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Influence of emulsols type on energy-power consumption and surface contamination at DC01 steel cold rolling on the continuous four-stand mill

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Abstract

The article presents the results of experimental and industrial tests of physical and chemical parameters of the experimental emulsol "Quakerol". According to the physicochemical parameters the experimental emulsol "Quakerol" differs from the used emulsol "Universal-1TS" by higher lubricating properties. Operating modes of stand and coiler electric motors of tandem mill at rolling of melts from experimental emulsol "Quakerol" lubricated with emulsol "Quakerol" and serial emulsol "Universal-1TC" lubricated with conservation oil "OK-2" at LPTs were analyzed. The results of analysis of loads at rolling of strips with 0.68×1000 mm cross-section from pre-rolled sheet with thickness of 3.0 mm showed that the values of average total loads on stand motors and coiler of four-stand mill 1680 were higher when using experimental emulsol "Quakerol". The comparative analysis of experimentally obtained data on influence of technological conditions of cold-rolled coils production at four-stand continuous tandem mill 1680 with using emulsols "Quakerol" and "Universal-1TS" on rolling power parameters, power consumption and contamination of DC01 flat carbon steel surface is presented. Multiple regression equations were obtained to describe power consumption during rolling using different emulsions, the values of cross-sectional area were taken as a varying factor. Specific power consumption and average total load on stands and coiler motors during rolling with the use of emulsion prepared from experimental emulsion "Quakerol" and emulsion prepared from standard emulsion "Universal-1TS" were estimated. The reasons of higher specific power consumption during LCL operation with the experimental emulsion were analyzed. A quantitative assessment of contamination of the surface of steel samples using the experimental emulsion "Quakerol", oil "OK-2" and standard emulsion "Universal-1TS" is given. The necessity of further tests to determine the optimal concentration of emulsion from "Quakerol" to ensure the reduction of energy costs per ton of cold rolled steel has been substantiated.

The practical significance of the work lies in the development of methods for analysis of lubricants with regard to the prospects of using "Quakerol" emulsion instead of "Universal-1TS" emulsion in order to improve the quality and increase the productivity of the cold-rolling shop.

Key words: cold rolling, 1680 continuous mill, emulsol, energy consumption, specific consumption of electricity, surface contamination

Introduction

Today, four-high mills are the most common rolling equipment for the production of cold rolled flat (& coiled) steel. Such equipment is quite powerful and energy-consuming. Four-high mills are used for production of cold-rolled sheets and strips 0.6-2.5 mm thick and 1300-1800 mm wide as finished products from 3-8 mm thick hot-rolled steel in coils weighing 25-50 tons. High energy consumption in such mills is due to the presence of a barrel 1500-2000 mm with a diameter of working rolls 500-550 mm and reserve 1300-1500 mm for the transfer of torque [1]. Rolling speed - at least 5-12 m/s, productivity - from 0.6-0.8 million tons per year [2]. The wide use of mills with 4-high stands of the tandem type in the composition of four and five stands for the production of strips, and five and six stands for the production of tinplate [3, 4] should be noted from the modern foreign experience in the field of cold rolling mills. The use of modern emulsions leads to improved quality indicators and increased production of the cold rolling shop (CRS) [5, 6]. The application of the "Quakerol" as a new emulsol instead of "Universal-1TS" requires establishing the effect of this lubricating and cooling liquid (LCL) on not only the indicators of quality and manufacturability, but also on the rolling power parameters. Thus, of scientific interest is the study of the effect of technological conditions for the production of cold rolled coils on a four-stand continuous tandem mill 1680 with the use of emulsions "Quakerol" and "Universal-1TS" on the power parameters of rolling, energy consumption and surface contamination at the cold rolled coils manufacturing in the CRS. On the metal strip after cold rolling there is always some amount of contamination particles, which are the wear products of rolls and strips and products of thermal transformation of technological lubricants. Therefore, when rolling cold-rolled sheets and strips, the issue of ensuring the quality of the surface arises. Determinations of contamination indicators of the metal surface contribute to the prevention of defects such as "sooty deposits", "emulsion spots, oil spots" and "spots of contamination".

