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Optimization of rolling modes on the mill 1700 of JSC "ArselorMittal Temirtau" with aim to increase quality of sheet rolled products

Naizabekov A.B.[1], Talmazan V.A.[2], Lezhnev S.N.[2a], Panin E.A.[2b], Erzhanov A.S.[2], Tolkushkin A.O.[2c]

[1]Rudny industrial institute, Rudny

[2]Karaganda state industrial university, Temirtau

[a]sergey_legnev@mail.ru, [b]cooper802@mail.ru, [c]mrgugimon@gmail.com

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Abstract. Used the influence of technological factors of the rolling process on the intensity of the rolling out of the defect to determine the value of deformation and the coefficient of use of the plasticity resource. Introduced the notion of residual coefficient of plasticity resource in the second stage of transformation of the defect. Found that the causes of deterioration of the quality of cold-rolled sheet can be numerous defects of mechanical origin, caused by mechanical damage of the sheet surface. Conducted an analysis of profiles rolling modes, rolled on the mill 1700. With the use of existing methods calculated DUPR on workshop modes of rolling of specified profiles with and without considering the surface defects. Carried an optimization of the modes of strip rolling with surface defects.

Introduction

The intensive development of production requires rolling production of high quality of rolled products, intended for the manufacture of various parts and equipment. Rolled products in addition to a high surface quality, thickness variation, waviness and buckling must have the best structure and high plasticity that enables the production of parts of complex configuration by the method of deep drawing. Along with the growth of production and consumption of steel sheet, requirements to the quality of this product continuously increase. Quality of sheets and strips determines by the accuracy of their size and shape, chemical composition and physic-mechanical properties of steel, surface quality [1].

Change of requirements to the surface quality of sheet metal for various purposes reflected in the standards and technical specifications for this product. Standards reflect and reach the steel industry, rolling production.

Industries, which consume metal, have different requirements to the surface quality of rolled products. This is due to the different purpose of the metal and it is determined by the technology of further processing of sheets, strips, sheet metal (stamping, painting, metal coating and others), and the requirements to the surface quality of products manufactured from steel sheet. The most stringent requirements apply to hot-rolled and cold-rolled steel intended for the manufacture of cold-formed body parts of automobiles, etc. In the classification of steel sheet by surface groups in standards for the main criterion accepted the presence of surface defects.

Thus, in mechanical engineering a significant portion of the sheet product subjected to stamping operations. The quality of the rolled products depends largely on the quality of finished products. Thus, one of the primary tasks is to improve the quality of steel products [2].

The surface of hot rolled and cold rolled strips and sheets for one reason or another often affected by defects. This metal cannot be used effectively in industry. The defect on the surface of the sheet billet during deformation will cause in the appropriate place stress concentration and a sharp increase of the degree of deformation of the metal. The defect will be the destruction zone of the metal during further processing.

Currently, the production of cold rolling oriented to the manufacturing of new products, including rolled metal for the cold upsetting, defining indicator of the quality of which is the absence of surface defects. In this regard, it is important to identify the factors influencing on the formation of such defects [3].

Research methodology

According to [4] the process of destruction of metal by cold deformation depends on the plastic characteristics, the degree of deformation and stress state. Any metal for a given stress state during the deformation has a resource of plasticity, defined as the degree of deformation of the metal to fracture λ_D. Use of reserve of plasticity characterizes by the magnitude:

$$\Psi=\lambda/\lambda_D, \tag{1}$$

where λ – current deformation, $\lambda=\ln(F_0/F_1)$;
λ_D – deformation of destruction, $\lambda_D=\ln(F_0/F_D)$.

For low-carbon steel in the cold rolling conditions and based on the known assumptions, according to the method [5], known equation:

$$\lambda_D = \lambda_{DU} \exp 0{,}565\left(\frac{2\rho_{mean} - 1{,}15R_{0.2mean}}{R_{0.2mean}} - 1\right), \tag{2}$$

where λ_{DU} –degree of deformation to fracture under uniaxial tension;
ρ_{mean} – mean specific pressure on the metal rollers;
$R_{0.2mean}$ – yield strength of the metal.

