ENERGY AND POWER PARAMETERS OF ROLLING PROFILES FOR WHEEL RIMS WITH REDUCED METAL INTENSITY AND TAPERED SEATS

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ABSTRACT

Analysis of experimental data on rolling asymmetric thin-walled sections with reduced metal consumption can be useful in identifying the features and prospects of application of profiles with reduced metal intensity, allowing obtaining significant economic and technological effects in production. The most mass-produced lightweight rim profiles 7.0-20-03 and 8.5-20-03 were studied to find the energy and power parameters. Rolling force, motor voltage current, revolutions and strip temperature were determined. The experimental data obtained indicate the possibility of mass production of high-performance rolled products for the automotive industry.

Keywords: rolled, metal, profile, stress state, metal saving.

INTRODUCTION

Reducing the metal intensity of rolled products is always associated with the deterioration of technological capabilities of production due to the drop in the temperature at the end of the rolling. A study on the influence of profile weight on the technological parameters of the process is of practical interest [1 - 3].

Rolling thin-walled profiles of complex shape is always accompanied by significant technological difficulties and production losses. This is due not only to the complexity of the profile, increased requirements of consumers to the quality of rolled products, but also due to temperature conditions of rolling. The rim profile is very “sensitive” to temperature. With slight delays, it cools down quickly, and it becomes impossible to continue the process, the rolled product is pushed aside. Everything associated with lowering the temperature at the rolling end is perceived sharply negatively by the shop technologists.

Reducing the profile weight leads to a sharp drop in the temperature of the rolling end, increase in rolling force, stand spring and, consequently, failure to achieve dimensions in thickness, lateral elements, wear of gauges. A series of studies was conducted at the Petrovskiy metallurgical plant to confirm this statement. These studies included measurement of the temperature of rolled product surface when rolling profiles of truck wheel rims in all passes. Based on these experiments, Dinnik et al. and Chigirinsky et al. present a wide range of studies of rolling parameters of auto-rims of different sizes and designs [4, 5].

Analyzing these data, it can be shown that the reduced thickness of the strip in a particular gauge, when rolling different types of rims, correlates with the profile weight and its temperature. Fig. 1 shows the dependence, according to the experimental data of Dinnik et al. and Chigirinsky et al., on the change of strip temperature during rolling depending on the reduced thickness of rolled product for different types of auto-rims [4, 5].

As the profile weight decreases, i.e. the thickness of rolled product, the temperature in the finishing passes

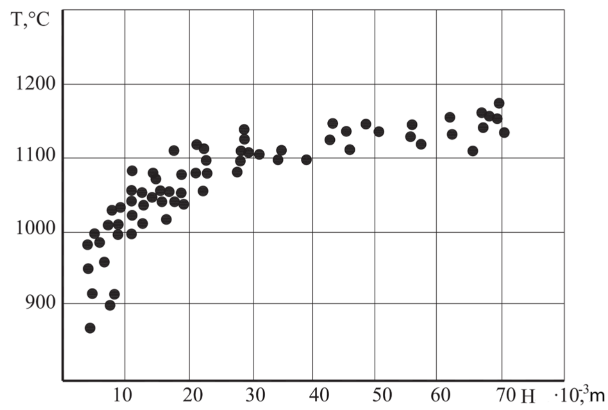

Fig. 1. Experimental dependence of rolled product temperature on the given thickness in the finishing pass.

decreases and can reach a minimum value of less than 900ºC. By weight, in terms of temperature regime, the strained metal can be divided into the following three categories for the profiles and workpieces: heavy weight rolled product for heights 20 - 70 mm the temperature of which varies slightly between 1100 - 1150ºC, intermediate weight rolled product for heights 8 - 20 mm with a temperature of 1000 - 1100ºC, thin-walled rolled product for heights 5 - 8 mm with a temperature of 860 - 1000ºC. Fig. 1 shows that the temperature of the rolling end drops sharply with decreasing profile weight i.e. reduced height, especially for thin-walled sections. This is a destabilizing factor, especially for dimensioning. The rolling process becomes unstable. These objective technological reasons for the implementation of light-weight thin-walled rolled products should be opposed to the possibilities and features of plastic forming, which allow changing the stress state of the rolled product, reduce the rolling force, create the prerequisites for obtaining thin-walled products in adverse thermo-mechanical conditions.

