiliary or additional. The difference lies in the power load. If the combined effects of metal pressure treatment are characterized by different force parameters, then, accordingly, these effects are characterized by different effects on the plastic shaping process itself. In this case, the effects with lower force parameters on the deformation zone and the factors that can implement such effects are of the greatest interest. Based on experimental data, it was shown that the factors that can affect the deformation zone with lower force parameters can include the factor of uneven plastic deformation (Chigirinsky & Volokitina, 2024).

Let's consider the features of uneven plastic shaping from the point of view of the controlling factor. Different compression by volume of the deformable workpiece forms the geometry of the finished product, and accordingly causes uneven deformation. At the same time, this leads not only to a change in the stress state, but also to a change in the flow pattern of the metal in different directions. Figure 1a shows a "template" of a cross-section of a complex roll with "witnesses" after compression in the rough passage. It can be seen that local plastic deformations, unrelated to the extraction capabilities of rough gauges, significantly change the flow of metal in the transverse direction (Chigirinsky et al., 2014).

The metal moves from areas of greater compression to areas with less compression. This is clearly visible in Figure 1b, where the circles show the centers of the "witnesses" before and after rolling. The graph of the compression distribution over the strip width, which is also shown in Figure 1b, characterizes the deformation in this case as extremely uneven.

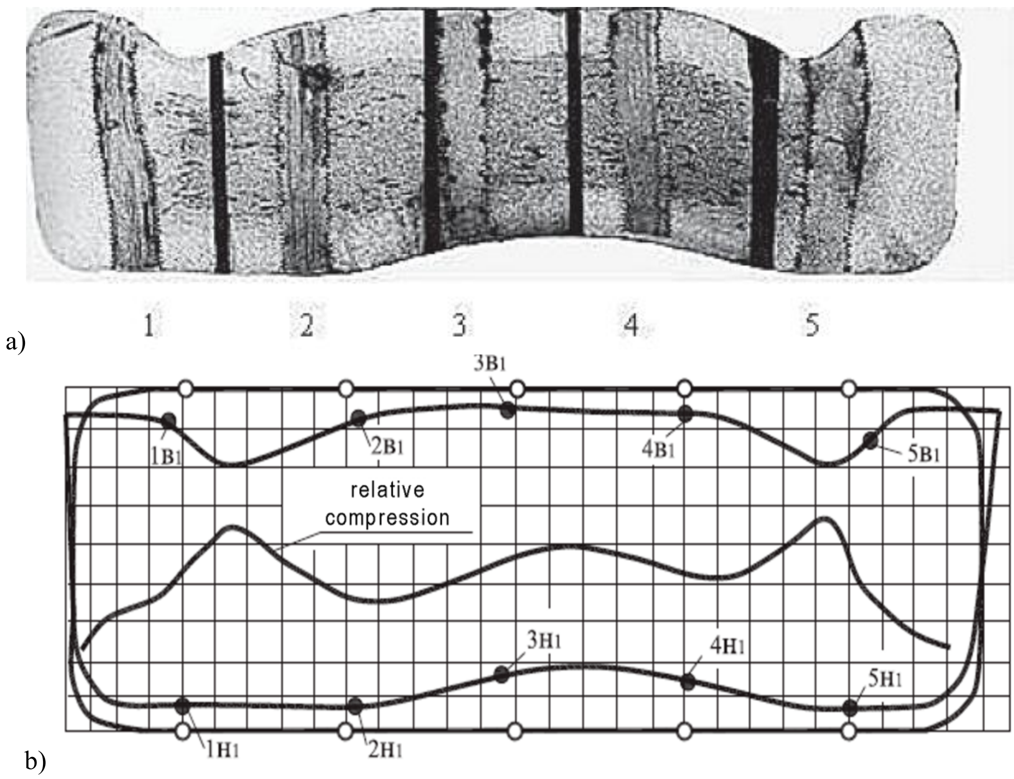


Figure 1. Location of the "witnesses" (a) and diagram of the transverse displacement with a graph of the compression distribution across the strip width (b)

The movements of the "witness" centers show the flows of the plastic flow of the medium in the transverse direction. Local (additional) deformations associated with uneven compression are those controlling influences that, based on the drawing capacity of the caliber, form plastic metal flows.

