

Specific features of steel corrosion propagation and inhibition during abrasive dilatant treatment

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Abstract

The rate of corrosion damage development on steel after hydroabrasive and abrasive dilatant cleaning treatment, as well as the effect of some inhibitors on the rate of corrosion development on specimens cleaned by different methods have been studied. It has been shown that abrasive-dilatant treatment combined with inhibition efficiently hinders corrosion on freshly-cleaned surfaces and can slow down the formation and growth of corrosion sites by an order of magnitude.

Key words: *hydroabrasive treatment, abrasive dilatant treatment, corrosion inhibitors.*

Received: June 1, 2014.

doi: [10.17675/2305-6894-2014-3-3-190-197](https://doi.org/10.17675/2305-6894-2014-3-3-190-197)

High quality surface cleaning and absence of residual corrosion deposits are known to be the major factors that determine the corrosion resistance of anti-corrosion coatings applied on such surfaces [1].

The most efficient methods include blast cleaning that can be subdivided into dry blast cleaning, blast cleaning with water injection, and high-pressure water jet cleaning. Judging by the combination of its properties, water jet treatment is the most promising cleaning method. However, indicators comparable to those of abrasive methods in terms of efficiency can only be reached using very high pressures (above 100 MPa), which makes the process very power-consuming and unsafe for an operator.

It is principally possible to lower the required pressure and improve the performance of water jet treatment considerably by changing the rheological properties of the liquid by using additives that impart dilatant properties to it [2, 3]. Dilatant additives, which are usually mixtures of a water-soluble polymer and a finely dispersed clay powder, increase viscosity and shear velocity, so that the behavior of the water jet in the zone where it hits the metal surface approaches that of a solid [4, 5].

One of the consequences of brittle rupture of a water jet containing dilatant additives involves intense mechanic destruction of the dissolved polymer followed by partial cross-linking and formation of a thin film (up to 10 μm) of products resulting from mechanochemical destruction and modification of dilatant additives on the metal surface [6].

Hydrodynamic treatment with water containing dilatant additives allows cleaning from the majority of paints and corrosion products, though some oxides and mill scale can be removed incompletely even at pressures up to 70 MPa.

From the practical point of view, it is more expedient to use abrasive dilatant treatment with a jet of an abrasive agent and water containing dilatant additives. This kind of treatment allows high-quality cleaning of a broad spectrum of contaminated surfaces at relatively low pressures up to 20 MPa.

However, any methods and modifications of water jet treatment encounter a serious problem that corrosion processes easily start and develop on a moist steel surface, thus limiting considerably the applicability of this method.

The purpose of this work is to study whether it is possible to inhibit steel surface during abrasive dilatant treatment. We intended to handle the following tasks in this work:

1. A comparative study of initiation and growth of corrosion sites on steel after water jet treatment and abrasive dilatant treatment.
2. A comparative study of the protective properties of a number of inhibitors during abrasive dilatant treatment.

Objects studied. Steel 3 specimens that underwent water jet treatment or abrasive dilatant treatment of various types were studied.

Hydroabrasive treatment and abrasive dilatant treatment were carried out in a specialized bench under identical conditions (liquid jet pressure = 20 MPa, treatment time 15 s, temperature = 25°C). The content of the abrasive agent (quartz sand with particle size up to 0.5 mm) was 80% with respect to water. The authors are grateful to G. S. Pupchenkov for his help in the cleaning of the specimens.

A water-soluble polymer, namely, polyoxyethylene with a molecular mass of 4 mln (WSR-301, USA), and a nano-dispersed clay powder (bentonite of BentoKon grade, BentoProm company) were used as the dilatant additives. The concentrations and component ratio in the comparative tests were kept at constant values close to optimum ones.

After treatment, the specimens were dried in air under the same conditions for each series.

Corrosion inhibitors based on amino-substituted tungstophosphoric and molybdophosphoric acids were studied. This group of inhibitors was selected because of their low migration capability.

Information about the corrosion inhibitors studied is provided below in Table 1.