Analysis of plastic deformation effects shows that additional and kinematic effects on the strain zone reduces the rolling force and makes it possible to compensate for the loss of manufacturability, which is associated with a decrease in temperature. This is a determining factor when mastering thin-walled profiles. A positive factor of the applied effects in the finishing passes is the change in profile shape, which can be used to reduce the weight due to recesses in the thin-walled part of the product. Technological features of plastic deformation when rolling thin-walled sections become elements of technological design, if the latter do not have a negative impact on the operational characteristics of the structure.

Reducing the metal intensity of rolled steel is a problematic issue [6 - 11]. In addition to technological problems, there are also problems associated with the strength and operational characteristics of the product. The fundamental question is where, or in what element, to implement the reduction in profile weight. Analysis of the literature shows that it is necessary to strive to create an equal-strength profile, although this problem is not completely solved. Here the loading of each element of the profile is related to its size and weight. The greater the load is, the greater the weight of the element or its dimensions that meet that load. At the sections with minimum stresses there is a possibility of thinning, i.e. reduction of the element weight. In truck wheel rims, such an area is the central part of the profile, called the web, a reduction in the overall size of which is appropriate [12, 13].

To solve the problem of strength, tend to choose the appropriate grade of steel [14, 15]. Recently, this problem has been solved not only by the selection of the chemical composition, but also using multiphase steels.

The contact pressure increases as the temperature decreases. A similar character of the temperature dependence takes place for the rolling force. The temperature factor, determined by thickness (weight), is decisive when rolling thin-walled sections. It has a decisive influence not only on energy consumption, roll wear, etc., but also on the possibility of obtaining the profile in geometric dimensions and, especially, on the rolled product thickness. In a line mill, this factor becomes the main one, because it limits the technical possibility of producing thin-walled sections.

When rolling the URAL - 375 rim profile, the change in torques is in accordance with the change in rolling forces. The torque arm ratio was obtained within the range of 0.45 - 0.79. When rolling ZIL-164 rim profile, total rolling torques is 0.09 - 0.10 MNm within the temperature range of 870 - 900°C. The torque arm ratio is 0.53 - 0.58. For ZIL - 158 rim, total torques is 0.120 - 0.123 MNm within the temperature range of 900 - 970°C. The torque arm ratio for this profile is 0.57 - 0.61.

The dependence of the torque arm ratio on temperature is indicated for different types of profiles. Thus, the force increases as the rolling temperature drops. This should lead to an increase in rolling torque. However, in many cases this is not the case because of the decreasing torque arm ratio.

The above analysis of experimental data of different authors shows that reducing the weight significantly worsens the parameters of rolling process of thin-walled sections [2, 6, 9, 16]. This is mainly due to the inability to get a given thickness profile, which makes it difficult to implement high-performance products. Therefore, this factor shall be taken into account in the development of technology and design of profiles with reduced metal intensity. Obviously, it is necessary to abandon the generally accepted approach, when the reduction of rolled product weight is achieved by its thinning. As shown by experimental preliminary rolling, such approaches have not been successful.

EXPERIMENTAL

The experiment was conducted at the Petrovsky Metallurgical Plant (Dnepropetrovsk, Ukraine) in the conditions of mill 550. The most mass-produced lightweight rim profiles 7.0-20-03 and 8.5-20-03 were studied. Rolling force, motor voltage current, revolutions, strip temperature were determined. To measure the rolling force, diaphragm-type load cells from 40NiCr6 steel were designed and manufactured. They worked in conjunction with a strain gauge amplifier and a magneto-electric oscilloscope.