As a result of the interaction of the elements, there is a forceful external support and tension in individual zones of the strip, as an additional external effect on the deformation zone, similar to external forces in the intercellular gap of a continuous mill. As a result, contact stresses in the deformation zone change, which is widely used in regulating the rolling process of continuous mills (Chekmarev et al., 1967). The above example indicates the regulating effect of external forces on the deformation zone, which is also indicated in case of uneven deformation.

Such deformation modes are typical for rolling profiles of complex asymmetrical shape. Their peculiarity is that the rolled strip is prone to sickling in the horizontal plane at the entrance and exit from the deformation zone. In this case, it becomes experimentally possible to establish a correspondence between uneven deformation and an external additional effect on the compression zone.

Method

As noted above, an assessment of the additional impact on the deformation zone is necessary in order to verify how effective and efficient this loading is for regulating the stress-strain state of the plastic medium. Therefore, a physical experiment was conducted to evaluate the additional effect on the deformation site under difficult loading conditions. The experiment was carried out at the DUO-150 rolling mill, with different ratios B_1/B_0 and H_1/H_0, which ranged from B_1/B_0 from 0.50 to 0.93 and H_1/H_0 from 0.65 to 0.91, respectively, were rolled on this mill (Fig. 2). The parameters H_1/H_0 and B_1/B_0 characterize to a certain extent the unevenness of plastic deformation along the width of the profile. The H_1/H_0 ratio quantifies the interaction between two adjacent elements. The ratio B_1/B_0 is the weight of each element in case of uneven deformation.

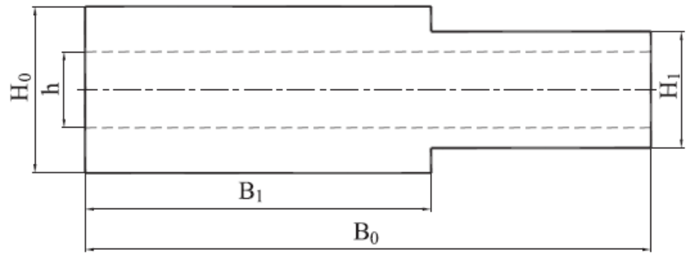


Figure 2. Asymmetrical step sample

During the experiment, the pressure of the strip on the side roll rulers of a special design was measured. Some of the experimental data on measuring the pressure of the strip on the side rulers are shown in Table 1. To assess the effect of the impact, it must be compared with the main one, which implements plastic deformation. The torques from the side lines, as external additional ones, and the torques of plastic bending, as the main load, were compared:

$$M_{pl} = \beta \cdot \sigma_y \cdot W_{pl}, \tag{1}$$

where β - characterization of the stress state at a point; σ_y - yield stress; W_{pl} - torque of plastic resistance.

Table 1. Experimental values of forces and torques from the side rulers

№	B_1/B_0	H_1/H_0	Values of force, N		Values of torque, N·m		Force ratio P_{ent}/P_{ex}	Torque ratio M_{ent}/M_{ex}
			Entrance	Exit	Entrance	Exit		
1	0,93	0,73	932	376	75,6	54,1	2,5	1,4
2	0,77	0,76	1340	550	110,7	79,2	2,5	1,4
3	0,62	0,72	1952	780	162,0	112,3	2,5	1,4
4	0,52	0,77	1783	770	153,0	111,0	2,3	1,4
1	0,93	0,82	480	212	40,5	30,5	2,3	1,3
2	0,78	0,83	888	380	75,8	54,7	2,3	1,4
3	0,63	0,79	1325	580	115,5	83,5	2,3	1,4
4	0,52	0,82	1250	559	109,0	80,6	2,2	1,5
1	0,92	0,76	772	319	62,4	46,5	2,4	1,4
2	0,77	0,75	1225	478	100,2	69,0	2,6	1,5
3	0,62	0,75	1805	786	151,2	113,2	2,3	1,3
4	0,52	0,74	1860	838	157,5	120,9	2,2	1,3