Inhibitor samples were synthesized and kindly provided by S.V. Oleinik.

At this stage of the study, inhibitor treatment was carried out by immersion of cleaned plates (as described above) into an aqueous solution or dispersion of an inhibitor. The inhibitor concentration was 1% and the exposure time was 10 min. After that, the specimens were washed pairwise (one specimen after hydrotreatment and one after abrasive dilatant treatment) for 10 min in distilled water, then placed in desiccators with controlled humidity conditions (70–7.5%) for corrosion tests. The test time was 10 days. The specimens were

visually examined every day. To do so, they were removed from a desiccator once in 24 h and photographed in order to keep track of changes in the corrosion damage [7, 8].

Table 1. Information about the corrosion inhibitors studied.

No.	Inhibitor	Designation	Aqueous solution pH
1	IFKhAN-P1	P1	3.74
2	IFKhAN-P2	P2	3.79
3	IFKhAN-P3	P3	4.92
4	IFKhAN-P4	P4	2.54
5	IFKhAN-P5	P5	3.61
6	IFKhAN-PE	PE	4.03

The number of corrosion sites per unit surface area and the fraction of surface area with corrosion damage were used as the main criteria for estimation of corrosion intensity on freshly cleaned surfaces. The fraction of corroded surface area was estimated using the Photo-M program based on photographic images of a 30×30 mm surface area. The number of corrosion sites was counted manually from photographic images at ×10 magnification on a 30×30 mm area [8].

At the first stage, two groups of specimens were prepared from St3 steel. Of these, 18 specimens underwent water jet treatment and 30 specimens underwent abrasive dilatant treatment.

Experimental results on the variation in the fraction of corroded surface are presented below.

Figure 1 shows averaged results of kinetic plots of corrosion area growth on St3 specimens at humidities in the range of 97.5–70%.

As one can see from the results obtained, at higher humidity, abrasive dilatant treatment slows down the corrosion growth on a freshly cleaned surface, which manifests itself as a smaller (1.5–2 fold) corroded area. However, in tests at lower humidity (up to 70%), the corrosion rates decrease and the difference between the specimens that underwent water jet treatment and abrasive dilatant treatment becomes insignificant.

During this study, we also estimated the number of corrosion sites and tracked how it increased in time. The number of corrosion spots for specimens exposed at 97.5%, 95%, 92.5%, 90%, 80%, and 70% humidity is shown in Fig. 2.

Based on the results obtained, we made an attempt to elaborate a kinetic model of corrosion propagation on freshly cleaned specimens that underwent water jet treatment and abrasive dilatant treatment.