A device consisting of a photoelectric pyrometer, isolating transformer, voltage stabilizer, and oscillograph was used to measure temperature. The loading of the finishing stand motor was studied by oscillograph.

During the experiment for special profile 7.0-20-03 (7.0 - rim width in inches; 20 - seating diameter in inches; 03 - mastered profile number) (ZIL-130) the rolling force was fixed in the 2nd, 4th, 5th, 6th and 7th passes. Current, revolutions and voltage - in the 5th, 6th and 7th pass. The temperature along the length of the strip was measured in the finishing gauge.

For the lightweight rim 8.5-20-03 (8.5 - rim width in inches; 20 - seating diameter in inches; 03 - mastered profile number) (MAZ-500) the rolling force was recorded in the 5th, 6th, and 7th passes, current, voltage and motor revolutions were recorded in the same passes.

RESULTS AND DISCUSSION

It should be noted that the rolling conditions for series and lightweight wheel rim profiles are different. By the time new profiles with a wave-shaped central part were introduced, there was a transition to a larger workpiece height from 90 to 100 mm. This led to an increase in the total reduction, hence the rolling force. Tables 1 and 2 present the values of rolling process parameters and experimental data on passes of series and lightweight profiles 7.0-20-03 and 8.5-20-03. In this regard, an analysis of the impact of technological capabilities of new design profiles was difficult for the above-mentioned reasons. Nevertheless, implementation experience shows high technological capabilities of their production, which was not observed on the lightweight profiles with traditional rectangular shape of the central part.

Comparative experimental data for rim profiles 7.0-20-03 of serial and lightweight are presented in Table 1. Results were compared for absolute reduction, temperature, rolling force, motor capacity, rolling torque, specific contact pressures.

Compared to the data on rolling of series profiles, the pressure during rolling of lightweight profiles in all passes, except for the 6th pass, increased by 35 - 45 %, which is in accordance with the pass reduction.

The increase in the finishing pass was up to 67 %. This significant increase in rolling force can be explained not only by an increase in reduction, but also by a drop in the temperature at the rolling end. The temperature decreased from 960 - 1000ºC to 820 - 940ºC, while the rolling force increased from 1.8 - 2.1 MN to 2.4 - 3.5 MN. Fig. 2 shows experimental rolling forces of profile 7.0-20-03 as a function of temperature.

The experimental data presented in Fig. 2 qualitatively defines and responds to the obvious dependencies of rolling force on temperature for lightweight rim designs.

Fig. 3 shows experimental data on the dependence of rolling torque on the temperature factor when rolling a lightweight profile 7.0-20-03 in the last pass. Data analysis in Fig. 3 shows that the rolling torque does not change with a change in temperature, i.e. the decrease in the product metal intensity does not affect the energy parameters of the process.

As the temperature decreases, the rolling force increases (Fig. 2), but for the torque (Fig. 3) this correspondence is not confirmed. It can be assumed

Table 1. Results of experimental data for rolling of series and lightweight profiles 7.0-20-03.

Rolling parameters	Profile type	Pass No.						
		1	2	3	4	5	6	7
Reduction, mm	Lightweight	24.8	22.1	19.2	15.8	6.4	2.4	2.4
	Series	19.5	21.0	25.8	9.8	7.5	4.5	2.2
Temperature, ºC	Lightweight	-	-	-	-	-	-	820 - 940
	Series	-	-	-	-	-	-	960 - 1000
Rolling force, MN	Lightweight	-	2.1 - 2.8	-	2.4 - 2.7	-	1.6 - 2.0	2.4 - 3.5
	Series	-	1.4 - 1.9	-	1.4 - 1.9	-	2.0 - 2.3	1.8 - 2.1
Motor capacity, kW	Lightweight	-	-	-	-	1307 - 1982	825 - 1228	1249 - 1789
	Series	-	-	-	-	-	1010 - 1230	1100 - 1230
Rolling torque, MNm	Lightweight	-	-	-	-	-	0.06 - 0.12	0.08 - 0.11
	Series	-	-	-	-	-	0.08 - 0.10	0.11- 0.12
Specific pressure, MPa	Lightweight	-	-	-	-	-		401.2 - 575.4
	Series	-	-	-	-	-		316.0 - 394.0

Table 2. Results of experimental data for rolling of series and lightweight profiles 8.5-20-03.