The data in Table 1 show that the torques of forces from the rulers uniquely respond to changes in the unevenness of deformation. The parameters B_1/B_0 and H_1/H_0 are able to assess the process of unevenness to a certain extent

when the number of elements is minimal. But they do not give a complete picture of the asymmetry of loading for profiles of complex construction, when their number is more than two and with other qualitative indicators. Fragments of such indicators can be static torques of a given section, as well as factors that take into account the longitudinal interaction in the deformation zone $\ln\mu_{av}/\mu_i$. Therefore, in our opinion, for a more complete characterization of uneven deformation, it is necessary to use the dimensionless parameters from the side of the entrance and exit of the metal from the deformation zone:
- entrance:

$$\delta_{ent} = \frac{\sum 2\frac{a_i}{1+a_i}\cdot\ln\frac{\mu_{av}}{\mu_i}F_{0i}y_{0i}}{W_{pl.ent}}, \tag{2}$$

- exit:

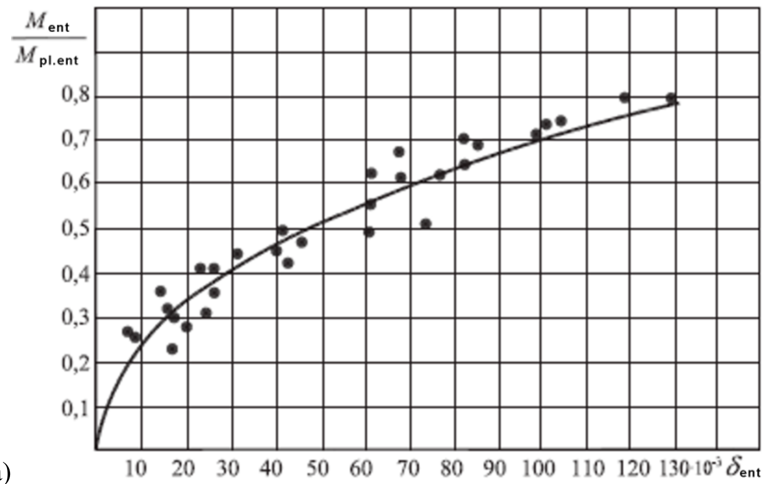
$$\delta_{ex} = \frac{\sum 2\frac{a_i}{1+a_i}\cdot\ln\frac{\mu_{av}}{\mu_i}F_{1i}y_{1i}}{W_{pl.ex}}, \tag{3}$$

where W_{pl} - torque of plastic resistance at the entrance and exit from the deformation zone; μ_{av} - average stretching in the compression zone; μ_i - private stretching.

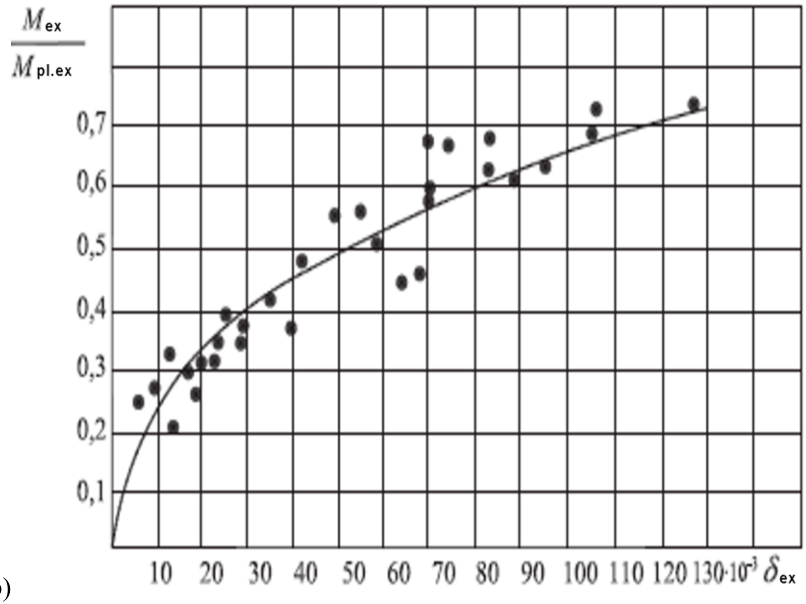
In addition to the dimensionless indicators (2) and (3), it is advisable to use a dimensionless indicator for torques from the rulers M_{exp}/M_{pl}. For this purpose, the torques of plastic bending for the sections used in the experiment were calculated within the limits: at the entrance: 152.0-234.2 N·m, at the exit: 97.9-197.5 N·m.