To determine the value of deformation and the coefficient of the plasticity resource at the stage of transformation of the surface defect use the influence of technological process factors on the intensity of the rolling out of the defect. As a criterion for the intensity of rolling out adopted a parameter:

$$I_\delta = 0{,}19\left(1 - e^{-0{,}9n_R}\right)\left[1 + \left(h_0^2/b_\delta^2 + 9h_0^2/l_\delta^2\right)\left(0{,}04 + 0{,}004Ra\right)\right], \tag{3}$$

where n_R – coefficient of stress state;
b_δ and l_δ – respectively, the width and length of a surface defect;
δ_0 and δ_i – initial and actual defect depth;
h_0 and h_i – initial and actual strip thickness;
Ra – roughness of the work rolls.

This parameter characterizes the change of the relative depth of defect per deformation unit.

It is known that during transition from tensile stress to compressive in the deformation process occurs recovery of plasticity resource. To account for this phenomenon introduced the concept of residual coefficient of plasticity resource in the second stage of transformation of the defect:

$$W = 1 - \psi^k, \tag{4}$$

where ψ – coefficient of use of plasticity resource of metal during defect transformation;
k – coefficient, determining the degree of plasticity resource recovery during transition from uniaxial tension to rolling.

Studies have shown that during changing uniaxial tension rolling coefficient k may be taken as 1.48 [6].

According to [7] total volume of production of cold rolled products at CRM-2 of JSC "ArselorMittal Temirtau" for the year 2009 concluded 674553.43 tons. In rolls produced 500638.45 tons (74%), in sheets– 173914.98 tons (26%).

Produced products characterizing by a variety of quality, availability of reject and non-condition (Table 1).

Table 1. Quality of products manufactured at CRM-2 for the year 2009.

Name	Rolls		Sheets	
	t	%	t	%
First grade	477871,07	95,453	166997,83	96,023
Second grade	18148,24	3,625	4176,14	2,401
Third grade	4407,30	0,880	2707,51	1,557
Non-condition	201,35	0,040	25,98	0,015
Reject	10,49	0,002	7,52	0,004
Total:	500638,45	100	173914,98	100

Quality of cold rolled sheet at JSC "ArselorMittal Temirtau" regulated by GOST 9045-93, GOST 16523-97, ASTM A568M-98, EN 10131-93, JIS G 3141-96, and other. According to them cold rolled sheets of various grades must correspond to certain requirements.

Causes of deterioration of the quality of cold-rolled sheet can be numerous defects of mechanical origin, caused by mechanical damage of the surface of the sheets.

On Fig. 1 and 2 shown graphs, characterizing by rejection of cold-rolled metal in CRM-2 for the year 2009 by defects of mechanical origin: "dimple", "imprints", "scribes" and "scratches".

The percentage of defects of mechanical origin out of total number of sorted metal are following: "dimples" – 1.82%, "imprints" – 0.46%, "scribes" – 0.29%, "scratches" – 0.7%.

