

## Dependence of Engineering Products Corrosion Resistance on Construction and Operation Conditions

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**Abstract:** The article presents a detail corrosion model, taking into account its material chemical composition, the surface layer quality, corrosion environment properties and corroding conditions, the kind of used inhibitor, its concentration, coating type, its quality. The article shows the dependence of the corrosion rate with the required detail lifetime. The paper shows the effect of material phase composition, detail surface layer quality integral parameter, detail surface moisture membrane thickness, corrosive environment aggressiveness, corrosive environment temperature, the concentration of  $H^+$  ions, a corrosion inhibitor, as well as coatings on the corrosion rate. The article presents the coating influence degree on the corrosion rate for non-metallic paint and varnish and powder coatings as well as metal galvanic coatings. The article presents the effect of the detail surface layer quality complex parameter, which characterizes the rate of detail corrosion after mechanical treatment for non-heat treated and heat-strengthened details.

**Key words:** Corrosion resistance • Corrosion rate • The quality of the surface layer • Corroded • Coverage details • Complex parameter of surface layer details • Inhibitor

### INTRODUCTION

One of the main indicators of machine quality is their reliability, which is largely determined by the performance properties of parts and connections: wear resistance, fatigue strength, corrosion resistance, connections impermeability, durability, fit strength and other. All of these performance properties depend on the material used, the dimensional accuracy and the quality of their working surfaces. Typically, all components fracture starting from the surface. Thus, the technical solution to improve the machines is largely due to the possibility of detail surface layer quality technological assurance that includes both geometrical characteristics and physicochemical properties [1].

Despite the existence of a large number of different methods to ensure engineering products corrosion resistance in their manufacture [2, 3], there is no holistic technique of rational method choice to provide the

required products corrosion resistance in view of their cost, which inevitably leads to unnecessarily large economic losses due to their operation corrosion, or because of overly expensive providing corrosion resistance method in the product manufacture.

When operating structural steel parts in corrosion after mechanical treatment, their resistance will be determined by the thermodynamic stability of the surface layer material. The thermodynamic stability of any material depends on several factors, from external to internal. Internal factors affecting the detail surface layer material thermodynamic stability are described as a set of surface layer quality parameters, including geometrical and physical and mechanical parameters of the surface layer state, which are formed in the process of detail manufacturing. Thus, there is a need to improve technology of manufacturing details that undergo corrosion stress. Providing engineering products corrosion resistance only with mechanical treatment is

often does not realized because of the lack of evidence-based calculation methods and product layer material thermodynamic stability changes prediction, the surface layers parameters choice and mechanical treatment conditions in terms of ensuring desired corrosion resistance.

When operating structural steel details in a corrosion with the use of corrosion inhibitors and various types of coating, their corrosion resistance is defined as the properties of protective membrane and coatings [4, 5], as their substrate adhesion, which in turn depend on the substrate surface layer quality. Providing the required engineering products corrosion resistance, using corrosion inhibitors and coatings are now also hampered by the lack of evidence-based calculation methods and their protective properties prediction, depending on the substrate surface layer quality and its treating conditions.

In this regard, of course, actual are researches, aimed at solving problems of technological engineering products corrosion resistance protection, based on the rational choice of surface layer quality, technological methods and treatment modes.

**Detail Corrosion Theoretical Model Development:** Detail corrosion resistance depends on its material chemical composition and the surface layer quality, on the corrosive environment properties and corroding conditions, on the using inhibitor kind, its concentration, coating type, its quality etc. [1, 5, 6].

In view of the above stated, detail corrosion model can be written as:

$$V_k = V_{k_0} \cdot KC \cdot K_{yk} \cdot K_i \cdot K_c \quad (1)$$

where

$V_k$  - Detail corrosion rate;

$V_{k_0}$  - The comparative sample corrosion rate;

$KC$  - Detail surface layer quality complex parameter, characterizing the detail corrosion rate after mechanical treatment;

$K_{yk}$  - Coefficient taking into account the effect of corroding conditions on corrosion rate;

$K_i$  - Coefficient taking into account the impact of corrosion inhibitor on the detail corrosion rate (inhibition coefficient);

$K_c$  - Coefficient taking into account the influence of the coating on the detail corrosion rate (coating coefficient).