Literature review

In this paper [7], considerable attention is paid to increasing the energy efficiency of rolling on tandem mills 1700 (in relation to the conditions of PJSC "Iron and Steel Works of Mariupol"). Through industrial rolling mills, it has been shown that the use of lubricants has an effect on the synchronization of the stands and on the power modes of rolling mills, which reduces the consumption of electricity during mill rolling by 1–6%. In tandem rolling mills, the modes of operation of electric motors of the stands must be synchronized [7] taking into account deformation phenomena (different hoods on the stands, heating-cooling during rolling, etc.), which affects quality indicators and electricity consumption. The conditions of the power load on the electric motor of the 1680 reversible mill of cold rolling are considered in this paper [8]. The importance of ensuring the reliability and stability of the operating modes of electrical equipment and automation in order to achieve high quality and the absence of defects in the rolling of thin cold-rolled coils has been revealed. Moreover, the necessity of carrying out rolling with emulsions of the type "Universal-1TS" and "Cold Roller" in order to achieve softening of the conditions of operation of electric motors of the rolling mill is especially emphasized. Studies [6, 9] are devoted to identifying the influence of the characteristics and physical and chemical properties of various emulsions, which has an effect on the friction coefficient, on the energy consumption of continuous cold rolling mills. They determined that the use of emulsol with a higher kinematic viscosity allows in some cases to reduce the specific consumption of electricity. Friction and lubrication conditions, as a rule, significantly affect the energy-force modes of deformation [10]. The coefficient of deformation friction is determined in various ways, among which the most common is the compression of samples with different conditions at the tool-workpiece contact [11]. In this paper [12] it was noted that for reversible one- and two-stand cold rolling mills, both by changing the contact conditions and by varying the tension, it is possible to set up energy-saving rolling modes of a coil with a thickness of 0.15-0.8 mm. The authors [13] established the regularities of the effect of lubricant composition on the wear of work rolls and energy consumption of cold rolling mills, and it is recommended to introduce Ti into the lubricating liquid. The paper [14] presents the test results of three rolling emulsions: "Gerolub 3022", "Gerolub CTS 87-1" and "Gerolub 6528". It was determined that the use of these rolling emulsols allows to increase the rolling speed while maintaining the quality of the product surface and reducing the energy parameters of rolling compared to the parameters previously obtained when using "Quakerol 683" and "Quakerol NLM 4.0" lubricants. At the same time, researchers [15] note that during their one-time evaluations, a more effective emulsol than "Quakerol 671" was not found for the conditions of 1700 CRS of OJSC "AMT". Electricity consumption during rolling depends not only on the type of emulsion used, but also on many factors: on the setting of inter-stand tension [1, 16], the realized stress-strain state of the material [16, 17], rheological properties of steels [18], efficiency of intermediate recrystallization annealing [19] and other methods of processing rolled steel [20], structural features of the rolling stock and its working and conductive elements [21], technological state and obsolescence of electrical equipment designs [22]. Indicators of power quality [23], which depends on the efficiency and stability of workshop converters and transformers [24], have a significant influence on the stability of the electrical equipment of heavy-loaded machines, and, as a rule, the controllability of rolling mills. However, when research is carried out on one piece of equipment under equal influence of all these conditions, it becomes obvious that the effect on electricity consumption depends only on the factor that changes, that is, the emulsol used.

Purpose of the work

The purpose of the study was to evaluate the loading of electric motors, power consumption and the value of contamination of the metal surface in conditions of continuous cold rolling, taking into account the prospects of using emulsion "Quakerol" instead of emulsion "Universal-1TS".

Research methodology, materials and equipment

For experimental and industrial tests 11 m^3 (~9900 kg) of experimental emulsol "Quakerol" was delivered. Emulsol samples were taken to determine the actual physical and chemical parameters. Physicochemical parameters of the experimental emulsol "Quakerol" in comparison with "Universal-1TS" emulsol currently used for cold rolling of carbon steel in the CRS-1 (PJSC "Zaporizhstal") delivered with an actual saponification value of 38.57 mgKOH/g, as well as previously tested by "Quakerol" emulsol are presented in Table 1.