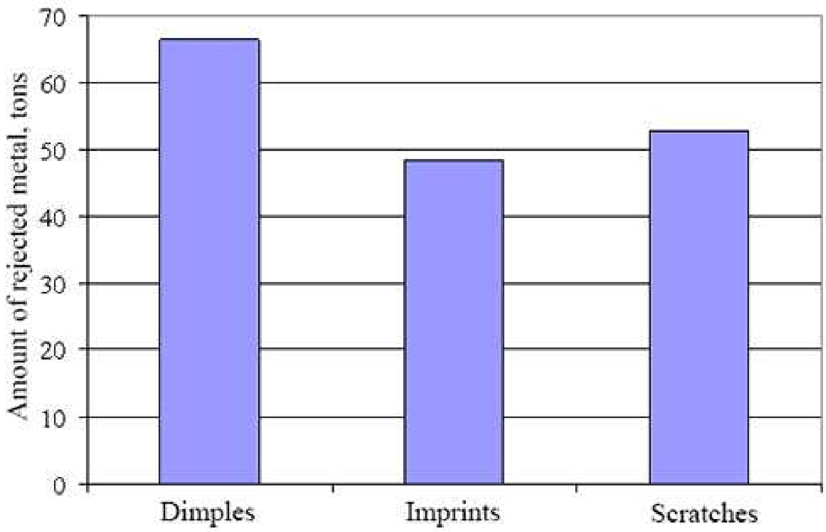

Fig. 1. Amount of sheet products, sorted in the second grade by the defects of mechanical origin

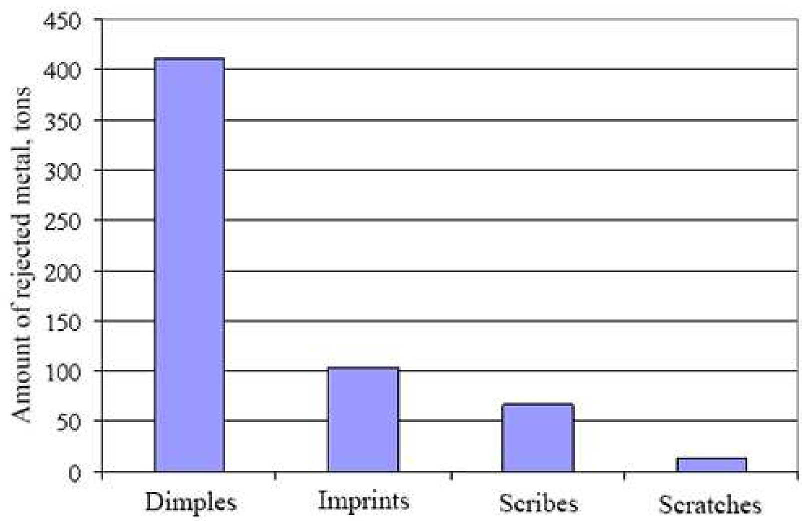

Fig. 2. Amount of roll products, sorted in the third grade by the defects of mechanical origin

Conducted an analysis of profiles rolling modes, rolled on the mill 1700. Probability of formation of strip burst evaluating with the use of degree the use of plasticity resource (DUPR). When plasticity totally exhausted in place of occurrence of surface defects are formed open tears.

