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Corrosion-Cracking Resistance Test Procedure of Stainless Steel Tubular Billets and Pipes

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The procedure of stress-corrosion cracking testing of stainless steel and alloy tubular billets and pipes was developed and tested at JSC "Sentravis" according to the foreign and domestic standards. The optimum types of test samples depending on steel class, grade and pipe size as well as assessment criteria of their corrosion resistance are recommended.

Keywords: STAINLESS STEELS AND ALLOYS, CORROSION CRACKING, TESTING PROCEDURE, MAGNESIUM CHLORIDE, SAMPLES, TENSILE STRESSES, STRESS-CORROSION CRACKING CRITERIA

Introduction

One of primary causes of stainless steel pipes failure under operating conditions in chemical, petrochemical, cellulose and paper, food-processing industry, thermal and atomic engineering is stress-corrosion fracture [1-6].

Stress-corrosion fracture occurs under the effect of tensile stresses and corrosion medium, and it depends on a number of external and internal factors among which are chemical and structural composition of steel, pipe manufacturing technique, composition and temperature of medium as well as residual stresses and stresses created when installing equipment.

Accordingly, more and more stainless steel and alloy pipe consumers specify requirements to corrosion-cracking resistance, in particular, according to standard ASTM-G-36. This standard provides testing of tensile strained samples in boiling solution of magnesium chloride $MgCl_2 \times 6H_2O$ (solution concentration is approximately 45 %) at 155 °C with estimation of corrosion-cracking resistance in time until the formation of fractures on the sample surface visible at optical magnification x20.

These tests are carried out in cone flasks with backflow condensers which eliminate evaporation and change of solution strength. However, the specified standard has a number of disadvantages that make its practical use difficult for acceptance testing of metal products, including stainless steel pipes.

In particular, there are no accurate requirements to test samples, and only references to standards recommending those or other types of samples are given: ASTM-G-1, ASTM-G-30, ASTM-G-38, ASTM-G-39 and others, there are no criteria of corrosion-cracking resistance (maximum stress and spall fracture time depending on sample type and chemical composition of test material), etc.

In conjunction with duration and labor content of corrosion-cracking resistance testing and also absence of proper standards for application in factory laboratories, there are no acceptance test of pipes on corrosion-cracking resistance at pipe plants of Ukraine and CIS countries till now, which does not allow complete information about their qualitative adjectives and forecasting behavior under operating conditions.

The purpose of present research is to develop acceptance testing technique on corrosion-cracking resistance of stainless steel tubular billet and pipes. The investigation was conducted at JSC "Sentravis Production Ukraine".

Results and Discussion

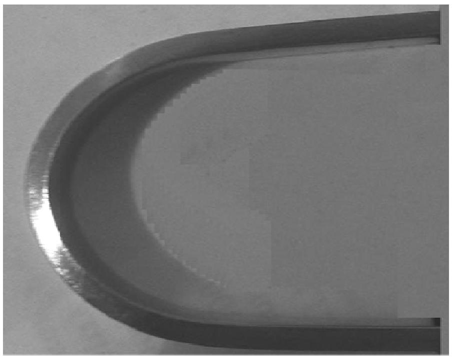
With account of consumer requirements, the standard ASTM-G-36 was taken as a basis for working out of acceptance test procedure for stainless steel tubular billet and pipes based on analysis of publications [3-7], domestic and foreign standards on corrosion-cracking resistance test (GOST 9.901 (1-5), ISO 7539 (1-5), ASTM G-01) and results of research scientific work conducted earlier at "Ya. Yu. Osada Scientific Research Tube Institute" [7].

On the basis of preliminary tests of austenitic and austenitic-ferritic steel tubular billet and pipes on corrosion-cracking resistance according to ASTM-G-36 with the use of various samples according to above-specified standards, the optimum types of samples for tubular billet, thick-walled pipes, cold - and warm-rolled pipes with diameter more than 18 mm as well as small diameter pipes (to 18 mm) were recommended.

For testing of austenitic high-nickel steel tubular billets and pipes with high corrosion-cracking resistance [3-6] and high ductility, it was suggested to use flat U- samples and U-samples-segments 2-3 mm thick, 10-15 mm wide and 90-100 mm long with rounded radius not less than double thickness of sample according to ASTM-G-30 (**Figure 1a**) as well as flat samples with three-point bending deflection according to ASTM-G-39 and ISO 7539-2 (**Figure 1b**).

