UDC 621.778:691.87:620.195:620.193.21

Effect of Technology Factors on Corrosion Resistance of Cold-Rolled Reinforcing Bar

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The corrosion behavior features of cold-rolled reinforcing bar during production and processing are considered, recommendations on increase of reinforcing bar corrosion resistance in the concrete are given.

Keywords: COLD-ROLLED REINFORCING BAR, CONCRETE, COLD WORKING, CORROSION, ELECTROLYTIC POTENTIAL

Introduction

Cold-rolled reinforcing bar is a new and perspective metal product for Ukraine. It is possible to produce reinforcing bar of small grades (4.0-14.0 mm). Application of reinforcing bar in coils allows avoiding loss in unmeasured lengths which provides metal economy up to 7-10 % [1] without account of metal consumption decrease due to raise of average yield stress from 400 N/mm^2 to 500 N/mm^2 [2]. This assumes the total economy of reinforcing steel not less than 20-25 % [3].

The further increase of standard yield stress to 600-800 N/mm^2 (cold-rolled reinforcing bar of these classes is possible to identify as B600C [3] and B800 [3, 4]) enables to reach more economy of metal. According to current classification, the specified cold-rolled reinforcing bar is considered to be high-strength and should correspond to corrosion resistance requirements.

According to current manufacturing process, manufacture of cold-rolled reinforcing bar includes steelmaking, hot deformation with heat strengthening with application of interrupted quenching with self-tempering for producing high-strength strip plate [5], cold working for obtaining necessary geometrical form of the surface, complex of properties and structure [6]. It also can include a number of additional operations for stabilization of structural condition and properties of rolled metal [7]. The pattern of metal corrosion stability change during technological treatment is complicated and defined by the following factors: content of alloying elements (mainly carbon), size and shape of cementite [8], level of macro- and microstresses. The joint effect of these factors is inconsistent, for example, cold deformation can result in both accumulation of surface energy and energy decrease which can affect corrosion-mechanical behavior of materials under tension [9]. Similarly, steel hardening on martensite can raise corrosion stability (due to formation of martensite with homogeneous distribution of carbon) and reduce corrosion stability leading to the formation of tensile stress in the surface layer of product [9].

The task of present investigation is to study effect of technology factors of manufacture and reprocessing of cold-rolled reinforcing bar on its corrosion behavior. Investigation includes study of cold deformation effect on corrosion behavior of prepared samples of semikilled steel 3 and 20Г2 reinforcing bar in pregnant solution $Ca(OH)_2$ that models its behavior in the concrete.

Methodology

The research material was semikilled steel 3 and 20Г2 cold-rolled reinforcing bar with diameter 10.0 and 11.0 mm and smooth rolled wire with diameter 12.0 mm for reinforcing bar manufacture.

The chemical composition of investigated steels is introduced in **Table 1**. Equivalent carbon content is computed using formula (2) DSTU 3760:2006. The specified steel grade billets were reprocessed into rolled wire with diameter 12.0 mm at JSC "Mittal Steel Kryvyy Rih" according to Specifications of Ukraine 27.1-24432974-007:2005 on the continuous wire mill MPS 250/150 with two-stage cooling.

This rolled wire was used as a raw material for production of cold-rolled reinforcing bar with diameters 10, 11 mm and strip plate with diameter 11 mm. Processing was carried out at JSC "Dneprometiz" and JSC "Konstantinovsky Iron & Steel Works".

Preparation of rolled wire surface (descaling by chemical etching in 20 % sulfuric acid with the subsequent lime pretreament) was carried out by method accepted at the plant.

Mechanical properties of original rolled wire and produced cold-rolled reinforcing bar are presented in **Table 2**.

When applied in construction, high-strength cold-rolled reinforcing bar (with planned yield stress more than 600 N/mm^2) provides application of electric thermal tension with heating to temperatures not above 400 °C. Therefore, cooling of rolled metal after heating in various water medium affecting the corrosion stability of cold-rolled reinforcing bar surface was considered as a possible operation when processing cold-rolled reinforcing bar. Electric thermal tension was modeled by heating in the furnace SNOL - 3.2.4/12 [10].

Water, solution of sodium salts of fatty acids and inhibitor KC-2 were used as cooling medium [11]. Air-cooled samples of the same material were used for comparison.

Research technique

Electrochemical research and accelerated corrosion tests were conducted in the hystat G-4 (GOST 9.308-85) to determine corrosion resistance of cold-rolled reinforcing bar in the concrete.