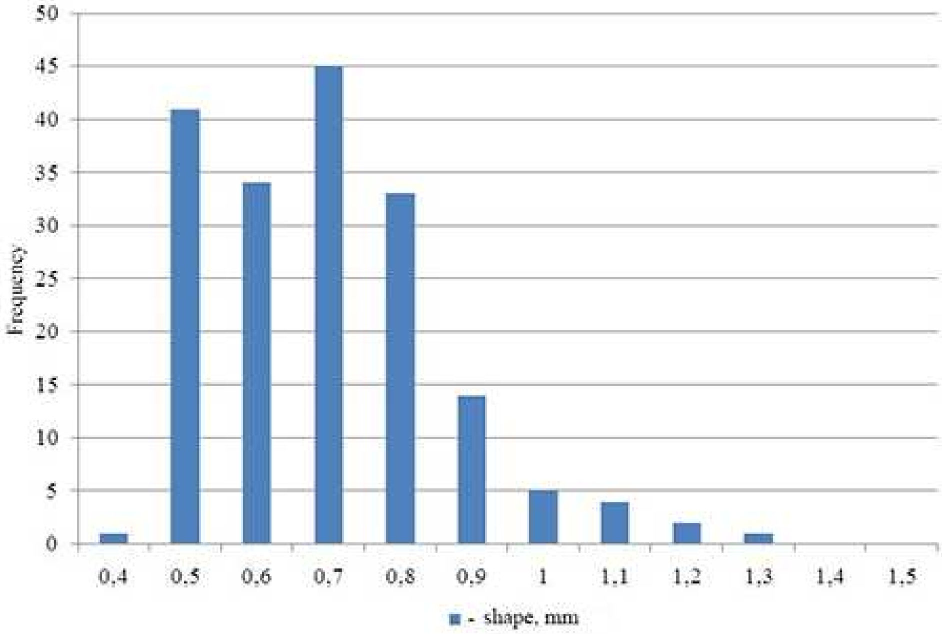

Fig. 3. Rejection of profiles by surface defects

From Fig. 3 it is seen, that the most frequently surface defects occurs in thin shapes with thickness 0.5 and 0.7 mm. Respectively, during rolling of thin sheets there is a great probability of occurrence of strip burst.

In Tables 2 and 3 presented modes of rolling of shapes 0.5×1000 mm and 0.7×1000 mm.

Table 2. Workshop modes of rolling of shape 0.5×1000 mm

Stand number	h_0, mm	h_1, mm	ε, %	ε_Σ, %	q_0, MPa	q_1, MPa
1	2,50	1,67	33,4	33,4	50,00	181,92
2	1,67	1,07	36,0	52,7	181,92	201,50
3	1,07	0,73	32,0	70,8	201,50	174,52
4	0,73	0,55	25,0	78,0	174,52	160,36
5	0,55	0,50	8,0	80,0	160,36	90,00

Table 3. Workshop mode of rolling of shape 0.7×1000 mm

Stand number	h_0, mm	h_1, mm	ε, %	ε_Σ, %	q_0, MPa	q_1, MPa
1	2,80	1,99	29,06	29,06	50,00	201,91
2	1,99	1,39	30,00	50,35	201,91	204,46
3	1,39	1,00	28,00	64,29	204,46	176,40
4	1,00	0,76	24,00	72,86	176,40	167,63
5	0,76	0,70	8,00	75,00	167,63	90,00

With the use of existing methods calculated DUPR on workshop modes of rolling of specified profiles with and without considering the surface defects (Fig. 4 and 5). During calculations used sizes of defect "dimple". The most common defect is "dimple" with diameter 2 mm and average relative depth δ_0/h_0=0.16.

