THE ESTABLISHMENT OF A CORRELATION OF COMPLEX CRITERION WITH THE PARAMETERS OF ROLLING TECHNOLOGY FOR REINFORCING BARS

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ABSTRACT

In the article is given a qualitative evaluation of the quality of rebar produced in the conditions of the shape rolling mill of «Arcelor Mittal Temirtau» company. The evaluation was conducted using complex criteria of quality, which has dependence on group of quality indicators, such as technology parameters, mechanical properties, chemical composition and others.

It is revealed that the mechanical properties are not the most critically dependent on the quality of the chemical composition; significant impact on the quality is also influenced by technological parameters.

Keywords: shape rolled metal, reinforced steel, steel quality, qualimetry, comprehensive quality assessment.

INTRODUCTION

Shape rolling is characterized by many quality indicators, each of which can serve as a criterion for selecting technological parameters, although mathematically correct formulation of the optimization problem requires one criterion. Improvement of technological process of rolling, which consists in choosing the optimal parameters, involves a relationship with some complex criteria K_0, which takes into account a group of quality indicators.

To determine this dependence, it is necessary to solve the task of bringing the quality of products (compliance with standard) to the complex criterion K_0 and establish the correlation between the complex criterion and the technology parameters from experimental data or theoretical formulas.

Comprehensive evaluation (K_0) can be defined at any level of the hierarchy, but the most common is at zero [1]. Hence:

$$K_0 = \prod_{i=1}^{m} \prod_{j=1}^{n} \left(k_{ij} \cdot w_{ij} \right)$$

where:
m is the number of levels of subordination ($0 \leq i \leq m$);
n - the number of quality indicators ($1 \leq j \leq n$).

At the zero level there is a quality of rolled products in general. The quality of the products can be characterized by three main components (geometric dimensions, quality of metal, quality of the surface), these properties being less common, constitute the first level of the hierarchy, respectively $k_{1.1}$, $k_{1.2}$, $k_{1.3}$.

The analysis of the properties allows detecting second and higher hierarchy levels to simple properties $k_{m.j}$.

Rolled products are characterized by the match of sizes of the individual profile elements with the fields of the tolerances. The dimensions of long products cannot be further decomposed, therefore, these four properties that comprising the second level of the hierarchy, adopted as simple.

The quality of metal on the second level of the hierarchy is characterized by chemical composition, structure, mechanical properties, the presence of internal defects of metallurgical origin and the number of special properties. All of these properties are decomposed into less common. Thus, for example, the chemical composition normalizes the content of major elements, which provide specified properties. Also set limits on the deviation of the composition of individual elements in finished rolled products from melting (ladle) analysis. The content of separate elements and their variation constitute the third level of the hierarchy and are simple.

In some cases the quality of metal is characterized by the control of the macro - and microstructure, which constitute the third level of the hierarchy. These properties can be simple at the third level, but if the control structure is determined by several indicators, each of them becomes an element of the fourth level of the hierarchy, and at the same time are simple.

The mechanical properties are defined during the tensile tests, impact strength, hardness and under various technological tests – cold bend, upsetting, etc. These properties constitute the third level of the hierarchy and could be decomposed into less common.

The tension allows to determine yield strength, tensile strength, relative elongation and relative narrowing, i.e. properties, which constitute the fourth level of the hierarchy and are simple.

The integrated quality assessment system with the use of recommendations of [1] can be converted to a dimensionless scale (Table 1).

It is theoretically possible that a low differential rating in one parameter will be blocked by another high indicator, i.e. comprehensive assessment will be quite high, and the measured values r_{ij} will fall outside the limits $\left[r_{ij}^{\min} ; r_{ij}^{\max} \right]$. To prevent such situations in the qualimetry apply the condition for the vanishing of a comprehensive evaluation under certain conditions. This is referred to as the «Coefficient of veto». Coef-

ficient of veto W is used as a cofactor and has only two values: either 1 or 0.