Electrochemical investigation was carried out in the pregnant solution $Ca(OH)_2$ modeling the conditions of corrosion processes development in the concrete [12].

To determine electrode potential we used potentiostats PI-50-1. Silver-chloride electrode was used as comparison electrode. Investigation was carried out on the rectangular fragments of surface, all edges and end faces of samples were isolated by glue.

Electrode potential was defined in the electrolit of concrete - pregnant solution of calcium hydrated oxide. Measurements were taken every minute during 30 minutes.

To determine cathodic density of current we used potentiostats PI-50-1 with programming unit PR-8 by three-electrode scheme in which comparison electrode (silver-chloride) and auxiliary (platinum) were used except for working electrod.

Table 1. Chemical composition of investigated steels

Steel grade	Number of smelting	Element concentration, % by weight					C_{eq}, %
		C	Mn	Si	S	P	
Semikilled steel 3	10-1276	0.21	0.56	0.06	0.019	0.012	0.31
25Г2С	215439	0.21	1.41	0.21	0.015	0.010	0.47

Table 2. Mechanical properties of rolled wire and cold-rolled reinforcing bar (average values)

Steel grade	Diameter, mm	Strength index	$\sigma_{0.2}$, N/mm^2	σ_{TS}, N/mm^2	σ_5, %
20Г2	12.0	A400C	458	642	30.0
	11.0	B500C	703	770	14.0
	10.0	B600	766	822	12.0
	10.0	B800. B600	800	857	18.5
Semikilled steel 3	12.0	A400C	450	575	27.0
	11.0	B500C	665	700	13.5
	10.0	B600	715	755	11.5

*Classes B600 and B800 have a conditional name [5, 7, 8]

Pregnant solution of calcium hydrated oxide was used as electrolit. Potential was changed by 600 mV in the negative side.

When modeling the material behavior in the hystat we observed the corrosion products after heating and cooling in the standardized test solution. Test results were estimated according to GOST 9.509-89 by visual method by means of definition of total area of all corrosion damage on the metal surface of samples expressed in percentage.

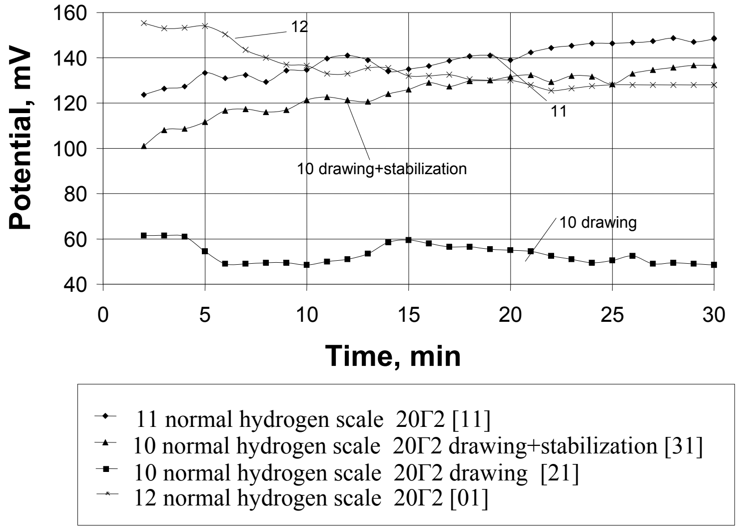
Results and Discussion

Kinetic curves of deformation effect on change of stationary potential are shown in **Figure 1**.

The analysis of results shows that electrode potential of steel 20Г2 rolled wire samples with diameter 12.0 mm (deformation degree *e = 0*) during exposing in the model electrolit decreases a little and is 130 mV after 30 minutes. Electrode potential increases and reaches 180 mV in 30 minutes for the same samples of semikilled steel 3 which is indicative of the formation of more corrosion-resistant layers on the surface in the latter case.

Samples of cold-rolled reinforcing bar of both steel grades with diameter 11.0 mm (*e = 0.17*) behave almost the same differing by little changes of potential towards reduction.