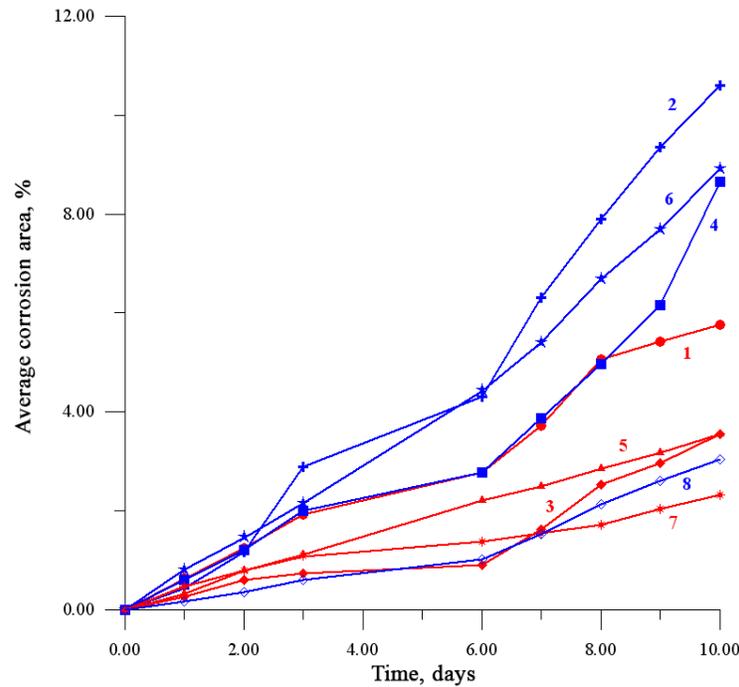


Figure 1. Corrosion growth at 97.5%, 95%, 90%, and 70% humidity. 1, 3, 5, 7 – specimens that underwent abrasive dilatant treatment. The specimens were exposed at 97.5%, 95%, 90%, and 70% humidity, respectively; 2, 4, 6, 8 – specimens that underwent water jet treatment. The specimens were exposed at 97.5%, 95%, 90%, and 70% humidity, respectively.

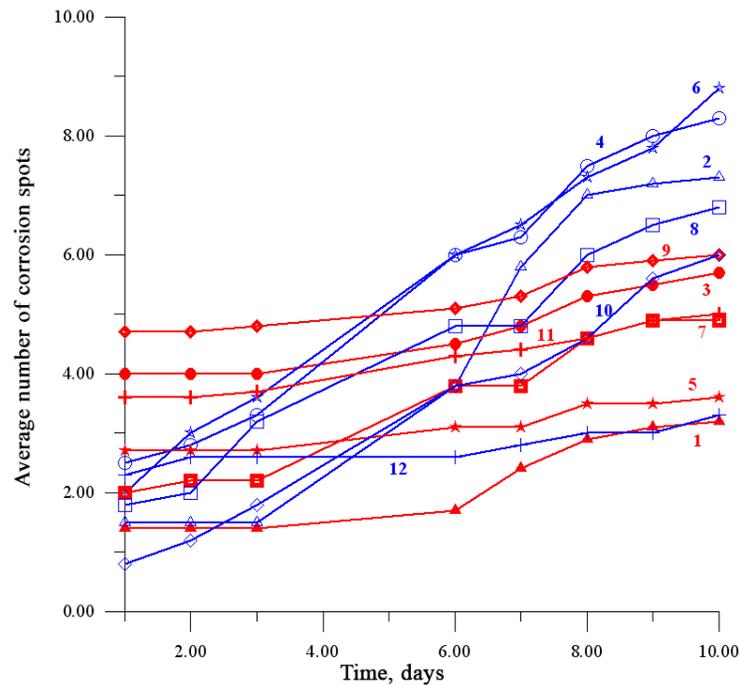


Figure 2. Average number of corrosion spots per 1 cm² of a specimen. 1, 3, 5, 7, 9, 11 – specimens that underwent abrasive dilatant treatment. The specimens were exposed at 97.5%, 95%, 92.5%, 90%, 80% and 70% humidity, respectively. 2, 4, 6, 8, 10, 12 – specimens that underwent water jet treatment. The specimens were exposed at 97.5%, 95%, 92.5%, 90%, 80% and 70% humidity, respectively.

This model is based on the concept that the total area of corrosion spots can be regarded as the sum of products of the mean size (area) of corrosion spots in the histogram by the number of such spots:

$$S = \sum n_i \times S_{m,i},$$

where n_i is the number of corrosion sites (spots) of mean area $S_{m,i}$ and n_i is a function of time: $n = f(\tau)$.

As one can see from the results presented above (Fig. 2), in a first approximation, the rate of formation of corrosion sites after water jet cleaning does not depend on time, hence:

$$n = n_0 + V_0 \times \tau,$$

where n_0 is the initial number of corrosion sites and V_0 is the formation rate of corrosion sites.

Then, in the simplest case, at a constant linear growth rate of a corrosion spot $V_c = \text{const}$, the area of a single corrosion spot is expressed as:

$$S_m(\tau) = (r_0 + V_c \times \tau)^2 \pi,$$

while the kinetic plot of the total area of corrosion spots on freshly cleaned specimens can be represented as

$$S = (n_0 + V_0 \tau)(r_0 + V_c \tau)^2 \pi$$

One can assume that $n_0 = 0$ and $r_0 = 0$ at the initial time instant, hence the expression can be simplified:

$$S = V_0 V_c \tau^3$$

As follows from the above equation, the experimental data on corrosion area on freshly cleaned specimens in “ $(S)^{1/3} - \tau$ ” coordinates can be described by linear kinetic relationships, as the results in Fig. 3 confirm.