Table 1

Results of laboratory tests for "Quakerol" emulsol in comparison with "Quakerol ZAP 3.0" emulsols manufactured by Quaker, and Universal-1TS manufactured by LLC "METINVEST - Mariupol Repair and Mechanical Plant"

№	Physical and chemical indicators	"Quakerol"		"Quakerol ZAP 3.0"	"Universal-1TS"	
		Actual batch	*Quality certificate*	*Actual sample*	*Actual batch*	*Technical conditions*
1	Appearance	homogeneous brown liquid	clear dark amber liquid	clear dark amber liquid	responds	homogeneous oily liquid
2	Scent	responds	characteristic weak smell	specific not annoying	responds	specific not annoying
3	Density at 20 ºC, kg/m^3	927	929	930	934	920-960
4	Kinematic viscosity at 50 ºC, mm^2/s	40.58	not standardized	42.92	34.07	≤35.0
5	Kinematic viscosity	60.97	60.60	61.90	–	–
6	Acid value, mg KOH/g	11.60	11.70	11.90	11.23	> 12.5
7	Saponification value, mgKOH/g	164.44	163.0	174.31	38.57	≥13.5
8	Water content, %	0.09	not standardized	0.06	0.28	≤0.5
9	Stability during storage	withstands	not normal	withstands	withstands	withstands
10	Ash content, %	0.06	Not stand-ardized	0.031	–	≤0.04
11	The freezing point, ºC	minus 5 (at 0ºC – lost mobility)	0	minus 3	–	–
12	Flash point, °C	170	>150	–	–	–
	3% emulsion					
13	Stability of the emulsion prepared on hard water 4.6 mg-eq/dm^3 during 6 hours, % of oil	withstands, 1.5% drain	not normal	withstands, 3.0% drain	withstands 0%	withstands (the allocation of traces of "draining" and oily secretions is allowed)
14	Corrosive attack on gray cast iron by water emulsion	can't stand	not standardized	can't stand	stands	stands
15	Hydrogen index pH of 3% aqueous emulsion (on hard water 4.6 mEq/dm^3)	3.8	not standardized	4.0	9.18	8.2-9.2
16	Tendency to foaming at (20±5) °C, см^3	0 points	not normal	2 points	–	> 40

Taking into account the fact that hot-rolled pickled rolls can be in an open space for no more than 48 hours before rolling, and the test campaign of the experimental emulsion "Quakerol" lasted about a month, the distribution of the experimental melt for the comparative rolling of part of the rolls on the serial emulsol "Universal-1TS" did not perform. For comparison, we used the data obtained earlier on the rolls rolled on emulsion from the "Universal-1TS" emulsol of earlier deliveries. The incoming control of compliance of the characteristics of the emulsol with the requirements of the technical conditions of the enterprise was carried out. It was established that the tested sample of experimental emulsol "Quakerol" meets the requirements of the quality passport. According to its physicochemical parameters, the experimental emulsol "Quakerol" differs from the used emulsol "Universal-1TS" in that it has higher lubricating properties (the saponification value is 164.44 mgKOH/g, against 38.57 mgKOH/g in the emulsol "Universal-1TS").

The continuous four-standmill 1680 (see Fig. 1) is the main rolling mill of the CRS-1 (PJSC

"Zaporizhstal"). It consists of 4 consecutively arranged quarto stands, which include two supporting and two working rolls, as well as auxiliary equipment (under-receiving device, rotary bed, unwinder, drum-type winder, etc.). The characteristics of the roller drive are given in Table 2. The drive of the working rolls from electric motors is carried out through intermediate shafts with a toothed clutch, gear stands and spindle connections. The rolls' characteristics are given in Table 3.