Samples of cold-rolled reinforcing bar with diameter 10.0 mm (*e = 0.37*) are characterized by



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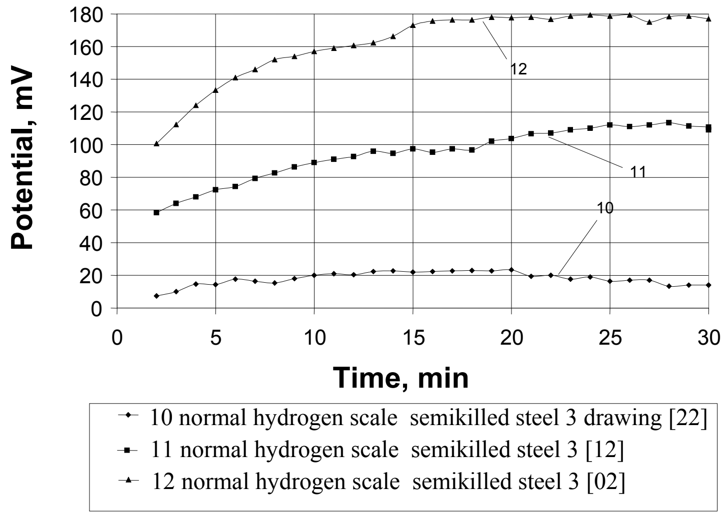

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Figure 1. Kinetic curves of stationary potential change of steel 20Г2 (*a*) and semikilled steel 3 (*b*) samples in the pregnant water solution $Ca(OH)_2$

lower values of potential which testifies to negative effect of cold deformation on corrosion stability of material. Application of intermediate heating for stress relief (stress stabilizing annealing) at 350°C during 1 hour between drawing passes of steel 20Г2 on diameter 10.0 mm leads to increase of potential value (by 90 mV). This fact can testify to effect of residual pressure value on corrosion resistance of cold-rolled reinforcing bar which is confirmed by data presented in [9, 10].

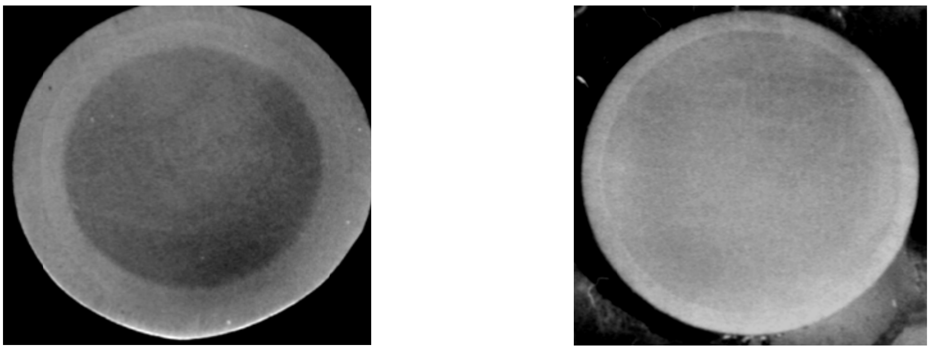
Various patterns of original strip plate (rolled wire) corrosion behavior especially at the initial stages of tests are possible to explain by manufacture technology. At the identical strength level in the initial condition (**Table 2**) the indicated rolled metal has a different chemical composition, carbon equivalent of steel grades differs in 1.5 times (**Table 1**). Similar level of strip plate strength properties is provided by thermal hardening in the rolling mill. A non-uniform macrostructure of finished rolled metal consisting of ferrite-perlite center and hardened-tempered layer on the surface is formed after this operation.

At such processing, the system of residual stresses, namely compression stresses on the surface and tensile stresses in the central layers [7] is observed in samples. However, the surface of hardened layer for semikilled steel 3 is much thicker than for steel 20Г2 (**Figure 2**) which significantly affects the residual stress diagram and, as a result, corrosion behavior of rolled metal.

The curves of exposition time effect on cathodic density of current of cold-rolled reinforcing bar at identical value of cold deformation degree ($e = 0.37$) of rolled metal with diameter 10.0 mm in the initial condition and after modeling of electric thermal tension and cooling in the standardized test solutions are presented in **Figure 3**.

It follows from presented data that increase of manganese and silicon content in steel 20Г2 and stabilization of cold-rolled condition lead to increase of corrosion stability in the concrete.

Results of investigation of corrosion resistance of samples after tests in the hystat after modeling of electric thermal tension and cooling in standardized test solutions are presented in **Table 3**. Presented data show possibility of increase of rolled metal corrosion resistance after modeling of electric thermal tension due to cooling in special medium. It is determined that high corrosion resistance is provided by cooling in inhibitor solution КС-2.