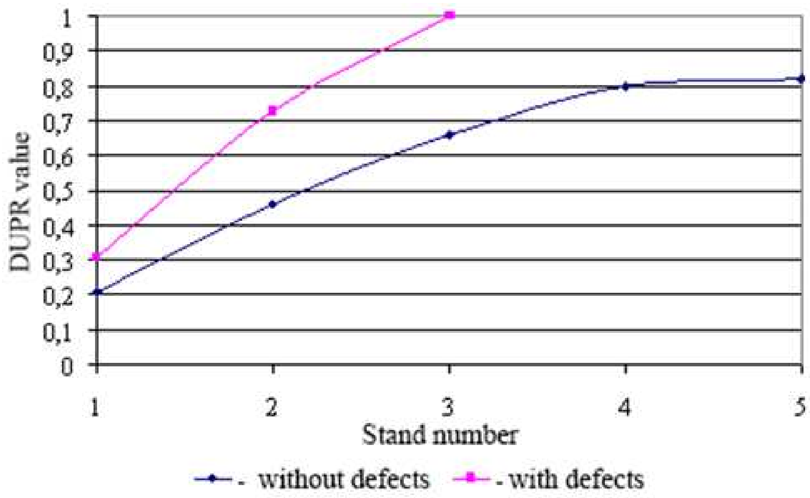

Fig. 4. DUPR for workshop mode of rolling of shape 0.5×1000 mm

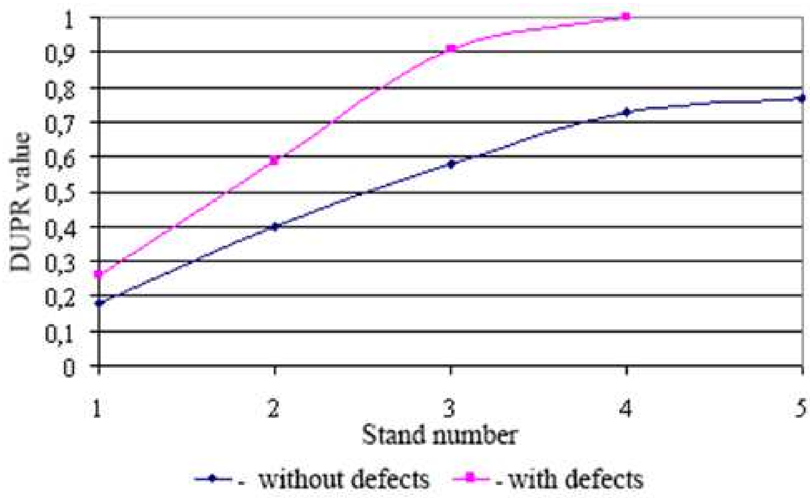

Fig. 5. DUPR for workshop mode of rolling of shape 0.7×1000 mm

Results and discussion

Analysis of the calculations shows that the presence of a surface defect on the strip for shapes 0.5×1000 mm and 0.7×1000 mm during rolling in the defect zone occurring the exhaustion of the plasticity resource in the third and fourth stands, respectively. Exhaustion of the plasticity resource in some cases leads to the destruction of the strip. During rolling of strips without defects for the specified profiles DUPR concluded 0.82 and 0.77, respectively.

The deformation zone during rolling is characterized by the presence of the backward and forward slip zones. Sources of contamination of the surface, reducing its degree of purity, are mainly the products of wear of the surface layers of the strip and the rolls in the deformation zone, as well as the decomposition products of coolant. The main causes of these products - contact friction in the deformation zone and the high level of normal contact stresses. For the backward slip zone in the deformation zone is characterized by the following: the vector of linear speed of the roll is greater than the velocity of the strip; therefore, in the backward slip stress of friction is directed forward to rolling direction. Resulting products of decomposition and deterioration actively submitted by rollers out of deformation zone, thereby continuously self-cleans. In the forward slip zone friction stress is directed against the course of rolling, so the removal of the products of decomposition and deterioration out of deformation zone is difficult, they accumulate in the deformation zone, which leads to the increase of the amount of contaminants on the strip and defect formation. Especially this phenomenon is important during rolling in last stands, where occurs the final formation of the strip surface.

Surface defects are a kind of stress concentrators in the places of which occurrence, during rolling can be formed open tears, and, as a consequence, this can lead to the burst of the strip, as well as the integrity of the working layer of rolls barrel. Control of the degree of use of the plasticity resource in the zone of surface defects will increase their rolling out, reduce burst of the strip during rolling, and as a consequence improve the quality of steel products.

As the objective function during optimization of rolling modes can be considered the total length of the forward slip zone for all deformation passages, with the existing constraints [8, 9]:

$$\sum_{i=1}^{n} l_2 = \min\left\{l_{2_i} + \ldots + \left(l_{2_n}\right)_{\min}\right\}. \quad (5)$$

Using works [10-14] made the optimization of the rolling modes of strip with surface defects. Calculation of power parameters consists of finding the main parameters of rolling (load, rolling power and others) and the deformation zone (the length of the forward and backward slip zones and others). Calculation of DUPR consist of determining the intensity of the rolling out of the surface defect and calculating of degree of use of the plasticity resource.

In the forward slip zone of the deformation zone may occur the process of defect formation due to friction directed against rolling process and caused by the increase of the velocity of metal relative to the speed of rolls. To reduce defect formation for the optimization parameter adopted the total length of the forward slip zone for the whole cycle of rolling. Rolling cycle is divided into five stages (by analogy with the continuous five stand cold rolling mill 1700 of JSC "ArcelorMittal Temirtau"). The program is designed in such a way that the final parameters of each previous stand are the initial parameters of each subsequent.