Therefore, machine details corrosion resistance using technological methods, can be provided by selecting a material with desired chemical composition, creating a certain quality of the surface layer during the mechanical and thermal treatment or enhanced by the use of corrosion inhibitors and various protective coatings: nonmetal and metal [7-9].

If necessary, to provide the required detail corrosion resistance we determine the allowable corrosion rate  $[V]$ , according to the required detail service life. Knowing the detail operating conditions, we can write the following relationship:

$$\frac{[V_k]}{K_{yk}} = V_{k_0} \cdot KC \cdot K_i \cdot K_c \quad (2)$$

Having determined the variables values combination on the right side of equation (2) satisfying the equality condition, thus provide the desired detail corrosion resistance in the given conditions. The variable values on the right side of equation (2) will depend on the method of providing corrosion resistance.

At the same time as the comparative sample we take sample from the same material after normalization and the fine abrasive treatment and corroding, when fully immersed in distilled water. Take into account possible differences between material phase composition of detail and sample we can with the help of phase composition coefficient  $K_f$ :

$$V_{K_0} = V_{K_{0s}} \cdot K_f \quad (3)$$

where

$V_{K_{0s}}$  - Comparative sample standard corrosion rate [7];

$K_f$  - Phase coefficient [8].

$KC$  - Detail surface layer quality complex parameter, characterizing the detail corrosion rate after mechanical treatment [10];

- For details, do not exposed to heat treatment, the detail surface layer quality complex parameter is determined by the relation (4):

$$KC = Un^{5,2} \cdot \left( \frac{28 \cdot 10^6 Rv}{(100 - tm)^2} \cdot Sm^2 \right)^n \quad (4)$$

Table 1: Treatment methods possibilities to ensure quality parameters and the complex parameter of the detail flat surfaces corrosion rate.

Processing method	Detail surface layer quality parameters				
	Ra, micron	Sm, mm	U <sub>H</sub>	h <sub>H</sub> , mm	KC
1	2	3	4	5	6
Face milling					
black	4.0-16.0.	0.16-0.50.	1.2-1.4.	0.2-0.5.	7.3-13.3.
fine	1.0-4.0.	0.08-0.20.	1.1-1.3.	0.08-0.15.	5.2-7.9.
finish	0.32-1.25.	0.25-0.10.	1.1-1.2.	0.05-0.10.	4.2-6.6.
Cylindrical milling					
black	3.2-10.0.	1.25-5.0.	1.2-1.4.	0.15-0.25.	6.0-9.4.
fine	0.8-3.2.	0.50-2.0.	1.1-1.3.	0.1-0.15.	4.1-7.6.
finish	0.20-1.6.	0.16-0.63.	1.1-1.2.	0.08-0.12.	2.2-5.3.
Planing mill					
black	6.4-40.0.	0.20-1.6.	1.2-1.4.	0.25-0.6.	7.3-14.2.
fine	1.0-6.3.	0.08-0.25.	1.1-1.3.	0.15-0.30.	5.2-9.1.
finish	0.32-1.6.	0.025-0.125.	1.05-1.1.	0.05-0.15.	2.6-6.1.
Face turning					
black	6.4-3.2.	0.2-1.25.	1.1-1.4.	0.2-0.45.	7.2-9.2.
fine	1.6-6.4.	0.08-0.25.	1.1-1.3.	0.05-0.20.	4.3-7.3.
finish	0.32-1.6.	0.025-0.125.	1.05-1.1.	0.02-0.05.	2.8-5.9.
Broaching					
black	1.0-3.2.	0.16-2.0.	1.1-1.3.	0.2-0.6.	1.9-6.5
fine	0.32-1.25.	0.05-0.50.	1.1-1.2.	0.1-0.3.	1.5-4.3.
Scraping					
black	2.5-8.0.	0.25-1.0.	1.0-1.2.	0.05-0.1.	3.6-6.2.
fine	0.63-2.5.	0.063-0.25.	1.0-1.1.	0.05-0.1.	2.0-4.4.
finish	0.10-0.8.	0.02-0.10.	1.0-1.1.	0.04-0.1.	1.4-3.9.
Rolling by rollers and ball heads					
black	0.63-2.5.	0.2-5.0.	1.3-1.7.	0.5-4.0.	6.3-14.
fine	0.1-0.83.	0.025-0.25.	1.2-1.6.	0.2-0.6.	3.0-8.6.
Vibro-rolling	0.16-2.5.	0.025-12.5.	1.1-1.6.	0.04-2.0.	4.8-12.4.
Superfinishing and polish					
normal	0.05-0.32.	0.01-0.032.	1.0-1.2.	0.005-0.01.	2.5-5.2.
flat-topped	0.1-1.25.	0.025-1.6.	1.0-1.1.	0.005-0.01.	1.4-3.0.
Grinding					
normal	0.02-0.1.	0.008-0.04.	1.0-1.2.	0.005-0.01.	3.6-5.0.
flat-topped	0.02-0.4.	0.02-0.25.	1.0-1.1.	0.005-0.008.	1.2-3.2.