Computer simulation shows that the suggested model works not only for $n_0 = 0$ and $r_0 = 0$, but also in those cases where the initial values are considerably smaller than the current ones.

The second goal of this study was to clarify the principal possibility of increasing the corrosion resistance of water jet treated metals by inhibitors and to compare the corrosion rates of specimens cleaned by various methods.

Two groups of St3 specimens were prepared for the experiment. Of these, 15 specimens underwent water jet treatment and 15 specimens underwent abrasive dilatant treatment. After that, the specimens were divided into five groups, each group containing three specimens after water jet treatment and three specimens after abrasive dilatant treatment.

After the treatment, each group of specimens was kept for 10 minutes in one of the five inhibitors. Thereafter, two specimens (one after water jet treatment and one after abrasive dilatant treatment) were placed for 10 min in distilled water, then dried with filter paper and placed in a desiccator for corrosion tests.

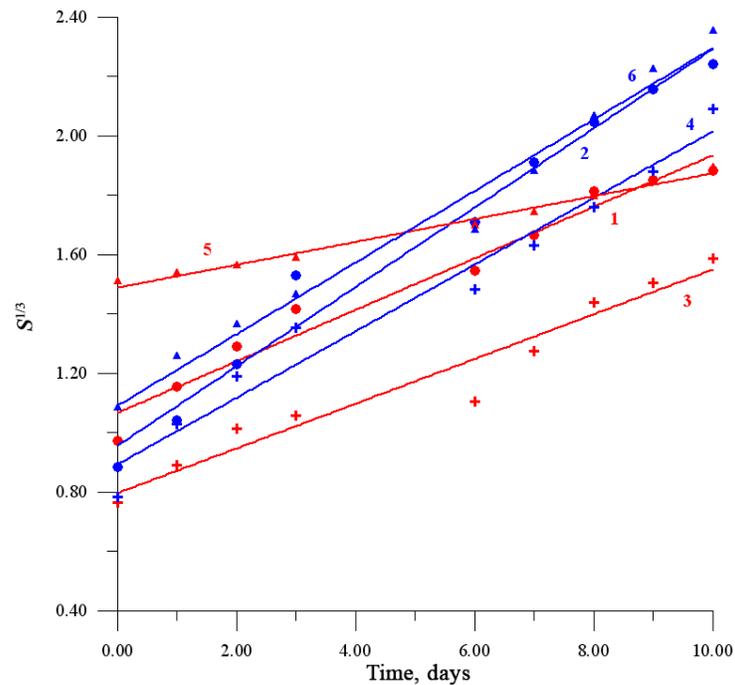


Figure 3. Dependence of $S^{1/3}$ on time for 97.5%, 95% and 80% humidity. 1, 3, 5 – specimens that underwent abrasive dilatant treatment and then kept at 97.5%, 95%, and 80% humidity, respectively. 2, 4, 6 – specimens that underwent water jet treatment and then kept at 97.5%, 95%, and 80% humidity, respectively.

The test results are shown in Table 2.

Table 2. Results of comparative corrosion tests (fraction of corroded surface) after exposure for 20 days at controlled humidity.