Rolling parameters	Profile type	Pass No.						
		1	2	3	4	5	6	7
Reduction, mm	Lightweight	25.5	24.1	18.1	6.8	11.5	3.1	1.6
	Series	20.5	19.0	18.8	6.2	10.7	2.6	3.5
Temperature, ºC	Lightweight	-	-	-	-	-	-	810 - 910
	Series	-	-	-	-	-	-	950 - 1000
Rolling force, MN	Lightweight	-	-	-	-	-	1.14 -1.98	3.09 - 3.91
	Series	-	2.4 - 2.7	-	2.25 - 2.6	-	1.45 -1.85	4.0 - 4.8
Motor capacity, kW	Lightweight	-	-	-	-	1329 - 1690	729 - 1095	1335 - 1749
	Series	-	-	-	-	-	610 - 775	1750 - 2000
Rolling torque, MNm	Lightweight	-	-	-	-	-	0.05 - 0.07	0.06 - 0.08
	Series	-	-	-	-	-	0.06 - 0.08	0.21 - 0.23
Specific pressure, MPa	Lightweight	-	-	-	-	-	-	517.0 - 671.8
	Series	-	-	-	-	-	-	385.0 - 461.0

that the torque arm depends on the temperature in the opposite way than the rolling force. Presumably, the torque arm ratio increases with increasing temperature, which is confirmed by many researchers [16 - 18]. The well-known formula for determining the rolling torque is [19]:

$$M = 2 . P . l_d . \psi, \qquad (1)$$

where P - rolling force; l_d - contact arc lenght; ψ - torque arm ratio.

The expression shows that to keep the torque M constant when the force P increases, the torque arm $l_d \cdot \psi$ shall decrease, and vice versa, when the force P decreases, it shall increase. Within the investigated values, it can be seen that with increasing rolling force

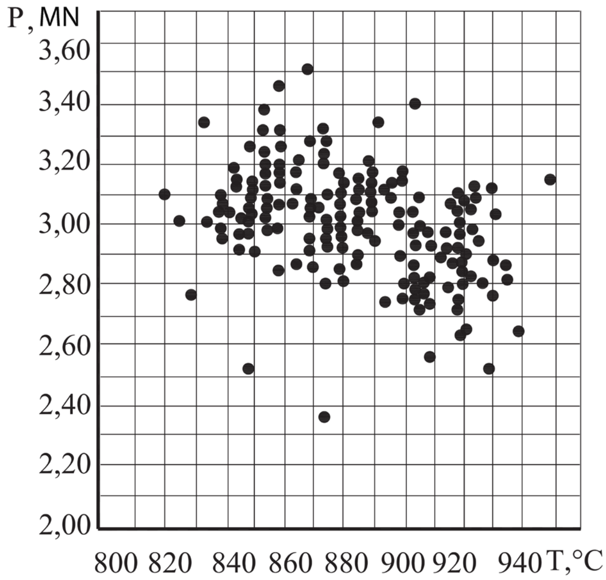

Fig. 2. Dependence of rolling force on temperature in the finishing gauge of lightweight profile 7.0-20-03.