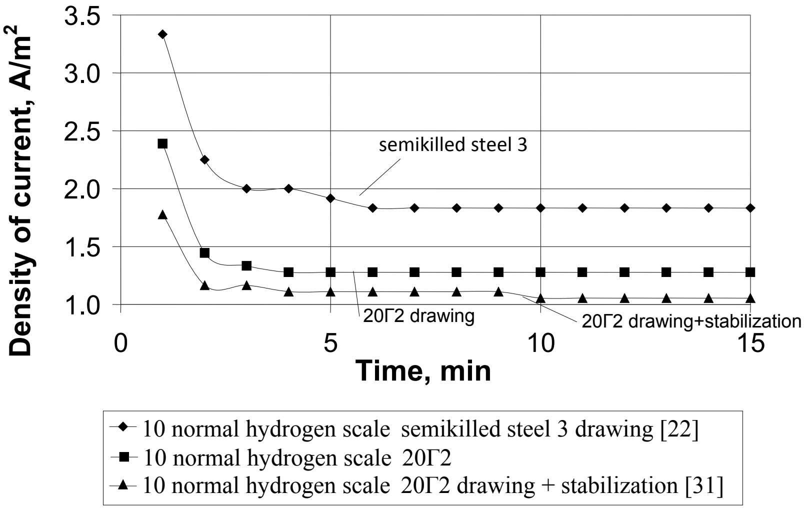


a b

Figure 2. Macrostructure of heat-strengthened rolled metal by interrupted quenching with self-tempering: *a* - semikilled steel 3, *b* - 20Г2

Table 3. Degree of damage (%) in the hystat (temperature 45 °C, humidity 95 %) of reinforcing bar samples (20Г2, Ø10.0 mm) subjected to modeling of electric thermal tension and cooled in the standardized test solutions

Cooling means	Test period, days		
	3	6	9
Water	64	70	82
Air	65	66.8	83
Soap	16	17.5	25
КС-2	5.25	4.4	5
No treatment	25	35	35



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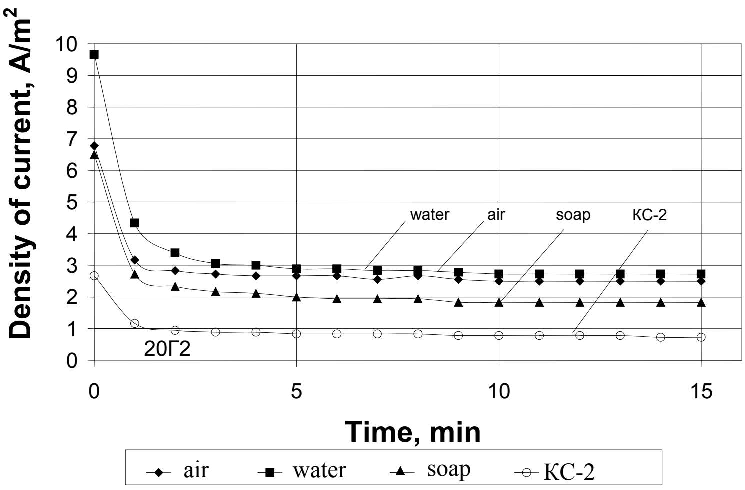

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Figure 3. Dependence of current cathodic density of cold-rolled reinforcing bar with diameter 10.0 mm on exposition time in pregnant water solution of $Ca(OH)_2$ in the initial condition (*a*) and after modeling of electrotension and cooling in various medium (*b*)

Conclusions

Conducted investigations have confirmed the importance of effect of certain stages of technological process of manufacture and processing of reinforcing bar on properties of high-strength cold-rolled reinforcing bar. It is determined that residual macrostresses have a substantial impact on corrosion behavior of reinforcing bar in the concrete. Cold working in the investigated range of deformation degrees has a negative effect on corrosion stability of reinforcing bar in standardized test solution of concrete. Therefore, application of technological process of cold-rolled reinforcing bar manufacture including additional technological operations for stabilization of structural condition and properties of end production is expedient. For this purpose it is recommended to use additional operations of mechanic-cyclic treatment or heat aging and cooling in inhibitor solution КС-2 on the basis of sodium salts of fat acids after electric thermal tension when producing concrete products.

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* Published in Russian

Received May 28, 2010

Влияние технологических факторов производства на коррозионную стойкость

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Рассмотрены особенности коррозионного поведения холоднодеформированного арматурного проката в процессе его производства и переработки, предложены решения по повышению его коррозионной устойчивости в бетоне.