Performed calculations by optimization of reductions modes on the mill 1700 of JSC "ArcelorMittal Temirtau" with shapes of 0.5×1000 mm and 0.7×1000 mm made of steel AISI 1008. As a result of calculation on the computer optimized the variants of reductions modes and tensions, providing rolling of these shapes and satisfy specified constraints. Optimization of the rolling mode calculated by minimizing the length of the forward slip zone in the last stand, this is due to the fact that in this stand occurs the final formation of the strip surface.

Data comparison of workshop and optimized rolling modes are shown in Table 4.

Table 4. Rolling modes of strip with thickness 0.7 mm, obtained from steel with thickness 2.8 mm

Stand number	Workshop mode				Proposed mode			
	ε	ε_Σ	q_1	Ra	ε	ε_Σ	q_1	Ra
	%	%	MPa	micron	%	%	MPa	micron
1	29,06	20,0	201,91	0,8	32,14	32,14	262,48	1,2
2	30,00	50,35	204,46	0,8	34,21	55,36	306,69	1,2
3	28,00	64,29	176,40	0,8	32,00	69,64	264,60	1,2
4	24,00	72,86	167,63	0,8	16,47	74,64	217,92	1,2
5	8,00	75,00	90,00	3,2	1,40	75,00	90,00	5,6

Rolling energy-power parameters of the optimized mode do not exceed the maximum permissible values. Comparison of workshop and optimized modes are given in Fig. 6-9.