Results and Discussion

Comparing the plastic torques with the data given in Table 1, it can be seen that they are higher than the values obtained experimentally. The use of relative data for torques and parameters δ makes it possible to eliminate the influence of yield strength and absolute band sizes when constructing a mathematical model under conditions of asymmetric impact. Also, when comparing the results of the measurement and calculation of the torques, it can be seen that the additional impact, through uneven deformation, is less than the main load, and the ratio of torques M_{exp}/M_{pl} is less than one and ranges from 0.2 to 0.8. Analysis of the data obtained shows that the torques of forces from the lateral rulers in relation to the torques of plastic bending in this range plastic interaction is always less than one. This is evidence that the additional load from the rulers on the deformation zone is less than the main one, which determines the plastic deformation process. Based on the processing of experimental data, some of which were given in Table 1, the dependence of the ratio of loading torques on a dimensionless indicator characterizing the unevenness of deformations was constructed (Fig. 3).



a)



b)

Figure 3. Dependences of the ratios of the M_{exp}/M_{pl} torques at the entrance (a) and at the exit (b) from the deformation zone on the δ parameters

Mathematical processing of experimental results using the least squares method for a power function allowed to obtain expressions of the form:

- entrance:

$$M_{ent} = 1.938 \cdot M_{pl.ent} \cdot \left[\frac{\sum 2 \dfrac{a_i}{1+a_i} \cdot \ln \dfrac{\mu_{av}}{\mu_i} F_{0i} y_{0i}}{W_{pl.ent}} \right]^{0.443}, \tag{4}$$

- exit:

$$M_{ex} = 1.827 \cdot M_{pl.ex} \cdot \left[\frac{\sum 2 \dfrac{a_i}{1+a_i} \cdot \ln \dfrac{\mu_{av}}{\mu_i} F_{1i} y_{1i}}{W_{pl.ex}} \right]^{0.485}. \tag{5}$$

The closeness of the relationships between the studied parameters for the input and output, respectively, is 0.946 and 0.937. Expressions (4) and (5) make it possible to calculate the torque values for asymmetric rolling of different profiles of any size and with any number of elements. Attention should be paid to the difference in the values of the main and additional loads, which can be explained by different physical processes occurring during plastic deformation. During plastic bending, the stresses of the latter reach maximum values equal to the yield strength, which characterizes the main load. When rolling with uneven compression, longitudinal interaction forces appear in the deformation zone, determined by additional stresses. The magnitude of the additional stresses, as can be seen from the studies carried out, is less than the yield strength. It is characterized not by plastic loading, but by different extracts in the deformation zone, obeying the laws of mathematical models (4) and (5).

Conclusion

This experiment has shown that an external additional effect on the deformation zone meets the basic requirements for additional control effects - these are different force characteristics of additional and main loading (Figure 3, expressions 4 and 5). The ratio of the external moment to the plastic moment over the entire range of change is less than one, and it can be regulated by the parameter δ and everything that determines it. It follows that additional stresses may be the regulating factor that changes the stress state of the deformation zone.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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