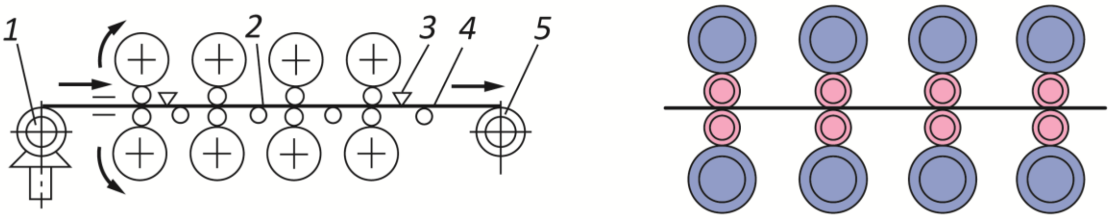

Fig. 1. Schemes of rolling on a four-stand continuous tandem mill 1680:
1 – unwinder, 2 – tensiometr, 3 – gauge of thickness, 4 – strip, 5 – winder

Table 2

Characteristics of the rolls' drives

Stand No.	Engine power, kW	Armature rotation number, rpm	Rolling speed, m/s
1	3300	110/200	2.75 – 5.0
2	3300	160/280	4.0 – 7.0
3	3300/2800	220/280	5.8 – 9.5
4	2 x 1650	200/450	2.6 – 10

Table 3

Characteristics of the continuous mill rolls

Kind of rolls	Roll diameter, mm	Roll length, mm	Roll mass, t	Bearing's type
Working	510	1680	3.12	roller
Support	1300	1680	23.6	liquid friction

Notched working rolls are used to improve the grip of the first stand. In the fourth stand, working rolls with a notched surface are also used to make it impossible to weld the turns of the rolls during subsequent heat treatment. For each grade of steel, as well as the final section of cold-rolled strips, crimping modes have been developed. The mill is equipped with a technological lubricant supply system (emulsion with an emulsol concentration of 2–4%), anti-bending systems of work rolls, control and measuring equipment, which was used to control the energy parameters of rolling and energy consumption. No comments (fluctuations in loads, tension instability) were noted by the technological personnel of the continuous four-standmill 1680 during the testing period.

Analysis of rolling energy parameters

The modes of operation of the electric motors of the stand and the winder of tandem mill were analyzed during the rolling of melts on the LCL from the experimental emulsol "Quakerol", lubricated with the emulsol "Quakerol" and the serial emulsol "Universal-1TS", lubricated with preservation oil "OK-2". The results of the loads analysis when rolling strips with the 0.68×1000 mm cross-section from a 3.0 mm thick pre-roll plate are summarized in the Table 4.

Table 4

Average total loads on engines during rolling

Steel grade	Size	Average total load on the electric motors of the stand and the winder when rolling one coil of experimental melt, kVA	
		Rolling on emulsion from experimental emulsol "Quakerol"	*Rolling on emulsion from emulsol "Universal-1TS"*
DC01	3.0/1.0x1265 mm	10.965	10.505

As it can be seen from the table 4, the average total load on the stand motors and the winder of the four-standmill 1680 in the established rolling mode when using the emulsion from the experimental emulsol "Quakerol" on the metal oiled with the emulsol "Quakerol" is 4.19% higher than during rolling of the same assortment, oiled in continuous pickling unit (CPU-4) with "OK-2" oil and rolled on emulsion with "Universal-1TS".

Consumed electricity analysis

The electricity consumption during rolling of the same assortment of DC01 carbon steels during rolling of melts on LCL from experimental emulsion "Quakerol" lubricated with emulsion "Quakerol" and serial emulsion "Universal-1TS" lubricated with preservation oil "OK-2" was analyzed. Data on consumed electricity are presented in the Table 5.

Table 5

Power consumption during rolling on tandem mill

Strip cross-section, mm	Number of coils, pcs	Emulsion concentration during rolling, %	Electricity consumption, KWh	Coils mass, t	Specific electricity consumption, KWh/t	Total electricity consumption during rolling, KWh/t
X1	X2	X3	-	X4	Y	-
"Quakerol"						
0.5×1000	10	1.5	9063.9	98	92.49	504
1.5×1250	4	1.8	1746.9	53.06	32.92	
0.5×1000	13	1.9	12852	143.16	89.77	
1.5×1250	9	1.8	4236.3	117.23	36.14	
0.5×1000	6	1.7	5595.3	68.13	82.13	
1.5×1250	9	2	3919.5	113.76	34.45	
0.5×1000	5	2.4	5344.2	56.89	93.94	
1.5×1250	10	2	4609.8	109.75	42.00	
Average value of the emulsion concentration		1.9				
"Universal-1TS"						
0.5×1000	4	3.1	3800.7	44.21	85.97	490
1.5×1250	4	2.6	1693.8	54.74	30.94	
0.5×1000	7	3.8	6930.9	78.58	88.20	
1.5×1250	8	3	3631.5	93.95	38.65	
0.5×1000	9	2.7	8404.2	101.23	83.02	
1.5×1250	11	3.3	4701.6	147.54	31.87	
0.5×1000	9	2.2	9208.8	96.94	94.99	
1.5×1250	6	3	2781.9	76.58	36.33	
Average value of the emulsion concentration		3.0				