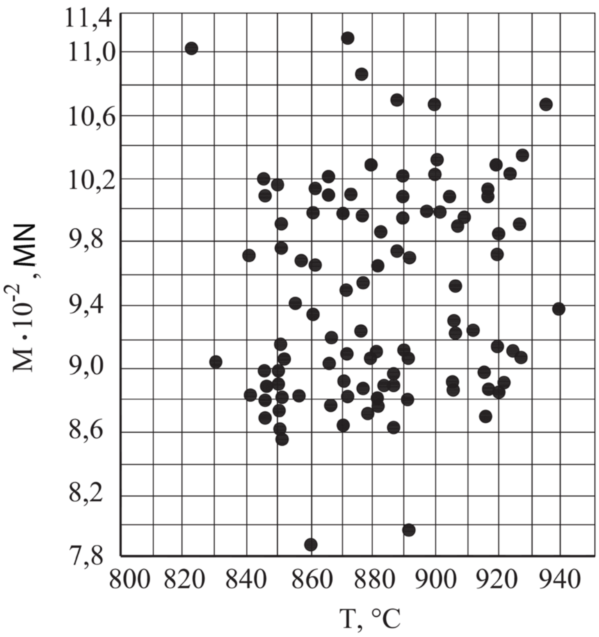

Fig. 3. Dependence of rolling torque on temperature in the finishing gauge of lightweight profile 7.0-20-03.

at decreasing temperature, torque constancy is possible when the torque arm ratio will decrease.

For profile 7.0-20-03, increased reductions and decreased temperature of the rolling end contribute to an increase in rolling force. Two factors contribute to the rise in pressure at the same time. At the same time, the rolling torque has not increased, and there is even a tendency for it to decrease on the lightweight profiles. Since profile 7.0-20-03 is the narrowest of the series of wheel rim profiles, then in combination with the effect of kinematic effects the rolling force fluctuations do not seem critical and for this mill is quite acceptable. Rolling of lightweight thin-walled profiles of this size and shape can be successfully implemented despite unfavorable parameters of the rolling process. In addition to the analysis of energy and power parameters of the process, the most important circumstance is the experience of lightweight profile rolling on the mill. It shows that when reducing the metal intensity of the product in the central area by traditional method by thinning the sheet, a positive result in the rolling process could not be obtained. The process of mastering the profile began to fail. The profile did not turn out according to thickness, there were roll breaks, and there were constant delays on the mill due to readjustment to size. At the same time, a rim with a wave-shaped central part lighter by the same value behaved differently during rolling: the profile thickness was obtained in all elements, mill downtime and roll failures were noticeably reduced. In the end, this was the decisive factor in the implementation of lightweight profiles in production.

The results were compared for absolute reduction, temperature, rolling force, motor capacity, rolling torque, specific contact pressures (Table 2), for profile 8.5-20-03.

Analysis of the rolling process of profile 8.5-20-03 (Table 2) shows that the rolling force in the finishing pass decreased, despite the drop in temperature from 950 - 1000ºC to 810 - 910ºC. This is facilitated by the decrease in reduction together with the kinematic effect on the strain zone.

Profile 8.5-20-03 has the widest rim. The maximum deformation forces for this mill were recorded in the range of 4.0 - 4.8 mN (400 - 480 Tf) during rolling. Technological capabilities on this rim design are minimal, as evidenced by the difficulties in obtaining the necessary thickness on the passes, and especially in the finishing gauge. The recorded rolling torque has not increased, and its value has a noticeable decrease in the finishing pass. There is a confirmation of the kinematic effect by forces and torques.

Fig. 4 shows the effect on rolling forces from the temperature in the finishing pass of the profile 8.5-20-03.

As the rolling temperature increases, the deformation force decreases for the widest profile 8.5-20-03. When the temperature at the rolling end decreases from 950-1000ºC to 810 - 910ºC, the rolling force increases accordingly from 3.09 - 3.91 MN to 4.0 - 4.8 MN. This is mainly due to the yield strength, which is essentially confirmed by the data when rolling the profile 7.0-20-03. Such a comparison over the profiles of obvious dependencies is necessary to obtain the result and analyze the torque arm ratio from temperature, since the same experimental data are used.