In case double-sided borders: unilateral restriction:

$$W_i = \begin{cases} 1, if \ r_{ij}^{\min} \le r \ and \ r \le r_{ij}^{\max}; \\ 0, if \ r_{ij}^{\min} > r \ or \ r > r_{ij}^{\max}; \end{cases} \qquad W_i = \begin{cases} 1, if \ r_{ij}^{\min} \le r; \\ 0, if \ r_{ij}^{\min} > r. \end{cases}$$

Summing up the requirements in present days for the quality of shape rolled products, it is possible on the basis of qualimetry methods to build a hierarchical set of properties [2]. To do this, a tabular form of a tree of properties recommended in the work [3] could be used.

In this work a comprehensive assessment of the quality of reinforcing bars with a single numerical index is carried out taking into account all its properties, produced on a continuous 16-stand shape rolling mill 320 at shape rolling shop of «Arcelor Mittal Temirtau» company. The qualimetric study of the quality of reinforcing bars with periodic profile is conducted after collecting samples of reinforcing bars made of steels 35GS, 25G2S and 5ps with diameters from 10 to 32 mm, in the period July to August 2014.

Research methodology

For a complex quality evaluation of reinforcing bars are used data of acceptance tests of 169 periodical profiles. According to the materials [4, 5], splitting into three clusters (small, average and large profiles) is conducted by the following method: Ø 10 - 16 mm, Ø 18 - 22 mm and Ø 25 - 32 mm. Given the absolute majority of small profiles in general, the group of small profiles was also split into 2 parts: Ø 10 - 12 mm and Ø 14 - 16 mm (Table 2), finally received 4 selections.

As indicators of the quality of reinforcing bars were selected: chemical composition of metal by the content of the main elements - carbon (C, %), manganese (Mn, %), silicon (Si, %), chrome (Cr, %), nickel (Ni, %),

Table 1. The scale of the valuation of complex assessments.

Dimensionless scale	Index K_0	Quality level
Very good	0,80 … 1,00	Standard
Good	0,63 … 0,80	Top grade
Satisfactorily	0,37 … 0,63	First grade
Bad	0,20 … 0,37	Second grade
Very bad	0 … 0,20	Reject

Table 2. Selections, sorted by the profile sizes.

Group of profiles	10-12	14-16	18-22	25-32
Selection volume	60	54	30	25

Table 3. Requirements of GOST5781-82 for the mass fraction of steel elements 35GS, content in %.

C	Mn	Si	Al	Cr	Ni	S	P	Cu
0,30-0,37	0,80-1,20	0,60-0,90	0,001-0,015	max				
				0,30	0,30	0,045	0,040	0,30

Table 4. Requirements of GOST5781-82 for the mechanical properties of hot rolled reinforcing bars.

Class of reinforcing steel	Diameter of profile, mm	Steel grade	Yield strength, MPa	Tensile strength, MPa	Relative elongation, δ_s, %
A-III (A400)	6–40	35GS, 25G2S 32G2Rps	390	590	14

copper (Cu, %), aluminum (Al, %), content of harmful impurities of nitrogen (N, %), sulfur (S, %) and phosphorus (P, %), alongside with the most important indicators of mechanical properties - yield strength ($Rp_{0,2}$, MPa), tensile strength (R_m, MPa), relative elongation (δ_s, %). The chemical composition and properties of steel were tested in cooperation with the Central plant laboratory of «Arcelor Mittal Temirtau» company in compliance with the requirements of GOST 5781-82 and GOST 10884-94. Tested steel grades are widely used at «Arcelor Mittal Temirtau» company for production of reinforcing bars with periodical profile.

According to recommendations [6] in table form are presented tree of properties of reinforcing bars with periodic profile. Values of the weight coefficients r_{ij} were determined on the basis of the recommendations of various literary sources with the coordination of workers at central plant laboratory of «Arcelor Mittal Temirtau» company.