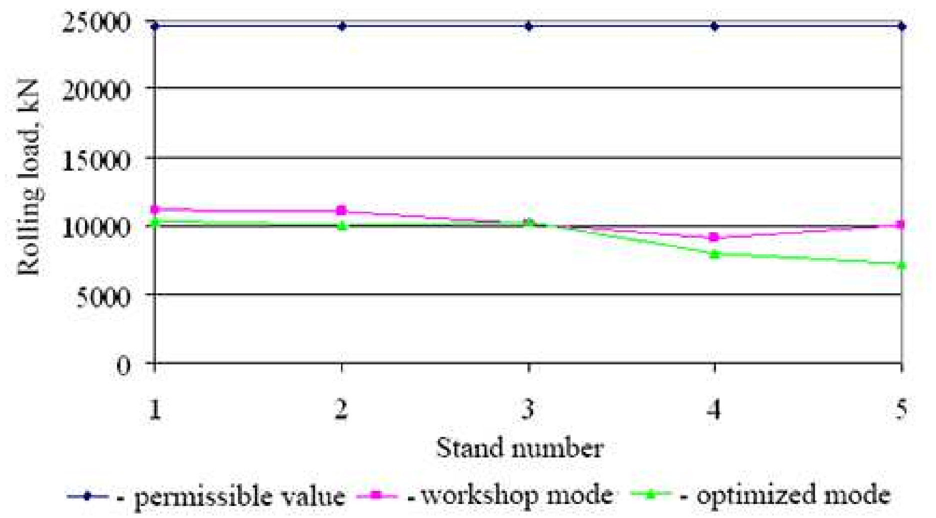

Fig. 6. Rolling load

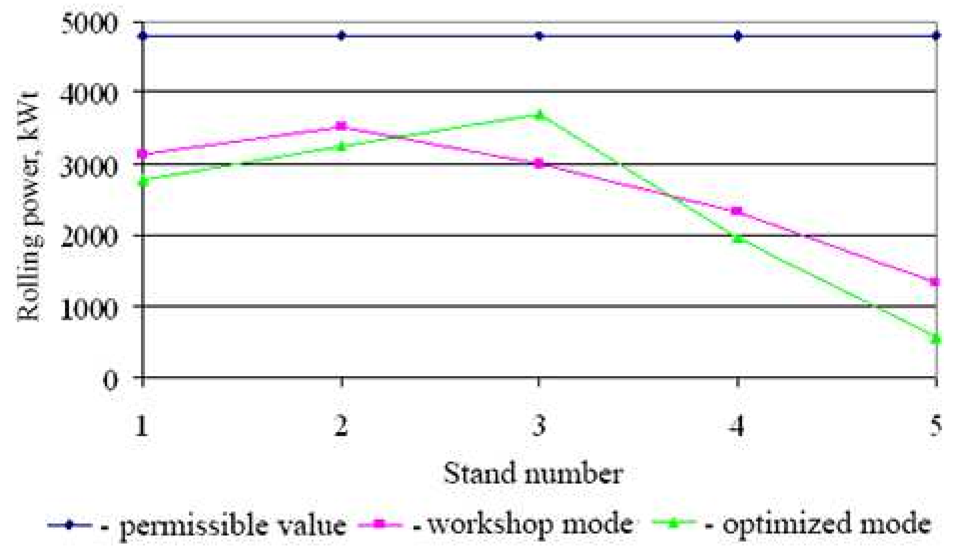

Fig. 7. Rolling power

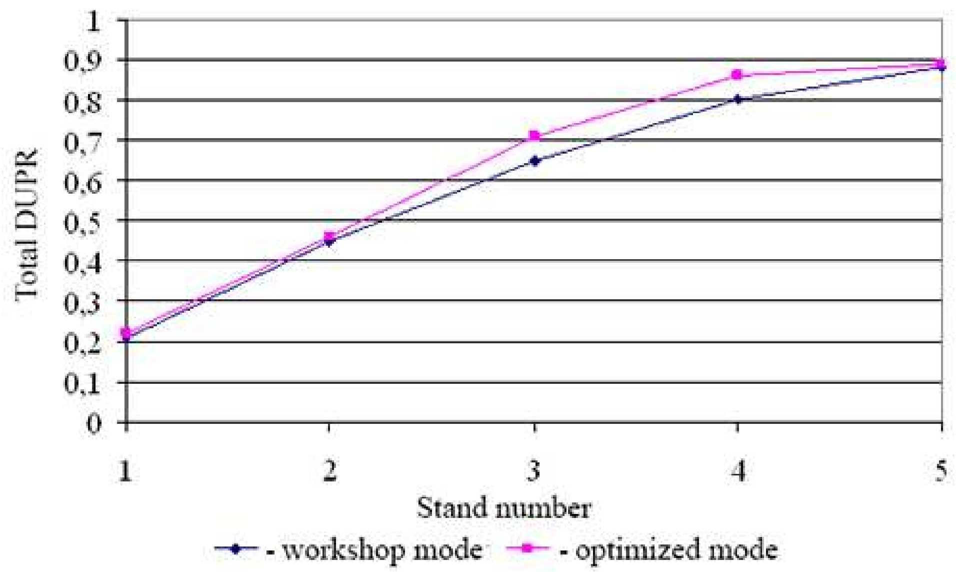

Fig. 8. Total degree of the use of plasticity resource

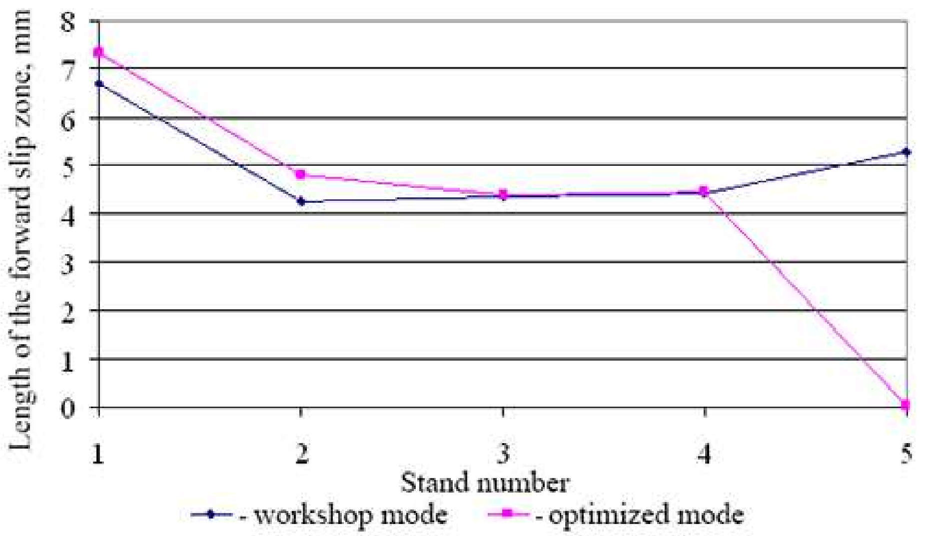

Fig. 9. Length of the forward slip zone

Tension during rolling on workshop mode is in the range of $0.2 \cdot R_{0.2}$, increasing the tension to $0{,}275 \cdot R_{0.2}$ causes a slight lowering of the rolling forces (Fig. 6). Redistribution of reductions in stands leads to some increase of rolling power in the third cage (Fig. 7). Optimized rolling mode is characterized by a more intensive use of the plasticity resource, without complete exhaustion of it (Fig. 8). More intensive use of the plasticity resource on the one hand has a positive effect on rolling out of surface defects, on the other hand there is a risk of exhaustion of plasticity resource, which can lead to the destruction of the strip in the deformation zone.

In the last stand occurs final formation of the strip surface, hence reducing the length of the forward slip zone will have a positive impact on reducing the defect formation during rolling.

According to [15, 16] regulation of the length of the forward and backward slip zones in the deformation zone, it is possible to influence on the process of reject of metal by surface defects such as "scratch", "scribe" and others In the last stand, the length of the forward slip zone in optimized mode is 0.02 mm, which is much less when compared with the workshop mode of rolling, therefore, theoretically it is possible to expect reduction of rejection by the surface defects of a mechanical origin.

Summary