Tests on U-samples are more stringent because metal, except for plastic flow while bending, is subjected to additional elastic strain at contraction of sample ends to make them parallel for U-shaping. Carried out corrosion-cracking resistance tests of U-samples of iron-chromium-nickel alloy pipes according to ASTM-G-36 showed that there were no cracks during more than 500 hours, i.e. high corrosion-cracking resistance of specified pipes was observed.

When testing U-samples of UNS S 31803 (02X22H5AM3) tubular billet and austenitic nickel-chromium and chromium-nickel-molybdenum steel samples (08X18H10T, 03X17H14M3, etc.), the fractures appeared in a rather short period of time from 5 to 24 hours. In some cases, there were brittle cracks when U-bending of duplex steel tubular billet samples (**Figure 2**), which did not allow using them for testing and corrosion-cracking resistance estimation.



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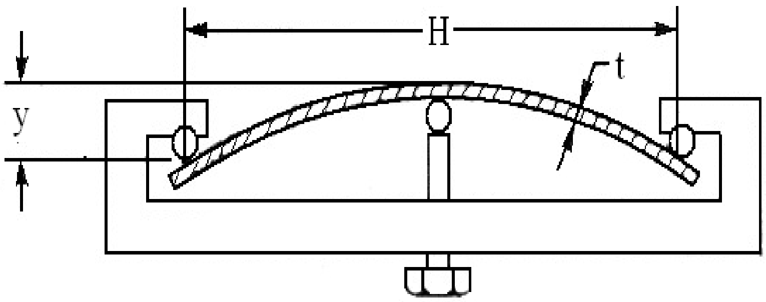


b

Figure 1. U-sample (*a)* and sample with bend deflection (*b)* for corrosion-cracking resistance test

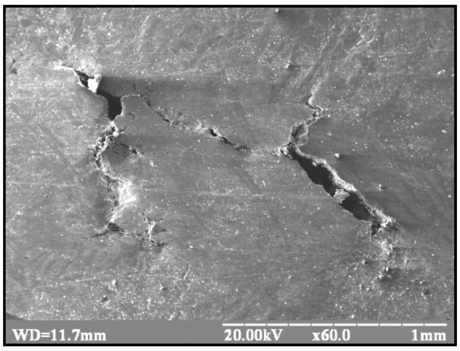


Figure 2. Cleavage cracks on the top of UNS S 31803 tubular billet U-sample before tests, × 60

In this connection, it is recommended to use flat samples with bend deflection according to ASTM-G-39 and ISO 7539-2 in the developed method for testing tubular billet and thick-walled tubes made of austenitic steel with lower corrosion-cracking resistance than high-nickel steels as well as for testing stronger ferritic-austenitic and ferritic steels. Advantage of these samples is a possibility to create tensile stresses of target value in them and determine crippling cracking stresses (maximum stresses at which fractures do not occur for a long time) for tubular billet and pipes made of different steel grades. Tensile stress in the upper metal layers of specified samples is calculated from:

$$\sigma = 6Ety/H^2 \qquad \text{(Eq. 1)}$$

where σ and E - maximum tensile stress in the sample and elastic modulus of steel, respectively, MPa; t, y and H - sample thickness, value of its maximum bend and distance between supports, respectively, mm.

Standardized according to specifications on tubular billet and tubes yield stress was suggested as a basis for selection of tensile stress value in samples with bend deflection.

Corrosion-cracking resistance tests were carried out on flat samples with bend deflection of ferritic-austenitic steel UNS S 31803 tubular billet and hot-pressed pipes. Tensile stresses in samples corresponded to standardized yield stress of steel (450 MPa), and also 80, 70 and 60 % from it. It was determined that tubular billet samples were subjected to long corrosion-cracking resistance testing at stress 270 MPa which corresponded to 60 % from yield stress, and hot-pressed tube samples - at 360 MPa (80 % from σ_{02}).

For corrosion-cracking resistance testing of cold-rolled and warm-rolled pipes, which geometrical sizes do not allow making flat samples, it is recommended to use spring C-samples (**Figure 3**) according to ASTM-G-38 and ISO 7539-5. Required tensile stresses in them are created by contraction of bolt and calculated from the following equations:

$$OD = OD_f - \Delta \qquad \text{(Eq. 2)}$$

$$\Delta = f\pi D^2/4EtZ \qquad \text{(Eq. 3)}$$

where OD and OD_f - outside diameter of C-ring before and after loading, respectively, mm; f and E - set stress and elastic modulus of steel, respectively, MPa; Δ - change of outside diameter after stress, mm; D and t - average diameter and wall thickness, respectively, mm; Z - correction index depending on the ratio between diameter and wall thickness of sample.