For calculation of differential quality assessment according to [3] are used the requirements of GOST 5781-82 as r_{ij}^{min} and r_{ij}^{max} (Tables 3 and 4).

Thus, using these data at all levels of the tree of properties are identified differential evaluation of the quality of reinforcing bars of periodic profile of steel grade 35GS for four size groups. Evaluation at the zero level is the outcome of a complex indicator of the quality of the group of given profile numbers.

RESULTS AND DISCUSSION

For the convenience of comparison of the results obtained in the analysis of different size groups of rolled products, all quality indicators presented on a bar chart (Fig. 1).

As seen in Fig. 1 the quality of mechanical properties of reinforcing bars made of steel 35GS are not directly dependent on the quality of the chemical composition. For example, the lowest value of «K_{chem}» corresponds to the highest value of «K_{mech}» in the group of large profiles Ø 25 - 32 mm. While in the group of small profiles Ø 10 - 12 mm the lowest value of «K_{mech}» corresponds to the second highest value of «K_{chem}». The lowest complex quality has the group of small profiles with the numbers 10 and 12 mm. To determine the quality of the group, with the use of same technique is calculated the quality of reinforcing bars of each profile number separately (Fig. 2).

As seen in Fig. 2 the most stable, with minimal variation, is the quality of chemical composition of the steel, while the quality of mechanical properties of different numbers of profiles significantly varies. At the same time the profile number 14 has the most uniform quality – its indicators have similar values.

Low quality of the first size group of profiles is explained by the fact that both 10 and 12 numbers have the lowest values of mechanical properties with relatively
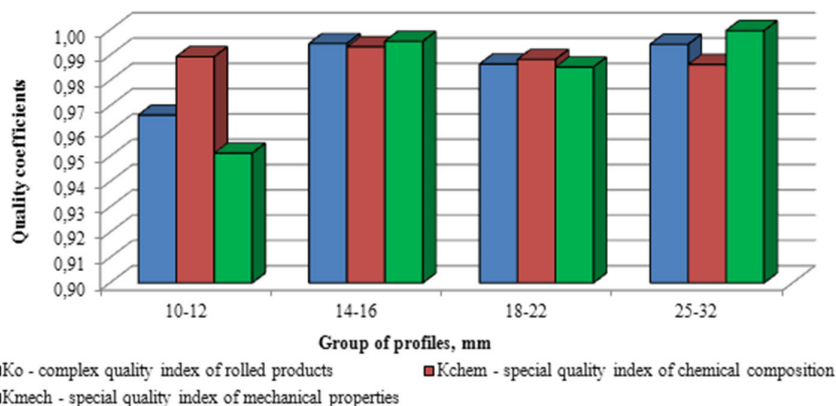
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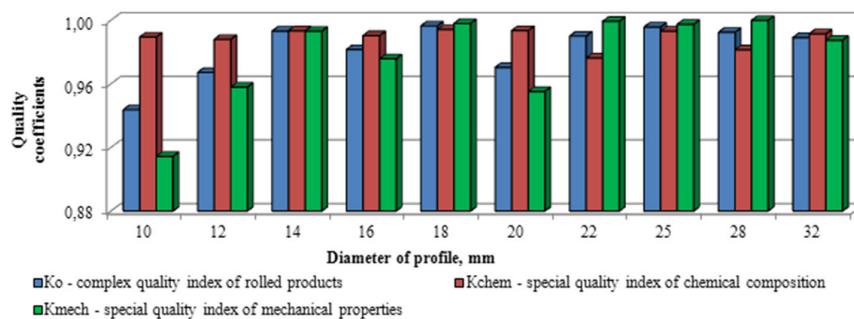Fig. 1. Quality indicators of the groups of rolled steel 35GS.