As a result of data processing from Table 5 obtained multiple regression equations, taking into account that instead of multiplying the linear dimensions of 0.5×1000 mm and 1.5×1250 mm, the cross-sectional area values of 500 mm^2 and 1875 mm^2 were used as the X1 factor. The measurement units of factors X2...X4 correspond to those indicated in the Table 4. Dependencies of specific electricity consumption (Y) on factors X1...X4 (see Table 5) for experimental emulsols:

- "Quakerol" (R^2=0.994):

$$Y = 81.096 - 0.035X1 + 4.946X2 + 11.146X3 - 0.403X4; \quad (1)$$

- "Universal-1TS" (R^2=0.995):

$$Y = 96.275 - 0.034X1 + 7.373X2 + 0.483X3 - 0.577X4. \quad (2)$$

As it can be seen from the Table 5, the total specific consumption of electricity during rolling on an emulsion prepared from the experimental emulsol "Quakerol" is slightly higher (by 2.7%) than the consumption during rolling on an emulsion prepared from the serial emulsol "Universal-1TS". At the same time, the average concentration of emulsion when rolling on "Quakerol" emulsol was 1.9% against 3.0% on rolls rolled on LCL prepared from "Universal-1TS" serial emulsol. A higher specific consumption of electricity during the operation of the LCL from the experimental emulsol, which has a higher saponification number, may be the reason for an incorrectly selected and underestimated concentration of the emulsion in order to reduce the consumption of emulsol for rolling.

Contamination of rolled steel after rolling

In addition, the indicators of contamination after rolling were investigated. The results of the determination are given in Table 6.

Table 6

Surface contamination of the test metal after cold rolling

<table>
<tr><td rowspan="2">Steel grade, size</td><td rowspan="2">Coil</td><td colspan="2">Contamination, mg/m²</td><td colspan="2">Average value, mg/m²</td><td rowspan="2">Average total contamination mg/m²</td></tr>
<tr><td>Fat</td><td>Mechanical</td><td>Fat</td><td>Mechanical</td></tr>
<tr><td colspan="7">Experimental coils rolled on emulsion of emulsol "Quakerol" oiled by "Quakerol"</td></tr>
<tr><td rowspan="6">DC01,
2.3/0.65x1000 mm</td><td rowspan="3">1</td><td>585</td><td>500</td><td rowspan="3">470</td><td rowspan="3">522</td><td rowspan="3">992</td></tr>
<tr><td>458</td><td>579</td></tr>
<tr><td>367</td><td>486</td></tr>
<tr><td rowspan="3">2</td><td>400</td><td>560</td><td rowspan="3">360</td><td rowspan="3">649</td><td rowspan="3">1009</td></tr>
<tr><td>470</td><td>520</td></tr>
<tr><td>210</td><td>867</td></tr>
<tr><td colspan="4">Average contamination of the rolled surface on the LCL with emulsol "Quakerol" oiled by "Quakerol"</td><td>415</td><td>586</td><td>1001</td></tr>
<tr><td colspan="6">Coils rolled on emulsion from serial emulsol "Universal-1TS" oiled by "OK-2"*</td><td>950</td></tr>
</table>

* – data obtained from other studies.

As can be seen from Table 6, the average value of surface contamination of metal samples oiled and rolled with the use of experimental emulsion "Quakerol" is 51 mg/m^2 or 5% higher than that of samples oiled with emulsion "OK-2" and rolled on serial emulsion "Universal-1TS" and is 1001 mg/m^2 against 950 mg/m^2.