where

n - coefficient depending on the corroding conditions;

n = 0,5 – for dry corrosion;

n = 0,7 – for wet and moist corrosion;

n = 0,66 – for corrosion by full immersion;

Un, tm, Sm, Rv - detail surface layer quality parameters.

- For details exposed to heat treatment, the detail surface layer quality complex parameter is determined by the relation (5)

$$KC = b_0 \cdot \left( \frac{HB}{HB_0} \right)^{b_1} \cdot \left( \frac{28 \cdot 10^6 Rv}{(100 - tm)^2} \cdot Sm^2 \right)^n \quad (5)$$

where HB and HB<sub>0</sub> - material hardness before and after heat treatment, respectively;

b<sub>0</sub> and b<sub>1</sub> - coefficients depending on the material type;

for low-carbon steels b<sub>0</sub> = 0,713; b<sub>1</sub> = 5,72;

for medium-carbon steels b<sub>0</sub> = 0,74; b<sub>1</sub> = 5,57.

KC coefficient values will be determined by mechanical treatment quality and surface layer quality, where KC for various mechanical treatment steps will take different values (Table 1) [7].

#### Corroding Conditions Influence on Detail Corrosion Rate:

Product corrosion rate is affected by the external corrosion factors, causing corroding conditions.

Table 2: Corrosive environment influence on corrosion rate.

Name	Steel corrosion resistance, mm / year	Steel corrosion resistance, point	Notion	Coefficient $K_a$	Environment composition
1	2	3	4	5	6
Nonaggressive	to 0.01	to 0.01	1-3.	H1	De-aerated fresh and sea water; Fresh very hard water without impurities $Cl$ , $SO_2$ ; room with humidity $\phi < 60\%$ and containing $SO_2 < 0,02 \text{ mg/m}^3$ and $Cl < 0,03 \text{ mg/m}^2$ day.
Weak	0,01÷0,05	0.01	4-5.	C1	Distilled water, clean atmosphere containing $SO_2 \leq 0,02 \text{ mg/m}^3$ and $Cl < 0,03 \text{ mg/m}^2$ day, $Fi \sim 70\%$
		0.02		C2	Fresh water containing $Mg^{2+} \cdot 10^{-4} \text{ M}$ , rooms with humidity $60 < Fi < 80\%$
		0.03		C3	Fresh water containing $Mg^{2+} \cdot 10^{-5} \text{ M}$ , rooms with humidity $Fi < 85\%$
		0.04		C4	Fresh water, village area with content of $SO_2 \leq 0,02 \text{ mg/m}^3$ and $Cl < 0,03 \text{ mg/m}^2$ day
		0.05		C5	Fresh mineral water, urban area containing $SO_2 = 0,1 \text{ mg/m}^3$ and $Cl \approx 0,03 \text{ mg/m}^2$ day, $Fi \sim 98-100\%$
Average	0,05÷0,5	0.06	6	C6	Fresh mineral water saturated with $CO_2$ , the city industrial zone, containing $SO_2 = 0,1 \text{ mg/m}^3$ and $Cl = 2 \text{ mg/m}^2$ day
		0.1		C10	Seawater, industrial sea zone containing $O_2 = 0,2 \text{ mg/m}^3$ and $Cl = 2 \text{ mg/m}^2$ day
Average	0,05÷0,5	0.2	6	C20	Sea spray, industrial area containing $SO_2 \approx 0,3 \text{ mg/m}^3$ and $Cl = 20 \text{ mg/m}^2$ day
		0.3		C30	Sea spray, industrial area containing $SO_2 \approx 0,5 \text{ mg/m}^3$ and $Cl = 30 \text{ mg/m}^2$ day
		0.4		C40	Galvanizing, pickling plant
		0.5		C50	Industrial area and plants containing $SO_2 \approx 0,5 \text{ mg/m}^3$
Strong	more than 0,5	0.6	7	C60	Contaminated industrial area and plants containing $SO_2 \approx 0,85 \text{ mg/m}^3$
		0.7		C70	Contaminated industrial area and plants containing $SO_2 \approx 1,0 \text{ mg/m}^3$
		0.8		C80	Contaminated industrial area and plants with a strong dustiness containing $SO_2 > 1,0 \text{ mg/m}^3$
		0.9		C90	Electrolytes containing $H_2SO_4 \approx 1,0\%$
		1.0		C100	Electrolytes containing $H_2SO_4 \approx 5,0\%$