Fig. 2. Quality indicators of individual profiles of rolled steel 35GS.

good chemical composition of the steel. On the other hand the profiles with numbers 22 and 28 have a reverse situation: the worse the chemical composition of the steel, the better mechanical properties are.

The resulting contradiction can be explained by the influence on the mechanical properties of rolled products not as much of the chemical composition of steel as the compliance of technological process during production of rolled products.

These results are consistent with the materials [7]. It can be concluded that it is necessary to include quality assessment and process parameters in the calculations, for example, temperature of self-tempering of metal and the speed of the end of rolling in the last stand.

The quality of reinforcing bars made of low alloyed steel 25G2S is also evaluated. In table form are given tree of the properties of reinforcing bars with periodic profile.

For calculation of differential quality assessment are used also the requirements of standards GOST 5781-82 and GOST 10884-94 as boundary conditions $r_{ij}^{\min}$ and $r_{ij}^{\max}$ (Tables 5 and 6).

As boundary conditions of the values of the process parameter (temperature of self- tempering) are used the recommendations of manufacturing Technological instruction, i.e. $r_{2.10}^{\min} = 540°C$ and $r_{2.10}^{\max} = 620°C$.

Finally taking the boundary conditions $r_{2.12}^{\min} = 750$ MPa and $r_{2.12}^{\min} = 14$ %, with the use of the obtained data, it was performed calculation of differential and comprehensive assessment of the quality of rolled steel 25G2S.

For the convenience of comparing the results, the data are presented in a bar chart (Fig. 3).

Data in Fig. 3 clearly show a 45 % difference in the values of quality indicators of the chemical composition and the mechanical properties, with good quality value

Table 5. Requirements of GOST 5781-82 for mass percentage of elements in steel 25G2S, content in %.

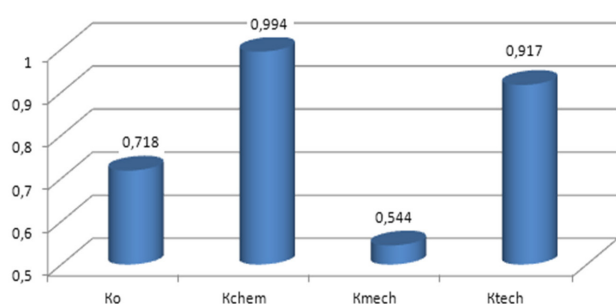| C	Mn	Si	C_{eq}	S	P
			min	max	
0,20-0,29	1,20-1,60	0,60-0,90	0,4	0,045	0,045

Fig. 3. Quality parameters of rolled steel 25G2C.

of technological parameter, which strongly reduces the complex parameter in general.

The quality of reinforcing bars made of carbon steel 5ps is similarly assessed. In table form are presented tree of the properties of reinforcing bars with periodic profile (Table 7).

Using the requirements of standards GOST 380-2005 and GOST 10884-94, alongside with technological instructions TI 01-2014, as boundary conditions $r_{ij}^{\min}$ and $r_{ij}^{\max}$ (Tables 8 - 10), are calculated the differential evaluation of the quality.

According to p. 5.3 of GOST 10884-94 for welded reinforcing steel with strength class At500S carbon

equivalent shall be not less than 0,40 %, then $r_{2.1}^{\min} =$ 0,40 % and $r_{2.4}^{\max} = 0,50$ %.

Using these data at all levels of the tree of properties the differential evaluation of the quality of heat-strengthened reinforcing bars of periodic profile steel 5ps are obtained.

For the convenience of comparing the results, the data are presented in a bar chart (Fig. 4).

As seen from Fig. 4 the quality of reinforcing bars for mechanical properties is on a sufficiently high level.

CONCLUSIONS

In paper described the principles of quality control in relation to bar iron and selected the methodology for complex estimation of quality of reinforcing bars. After qualimetric quality assessment of reinforcing bars produced at conditions of «Arselor Mittal Temirtau» company were received graphs of quality parameters of rolled steels 25G2C, 35 GS and 5ps and the values of the complex criteria in dependence of the technology parameters, mechanical properties and chemical composition.