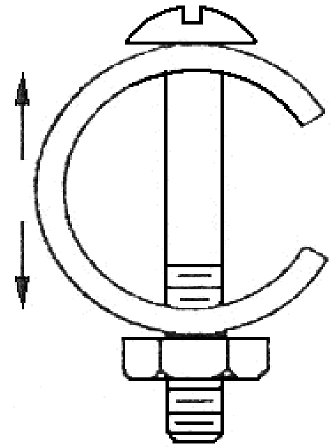


Figure 3. C-sample of warm-rolled tube for corrosion-cracking resistance testing

Tensile strain pattern in C-samples (in tangential direction in relation to outer generating line of the tube) differs from the strain pattern in samples with bend deflection (in the longitudinal direction). At the same time, application of C-samples for testing thin-walled tubes is, in our opinion, the most comprehensible as enables to create stresses of specified value and define critical stresses of cracking for various steel grade pipes.

C-samples were applied for corrosion-cracking resistance testing of ferritic-austenitic steel UNS S 31803 warm-rolled pipes ∅ 18×2.8 mm. Effect of surface preparation on test results was determined: polished samples had been tested for more than 200 hours at stress 360 MPa (80 % from yield stress of pipes) (**Figure 4 a**) and at stress equal to standardized yield stress 450 MPa they had cracked in 24 hours of testing (**Figure 4 c**). Transgranular pattern of corrosion cracking was observed (**Figure 4 d**).

C-samples of pipes with etched surface passed corrosion-cracking resistance test at high tensile stress 450 MPa during more than 240 hours. The negative effect of polishing on corrosion-cracking resistance is caused by additional tensile stress on the sample surface.

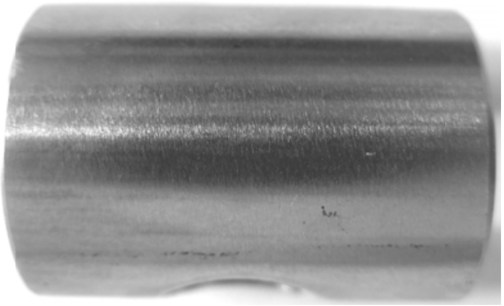
For corrosion-cracking resistance tests of pipes with small diameter less than 18 mm (for which it is impossible to make C-samples), it was recommended to use ring shaped samples in which tensile stresses are created by ring flattening by means of pulling together compressed surfaces to distance H (mm) computed for austenitic steel and alloys by formula (4) and for ferritic-austenitic and ferritic steels by formula (5):

$$H = \frac{1.08 \times D \times c}{0.08 \times D + c} \qquad \text{(Eq. 4)}$$

$$H = 0.5\ D + 2\ c \qquad \text{(Eq. 5)}$$

where *D* and *c* - outside diameter and wall thickness of tube, mm.

Results of corrosion-cracking resistance test of ring shaped samples of cold-finished ferritic-austenitic steel UNS S 31803 pipes ∅ 14×2.3 mm showed that even after 300 hours of boiling in solution of magnesium chloride there were no cracks on their surface (**Figure 5**). Similar samples of 03X17H14M3 pipes showed lower corrosion-cracking resistance which correlates with literary data about higher corrosion-cracking resistance of two-phase steels in comparison with monophase ones [4-6]. Corrosion-cracking resistance criteria of stainless steel pipes were recommended on the basis of test results.



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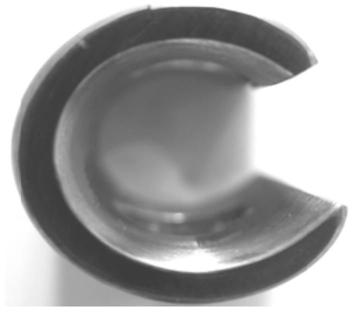

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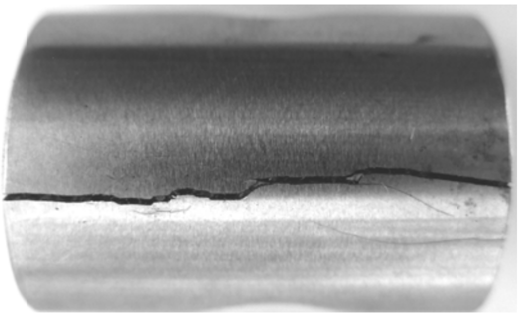