Coefficient  $K_{yk}$ , taking into account the corroding conditions on the corrosion rate is determined by the expression (6) [11]:

$$K_{yk} = K_t \cdot K_a \cdot K_T \cdot K_{ph} \quad (6)$$

where

$K_t$  - Coefficient taking into account the influence of moisture membrane thickness on the detail surface;

$K_a$  - Coefficient taking into account the aggressiveness of the corrosive environment (Table 2);

$K_T$  - Coefficient taking into account the influence of corrosion environment temperature on the detail corrosion rate;

$K_{ph}$  - Coefficient taking into account the influence of

$H^+$  ions concentration on the detail corrosion rate.

Dependence of the corrosion rate on moisture membrane thickness can be represented as a function of [10]

$$K_t = f(h) \quad (7)$$

where

$$K_t = \begin{cases} 20h & ; h \leq 10^{-2}; \text{ microns} \\ 5h^{0,695} & ; 10^{-2} \leq h \leq 10^{-2}; \text{ microns} \\ 5e^{-0,0016h} & ; 1,0 \leq h \leq 1000; \text{ microns} \\ 1,0 & ; 1000 < h; \text{ microns} \end{cases} \quad (8)$$

where  $h$  - moisture membrane thickness, microns.

Thickness of the moisture membrane on the metal surface can be determined by dependencies [10]

$$h = \begin{cases} 2,37 \cdot 10^{-8} \cdot Fi^{3,074} ; \text{ microns } Fi \leq 98 \% \\ Rz ; \text{ microns } 98 < Fi \leq 100 \% , \text{ small dew} \\ 100 ; \text{ microns large dew} \\ 100 - 500 ; \text{ MKM precipitation air} \\ 500 - 1000 ; \text{ MKM periodic immersion in liquid} \end{cases} \quad (9)$$

where  $Fi$  - relative humidity, %.

Environment aggressiveness can be taken into account by the coefficient  $K_a$  (Table 2) depending on the chemical composition of the environment, its pollution, etc. [11], taking values  $0.25 \div 100$ .

Influence of temperature  $T$  on the corrosion rate may be considered by a coefficient  $K_T$ , determined in dependences:

for atmospheric corrosion:

$$K_T = 0,674 + 0,019T \quad (10)$$

for corrosion by total immersion:

$$K_T = \begin{cases} -1,2476 + 0,106T ; \quad 20 \leq T \leq 70^\circ C \\ 21 - 0,2125T ; \quad 70 < T \leq 90^\circ C \end{cases} \quad (11)$$

Influence of environment pH on the corrosion rate may be considered by a coefficient  $K_{pH}$ , determined in dependences [10]:

Table 3: Coefficient  $K_i$  values for steel corrosion in liquid

Inhibitor	1,5% sodium water	1,5% sodium benzoate $C_6H_5CO_2Na$	1% disodium hydrogen nitrite $NaNO_2$	0,1% hexamethyl-sodium phosphate $Na_2HPO_4$	0,8% sodium phosphate $(NaPO_3)_6$	0,5% sodium silicate $Na_2SiO_3$
$K_i$	1.0	0.022	0.0067	0.0089	0.135	0.0067