Conclusions

1. The method with the use of emulsions has been developed and tested to estimate the energy-power parameters during cold rolling. The influence of rolling process conditions on energy-power parameters of rolling with the use of emulsol "Quakerol" is described for a four-roller mill.

2. The average total load on the stands' motors and the winder of the 1680 four-standmill in the stable rolling mode was found when using the "Quakerol" emulsion is 4.19% higher than when rolling the same assortment rolled on the emulsion from "Universal-1TS".

3. The level of energy consumption during rolling in the four-standmill using "Quakerol" and "Universal-1TS" emulsols was established. It is shown that the total specific consumption of electricity when rolling on an emulsion prepared from the experimental emulsol "Quakerol" is 2.7% more than when rolling on an emulsion prepared from the serial emulsol "Universal-1TS". The higher specific energy consumption during the operation of the LCL from the experimental emulsol, which has a higher saponification number, may be the reason for the incorrectly chosen and underestimated concentration of emulsion in order to reduce the emulsol for rolling consumption.

4. The average concentration of the emulsion on the analyzed coils rolled on LCL from the experimental emulsol "Quakerol" was 1.9% versus 3.0% on the coils rolled on LCL from emulsol "Universal-1TC".

5. The assessment of contamination of the metal surface after rolling is given. It was found that the use of the investigated emulsol "Quakerol" increases the average value of surface contamination.

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Кухар В.В., Малій Х.В., Спічак О.Ю. Вплив типу емульсолів на енерговитрати та забруднення поверхні при холодній прокатці сталі DC01 на безперервному чотирьохклітьовому стані

У статті представлено результати експериментальних і промислових випробувань фізико-хімічних параметрів експериментального емульсолу "Quakerol". За фізико-хімічними показниками експериментальний емульсол "Quakerol" відрізняється від використовуваного емульсолу "Універсал-1ТС" більш високими змащувальними властивостями. Були проаналізовані режими роботи електродвигунів кліті та моталки «тандемного» стану під час прокатки на ЛПЦ розплавів з експериментального емульсолу "Quakerol", змащеного емульсолом "Quakerol", та серійного емульсолу "Універсал-1ТС", змащеного консерваційною оливою "ОК-2". Результати аналізу навантажень під час прокатки полос перерізом 0,68×1000 мм із попередньо прокатаного листа товщиною 3,0 мм показали, що значення середніх сумарних навантажень на двигуни кліті та моталки чотириклітьового стану 1680 вищі за умови використання експериментального емульсолу "Quakerol". Дано порівняльний аналіз експериментально отриманих даних щодо впливу технологічних умов виробництва холоднокатаних рулонів на чотирьохклітьовому безперервному тандемному стані 1680 з використанням емульсолів "Quakerol" і "Універсал-1ТС" на силові параметри прокатки, витрату електроенергії та забруднення поверхні плоскої вуглецевої сталі DC01. Для опису витрат електроенергії під час прокатки з використанням різних емульсій отримано рівняння множинної регресії, як варійований фактор узято значення площі поперечного перерізу. Оцінено питому витрату електроенергії та середнє сумарне навантаження на кліті й двигуни моталок під час прокатки з використанням емульсолу, приготованого з експериментальної емульсії "Quakerol", і емульсолу, приготованого зі стандартної емульсії "Універсал-1ТС". Проаналізовано причини більш високої питомої витрати електроенергії при роботі ЛКЛ з експериментальною емульсією. Дано кількісну оцінку забруднення поверхні сталевих зразків під час використання експериментальної емульсії "Quakerol", оливи"ОК-2" і стандартної емульсії "Універсал-1ТС". Обгрунтовано необхідність проведення подальших випробувань з визначення оптимальної концентрації емульсії з "Quakerol" для забезпечення зниження енерговитрат на тонну холоднокатаного прокату.

Практична значимість роботи полягає в розробці методики аналізу мастильних матеріалів з урахуванням перспектив використання емульсії "Quakerol" замість емульсії "Універсал-1ТС", з метою поліпшення якісних показників і збільшення продуктивності цеху холодної прокатки.

Ключові слова: холодна прокатка, безперервний стан 1680, емульсол, енергоспоживання, питомі витрати електроенергії, забруднення поверхні