Fig. 5 shows the dependence of rolling torque on strip temperature in the finishing pass for the profile 8.5-20-03, which indicates that the rolling torque in the finishing pass does not depend on temperature.

The decrease of metal intensity of 8.5-20-03 profile does not affect the rolling torque as with 7.0-20-03 profile rolling. It is of interest to study the dependence of rolling torque on factors determined by thermo-mechanical production parameters. As the metal intensity of profile decreases, the temperature of the rolling end changes (Fig. 1) and the pressure increases. At the same time, the torque should also increase, because one of its components is the force of plastic shaping. However, the torque behaves differently according to experimental data.

After processing the experimental data, using the formula for torque, the values of torque arm ratio as a function of temperature were obtained. There is a correspondence between these values, which can be described by a linear regression equation. The method of least squares determined the regression coefficients. After calculating the regression coefficients for profiles 7.0-20-03 and 8.5-20-03, the expression is as follows:

$$\psi = 0,00145 \cdot T - 0,70670 \qquad (2)$$

The correlation coefficient of the obtained dependence is 0.65, which indicates a high density of the studied parameters. It follows from expression (2) that as the temperature T increases, the torque arm ratio ψ also increases. If the temperature of the rolling end is 900°C, the torque arm ratio takes a value of 0.598, i.e. the points of application of the resultant force are shifted towards the entry into the strain zone.

Reducing the metal intensity of the profile leads to a noticeable drop in the temperature of the rolling end

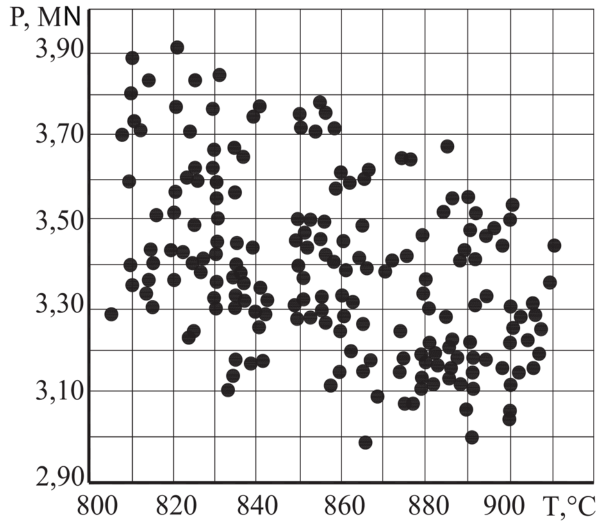

Fig. 4. Dependence of rolling force on temperature in the finishing gauge of lightweight profile 8.5-20-03.