Table 4: The values  $K_{i0}$  for the steel atmospheric corrosion

Inhibitor	Sodium nitrite water solution 10%	Sodium nitrite 20-30%+ soda 0,5-0,8%	Sodium nitrite 5-8%+soda 0,5-0,8%+ glycerol 55-60%	Monoethanolamine benzoate 20-30 g/m <sup>2</sup>	Sodium benzoate 10-30 g/m <sup>2</sup>	3,5-dinitro-benzoate, hexamethyleneimine-G4 1,5-3,0 g/m <sup>2</sup>
$K_{i0}$	0.0833	0.01	0.01	0.041	0.041	0.017

Table 5: Coefficient values  $K_{iRz}$

Rz, microns	0.5	0.8	1.0	2.0	4.0	5.0	8.0	12.5	20	40
$K_{iRz}$	0.05	0.08	0.1	0.4	1.0	1.57	1.6	1.67	2.0	3.0

Table 6: Coefficient values  $K_{ic}$

C, %	10	15	20	25	30
$K_{ic}$	1.0	0.7	0.4	0.27	0.15
	1.0	0.8	0.6	0.42	0.25

\* In the numerator  $K_{ic}$  values for the surface with  $Rz$  5 microns, in the denominator -  $Rz$  12,5 microns

$$K_{pH} = \begin{cases} 26 - 5pH ; \quad pH \leq 5 \\ 1,0 ; \quad 5 \leq pH \leq 5 \\ -23 + 2pH ; \quad 12 \leq pH \end{cases} \quad (12)$$

$K_i$  - Coefficient taking into account the impact of corrosion inhibitor on the detail corrosion rate (inhibition coefficient);

$K_c$  - Coefficient taking into account the influence of the coating on the detail corrosion rate (coating coefficient).

## RESULTS

Inhibition coefficient values will depend on the type of its concentration and application mode: introduction of electrolyte at liquid corrosion or coating at the detail surface from the fluid by dipping method at atmospheric corrosion. [12] In the first case  $K_i$  values depend only on the type and concentration of the inhibitor (Table 3).

In the second case  $K_i$  values will also depend on the detail surface layer quality:

$$K_i = K_{i0} \cdot K_{iRz} \cdot K_{ic} \quad (13)$$

where

$K_{i0}$  - Inhibition coefficient table value, under certain conditions adopted for the standard (Table 4);

$K_{iRz}$  - Correction coefficient that takes into account the component surface roughness (Table 5);

$K_{ic}$  - Correction coefficient taking into account the inhibitor concentration (Table 6).

KC coefficient is used to evaluate the performance of coatings (coating coefficient) and can be determined from the relationship:

$$K_c = \frac{V_{K_c}}{V_K} \quad (14)$$

где

$V_{K_c}$  - Coated detail corrosion rate;

$V_K$  - Detail corrosion rate under the same conditions without the coating.

The values of the coefficient  $K_c$  depend on many factors: coating type, coating material, porosity, etc. [11].

Coating coefficient value for non-metallic paint and varnish coatings and powder coatings can be determined by:

$$K_c = K_{c_r} \cdot K_{c_t} \cdot K_{r_w}, \quad (15)$$

where  $K_{c_r}$  - coefficient taking into account the influence of increasing the actual surface substrate area:

$$K_{c_r} = 0,96 \cdot K_r^{-21,63}, \quad (16)$$

where

$K_r$  - The enlargement of the actual surface area of the substrate due to surface roughness ( $K_r = 1,0 - 1,12$ );

$K_{c_t}$  - Coefficient taking into account the thickness of the coating  $t_c$  and high-rise roughness parameters:

$$K_{c_t} = 2,34 \cdot \left( \frac{t_c}{Rz} \right)^{-0,369}; \quad (17)$$

$K_{r_w}$  - Coefficient taking into account the radius of the substrate roughness profile troughs (for most surfaces);

$$K_{r_w} = 1,0. \quad (18)$$

The coating coefficient value for metal galvanic coatings can be determined by:

$$K_c = 2,9 Ra^{0,132} t_c^{-0,217}, \quad (19)$$

where  $Ra$  - arithmetic mean of substrate surface roughness profile;  $t_c$  - coating thickness, microns.

## CONCLUSION

Thus, proposed mathematical models allow the implementation of an approach to electrochemical corrosion process modeling, taking into account corroding conditions, detail material chemical composition, roughness and physical-mechanical properties of the surface layer and it enables science-based approach to regulating the detail surface layer quality parameters.

On the corrosion rate of the material surface layer influences the material hardening degree and its surface roughness parameters, but the hardening degree influence is higher.

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