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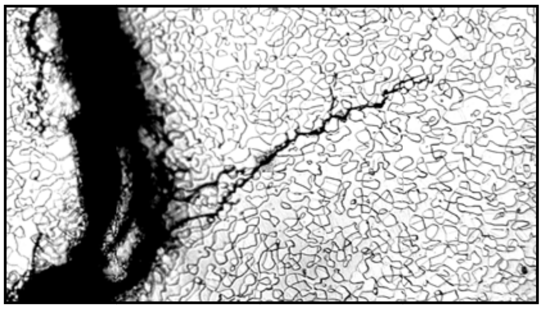

d

Figure 4. Appearance (*a-c*) and structure (*d)* of polished C-samples of UNS S 31803 warm-rolled pipes ∅ 18×2.8 mm after corrosion-cracking resistance test at stress: *a, b* - 360; *c, d* - 450 MPa

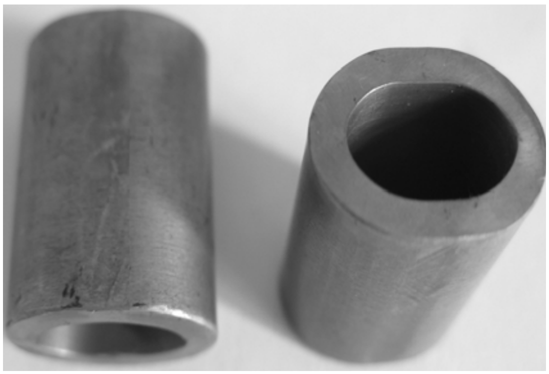

Figure 5. Samples of UNS S 31803 cold-finished pipes ∅ 14×2.3 mm after corrosion-cracking resistance tests, ×4

Conclusions

1. Acceptance test procedure on corrosion-cracking resistance of stainless steel and alloy tubular billet and pipes was worked out on the basis of foreign and domestic standards. Optimum types of samples depending on tube sizes, steel grade as well as corrosion-cracking resistance criterion were recommended and justified.
2. Samples of austenitic and ferritic-austenitic steel tubular billet and pipes were tested on corrosion-cracking resistance according to the developed technique. Test results showed that this procedure can be applied for acceptance testing in industrial conditions.
3. Parameters of corrosion-cracking resistance of various steel and alloy pipes can be included in corresponding regulatory documents.
4. Increase of pipe acceptance tests volume due to corrosion-cracking resistance testing will allow enhancing their operate reliability and competitiveness.

References

1. V. S. Vakhrusheva, T. A. Dergach, G. D. Sukhomlin. *Metallugicheskaya i Gornorudnaya Promyshlennost*, 2006, No. 5, pp. 56-58.*
2. A. S. Zubchenko, I. L. Kharina, A. E. Runov, et al. *Proizvodstvo Prokata*, 2006, No. 2, pp. 85-92.*
3. *Investigation, Research and Industrial Adoption of Corrosion Cracking Resistant Steel*, Moscow, TsNIITMASh, 1967, 172 p.*
4. V. P. Pogodin, V. L. Bogoyavlenskiy, V. P. Sentyurev. *Integranular Corrosion and Corrosion Cracking of Stainless Steels in Water Medium*, Moscow, Metallurgiya, 1970, 245 p.*
5. *Stainless Steel Seamless Tubes*. Proceedings of technical symposium, Kobe Steel, Japan, 1985, 138 p.
6. *Stainless Steel Pipe and Tubing. Mannesmann rushers – worker*, Proceedings by Mannesmann, 1987, 143 p.
7. *Astm G-36. Standard Procedure of Estimation of Corrosion-Cracking Resistance of Metals and Alloys due to Stress Corrosion in Boiling Solution of Magnesium Chloride*. ASTM, 100 Barr Harbor Drive, Conshohocren, 2000, 11 p. *

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Методика испытаний на стойкость к коррозионному растрескиванию трубной заготовки и труб из коррозионностойких сталей и сплавов

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Бездетный И.А., Юрков С.К.

На основе зарубежных и отечественных стандартов разработана и опробована в ЗАО «СЕНТРАВИС» методика сдаточных испытаний на стойкость к коррозионному растрескиванию (КР) трубной заготовки и труб из коррозионностойких сталей и сплавов, в которой предложены оптимальные виды образцов для испытаний в зависимости от класса и марки стали и от размеров труб, а также критерии оценки их стойкости к КР.