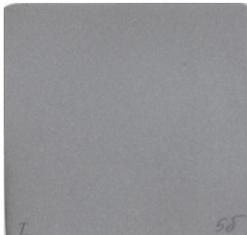
Environment humidity, %	S , %	Inhibitor brand									
		P1		P3		P4		P5		P-Exp	
		WJT	ADT	WJT	ADT	WJT	ADT	WJT	ADT	WJT	ADT
70	S_0	1.85	13.96	34.65	32.01	35.98	0	0	4.34	0.34	0.39
	S_c	47.4	43.17	58.48	42.77	43.5	0.19	0.96	7.22	6.42	0.42
85	S_0	33.41	0	59.02	30.84	34.51	0	0.06	0	0	0.04
	S_c	63.76	1.25	100	53.17	50.78	4.87	0.64	5.24	6.07	0.35
97.5	S_0	48.82	25.14	71.35	60.03	51.66	7.53	31.1	13.39	11.45	0
	S_c	64.4	29.03	92.45	86.97	61.83	14.52	46.05	44.63	29.63	0

Note: WJT – water jet treatment; ADT – abrasive dilatant treatment.

As one can see from the data in Table 2, the effect of all the inhibitors is insignificant in case of usual water jet treatment followed by exposure to inhibitors and water rinsing.

However, a pronounced effect is observed after abrasive dilatant treatment, but this effect depends considerably on the inhibitor (modifier) brand.

The photographic images from specimens with various kinds of surface treatment are shown below for IFKhAN-PE, the most efficient inhibitor, as an example.

Corrosion test duration, days	Surface treatment type		
	Water jet treatment	Water jet treatment followed by inhibitor treatment	Abrasive dilatant treatment followed by inhibitor treatment
1			
10			

It is noteworthy that the kinetics of corrosion propagation does not principally change upon additional inhibitor treatment and fits the model considered above (Fig. 4).

It follows from our results that the inhibitors studied are efficient in combination with abrasive dilatant treatment and that the best inhibitors combined with abrasive dilatant treatment can slow down the formation of corrosion sites and their growth by an order of magnitude. This undoubtedly allows us to believe that this line of research is quite promising.

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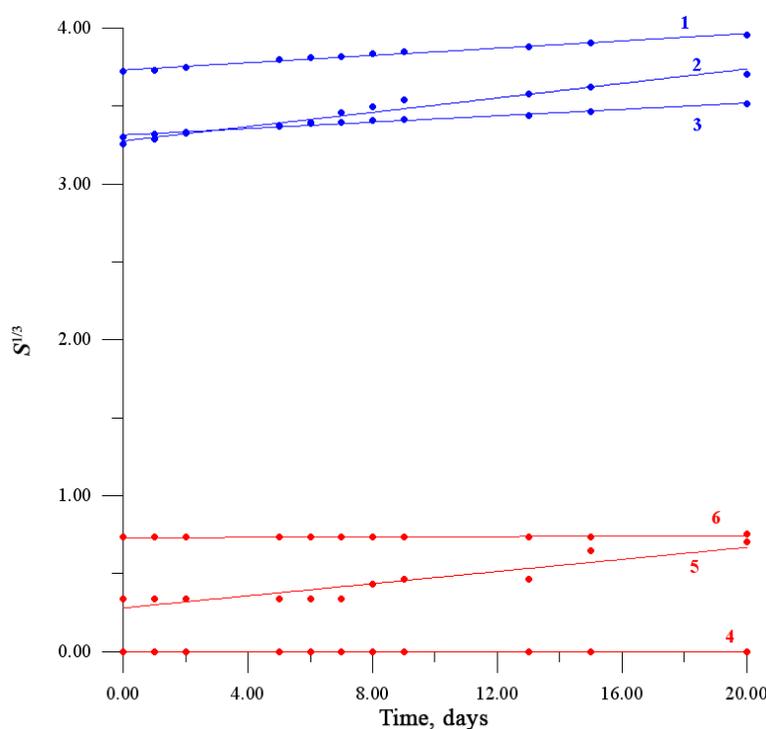


Figure 4. Plot of $S^{1/3}$ versus time for specimens treated with P6 inhibitor (exp.): 1, 2, 3 – specimens that underwent water jet treatment and then kept at 97.5%, 85%, and 70% humidity, respectively; 4, 5, 6 – specimens that underwent abrasive dilatant treatment and then kept at 97.5%, 85%, and 70% humidity, respectively.