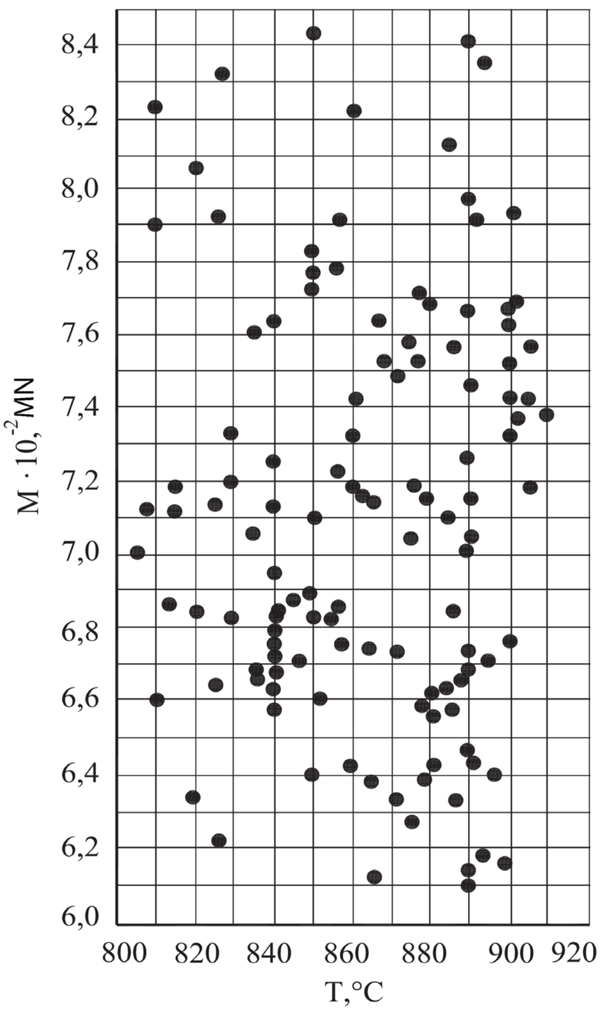

Fig. 5. Dependence of rolling torque on temperature in the finishing gauge of lightweight profile 8.5-20-03.

(Fig. 1). The strip temperature affects the rolling force and the torque arm ratio. This effect is reversed. The rolling force increases with decreasing temperature, while the torque arm ratio decreases.

Data analysis (Table 2) for the torques shows that for the series profile they are larger than for the lightweight one. On this profile, the torques was more sensitive to the influence of the rolling force than to the influence of the torque arm ratio.

The experimental data obtained indicate that the process of rolling thin-walled sections with reduced metal intensity is influenced by various factors, including strip width, temperature, reduction, and, as experience shows, the shape of the finish profile, which should be obtained in the last finishing pass.

According to the data presented in Tables 1 and 2, there is an increase in metal pressure on the rolls in the transition from narrow to wide profile. For the series profile of ZIL- 130 vehicle the transition to the profile of MAZ - 500 vehicle increases the rolling force by 55 - 56 %. With a decrease in temperature by 60 - 140°C, the increase in rolling force within the profile for 7.0-20-03 occurred by 6.0-14.6 %. At the same time, the reduction changed insignificantly in the finishing pass.

For a wide profile 8.5-20-03, a decrease in reduction by 54.3 % resulted in a decrease in rolling force by 18.5 - 22.8 %. It should be considered that the rolling temperature decreased by 9.0 - 14.7 %, contributing to an increase in pressure. For the profile 7.0-20-03, the decrease in rolling temperature is about the same as for the profile 8.5-20-03, giving an increase in force of 6.0 - 14.6 %. Increased force with a general decrease in temperature has to be compensated by something else. Then, presumably, the total reduction of force will be in relative values, respectively, 24.5 - 37.4 %, i.e. almost up to 40 % with a decrease in reduction by 54.3 %. This is not comparable, especially if we consider the nonlinearity of the process. Since the effect of force decrease is superior to the effect of reduction decrease, there shall be some other factor that reduces the rolling force. These are plastic flow effects in the case of a wave-shaped profile. It should be considered that the profile 8.5-20-03 (MAZ-500) is the widest and most “heavy” to get the size of the thickness. Experience with rolling a lightweight profile with a wavy center section (8.5-20-03) shows that all elements of the profile were made within the tolerances, and, moreover, it was possible to roll with a minus tolerance. At the same time, rolling the profile of reduced metal intensity with a thinned central part (without the kinematic effect) gave a negative result. The profile could not be obtained.

CONCLUSIONS

All the data presented in this article indicate that the production of profiles with a wave-shaped central part in real production conditions confirms the effects of plastic flow and allows the implementation of stable rolling process of thin-walled products with reduced metal intensity. The wavy shape of central part of the finishing profile increases the width of the web, which reduces the partial stretching of the heavily reduced element. Redistribution of partial stretches across the width of the strip changes the character of the stress state.

An important circumstance is the reaction of the rolling torque to the reduction of metal intensity of the rolled section. In fact, it does not react to the reduction of the rolling end temperature. Consequently, the rolling of lightweight profiles takes place without energy losses, because the rolling torque is an energy parameter.

The experimental data obtained indicate the possibility of mass production of high-performance rolled products for the automotive industry.

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