Conducted an analysis of existing modes of rolling at JSC "ArcelorMittal Temirtau" of profiles, sorted and rejected by defect "dimple". Found that the presence of surface defect on the strip with relative depth $\delta_0/h_0=0.16$, in the defect zone DUPR exceeded, this in turn can cause the burst of the strip during rolling. Carried an optimization of regimes of cold rolling at the mill 1700. Optimization of the rolling mode calculated by minimizing the length of the forward slip zone of the last stand, this is because that at this stand occurs the final formation of the strip surface. Comparison of workshop and optimized modes showed that the energy-power parameters of the rolling does not exceed the maximum permissible values. Reducing the length of the forward slip zone on the last stand has a positive effect on reducing the defect formation, because during final formation of the strip surface in this zone, the stress of friction directed against the course of rolling, so the removal of the products of decomposition and deterioration out of deformation zone is difficult.

The results of the optimization calculations showed that with the increasing the front tension and relative reduction is seen a slight reduction of the rolling force and power rolling, except for the cage number 3. It should be noted that DUPR increases. In the fourth and fifth stands both workshop and optimized modes of DUPR does not reach the critical value of 1.0. With regard to the target function, the length of the forward slip zone l_2 by optimized mode in the first two stands higher than in the workshop mode (for the first stand: l_2^{shop} = 6.7 mm and l_2^{opt} = 7.37 mm; for the second stand: l_2^{shop} = 4.37 mm and l_2^{opt} = 4.79 mm), in the subsequent third and fourth stands they are close by value (4.4 mm and 4.5 mm). The most important thing during optimizing of rolling mode is a sharp decrease of the length of the forward slip zone in the fifth stand to the values 0.098 mm (in workshop mode, the value of the length of the forward slip zone in the fifth stand is 5.29 mm).

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