Table 6. Requirements of GOST 10884-94 for mechanical properties of hot rolled heat-strengthened reinforcing bars.

Class of reinforcing steel	Diameter of profile, mm	Steel grade	Yield strength, MPa	Tensile strength, MPa	Relative elongation, δ_s, %
At600 At600S (At-IV)	10–40	20GS, 25G2S 35GS	600	800*	12*

* According to appendix for table 6 GOST 10884-94 for reinforcing steel of class At600S allowed reduction in the ultimate tensile strength for 50 N/mm² below standards, set by the table, with increasing relative elongation by 2 % (abs.).

Table 7. A hierarchical set of properties of rolled steel 5ps.

$i = 0$	$i = 1$	$i = 2$
The quality of reinforcing bars – K₀	Chemical analysis $k_{1.1}$; $\alpha = 0,2$	Content of carbon (C, %) $r_{2.1}$; $\alpha = 0,2$
		Content of manganese (Mn, %) $r_{2.2}$; $\alpha = 0,15$
		Content of silicon (Si, %) $r_{2.3}$; $\alpha = 0,2$
		The value of carbon equivalent (C$_{eq}$) $r_{2.4}$; $\alpha = 0,25$
	Mechanical properties $k_{1.2}$; $\alpha = 0,5$	Physical yield strength (Rp$_{0,2}$, MPa) $r_{2.5}$; $\alpha = 0,4$
		Tensile strength (R$_m$, MPa) $r_{2.6}$; $\alpha = 0,3$
		The relative residual elongation (δ_5, %) $r_{2.7}$; $\alpha = 0,3$
	Technology parameters $k_{1.3}$; $\alpha = 0,3$	Temperature of self- tempering $r_{2.8}$; $\alpha = 0,3$
		The speed in the last stand $r_{2.9}$; $\alpha = 0,35$
		Water consumption (total) $r_{2.10}$; $\alpha = 0,35$

Table 8. Requirements of GOST 380-2005 for mass percentage of elements in steel 25G2S, content in %.

C	Mn	Si
0,20-0,29	1,20-1,60	0,60-0,90

Table 9. Requirements of GOST 10884-94 for mechanical properties of hot rolled heat-strengthened reinforcing bars.

Class of reinforcing steel	Diameter of profile, mm	Steel grade	Yield strength, MPa	Tensile strength, MPa	Relative elongation, $\square_s$, %
At500S	6–40	5sp 5ps	500	600	14

Table 10. Requirements of TI 01-2014 for the initial configuration of the system of heat-strengthening of reinforcing bars.

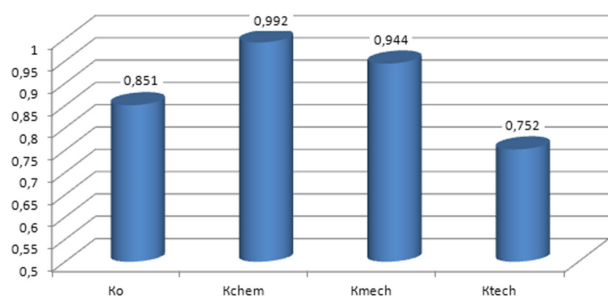| Steel grade	Diameter, mm	Rolling speed, m/s	Class of reinforcing steel	Water consumption, m^3/h	Temperature of self- tempering (°C) with the carbon equivalent, %	
					0,42 – 0,46%	0,47 – 0,51%
5sp	16	7,7	At500S	270	570-600	
5ps		8,4		310-370	560-580	560-580

Fig. 4. Quality parameters of rolled steel 5ps.

This evaluation showed that the quality of mechanical properties does not crucially depend on the quality of the chemical composition. A significant impact on the quality play the process parameters and their limit values.

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