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Effect of Steam-Plasma Charge Treatment of Stainless Steel Pipe Surface on Corrosive Resistance

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The effect of steam-plasma charge treatment on the corrosive resistance of stainless steel pipe is studied. The peculiarities of electrochemical behavior of stainless steel samples in aggressive environment of sodium chloride, as well as the topography and structural-phase composition of surface layer after conventional and steam-plasma charge treatment are considered.

Keywords: STEAM-PLASMA CHARGE, STAINLESS STEEL PIPE, SURFACE TREATMENT, CORROSION RESISTANCE, SURFACE, AGGRESSIVE ENVIRONMENT

Introduction

Durability of stainless steels is defined in many respects by protective ability of oxide layers on the surface and achieved by the formation of structure with no defects. Experience shows that the overall majority of defects in stainless steel pipe & tube making are in the subsurface layer at a depth of 0.3-0.5 mm. Due to stress concentration this layer reduces maintainability. Therefore stainless steel pipe surface is additionally treated to achieve higher corrosion stability. Steam-plasma charge treatment of pipe surface is rather perspective [1, 2]. Interest to steam-plasma charge with liquid electrode for use in the technological purposes consists in that it takes place under atmospheric pressure, and properties of chemical and plasma treatments are combined. As this treatment has a strong effect on morphology, structure and topography of surface layers it is possible to assume that this will result in considerable change of corrosion behavior of treated articles in corrosion environments.

Analysis of published theoretical, methodical and practical results enables to draw a conclusion that issues related to structural features of stainless steel article surface coats after steam-plasma charge treatment and to their corrosion behavior mechanism are studied not enough.

The task of present research is to study interrelation between change of stainless steel pipe surface coat state when using steam-plasma charge treatment and its corrosion behavior in corrosion environments.

Methodology

We used segments 16×1.5 mm cut from stainless steel 08X18H10T pipe as samples. The internal surface of pipe is studied.

Also we additionally investigated the surface of stainless pipe after rolling (with the subsequent removal of lubricant), heat treatment (with the subsequent flattening and polishing) and passivating treatment for comparative assessment of steam-plasma charge effect on stainless steel surface condition.

The samples are heat treated in the muffle electric furnace ОКБ-752 at the rate of 2.0-3.0 m/min and pipe temperature 1000 °C in the air. Polishing provided surface condition, average arithmetical profile deviation parameter Ra = 0.3-0.5 microns. Pipe surface passivating is accomplished at 50 °C during 5 minutes, in nitric-fluorhydric acid solution, g/l: hydrofluoric acid 40, nitric acid 120, water 90.

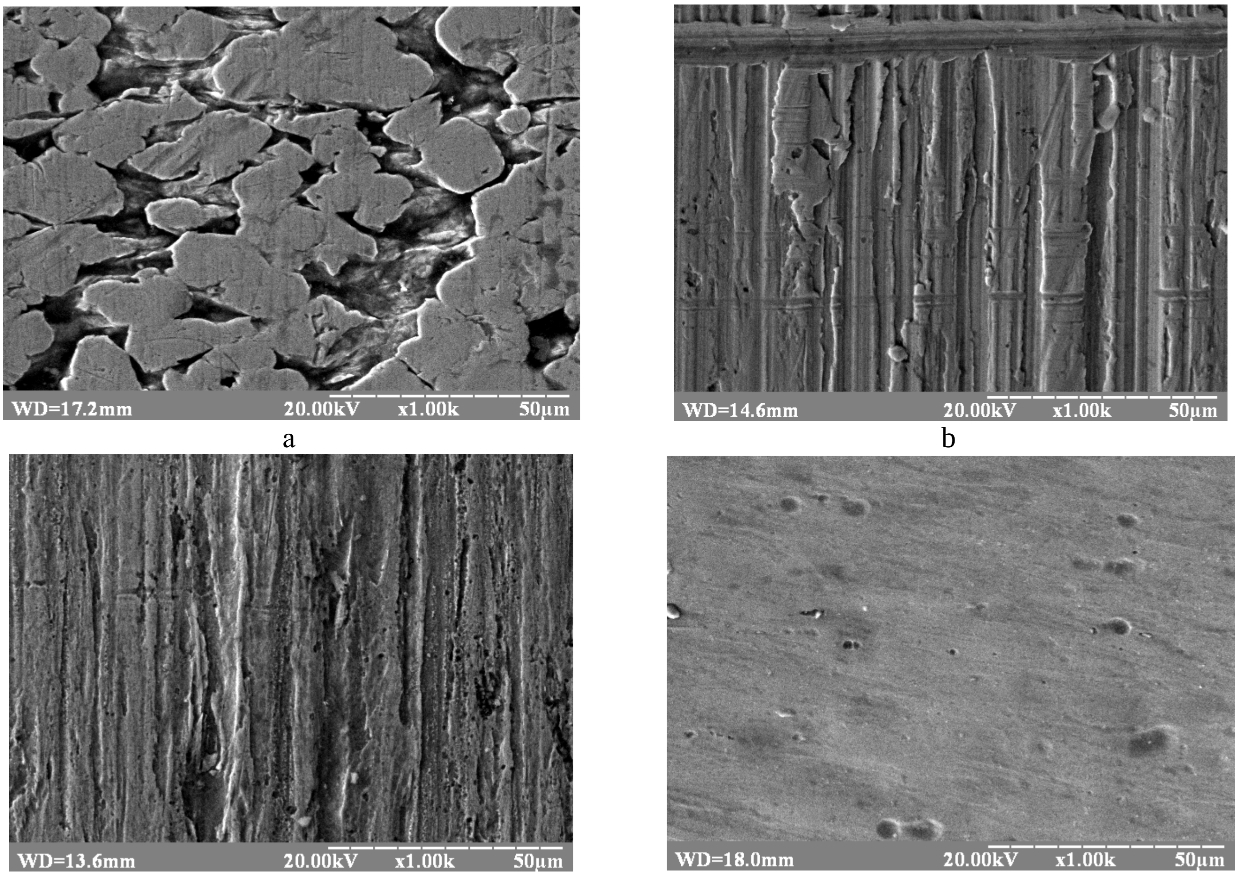
Cleaning of stainless steel sample surface by steam-plasma charge is carried out on the experimental unit presented in [3]. When processing internal surface of the pipe jet torch cathode is put in it and is spraying 10 %-solution of salt $NH_4 (SO_4)_2$ at the angle of 60 °. Voltage between electrodes varied in the range of 1400-1500 V, discharge current 0.7-0.8 A, electrolyte consumption rate $6 \cdot 10^{-6}$ m3/s.

When choosing electrolyte and its concentration we proceeded from the following. Combustion stability depends on electrolyte consumption, diameter and length of stream. Therefore it is obvious that electrolyte composition has a considerable effect on firing point. It is determined experimentally that the discharge is allowed “easier" and is burning steady at smaller stress in case of using $NH_4 (SO_4)_2$ with concentration 10 %. For comparative assessment of stainless steel corrosion stability after additional surfacing, we investigated electrochemical behavior of pipe samples funnels 3 %-solution NaCl at initiation of steel anodic dissolution reaction. Anodic curves are recorded using potentiostats ПИ-50-1 in potentiostatic regime step by step with the interval 20 mV. We used silver-chloride comparison electrode and subsidiary platinum electrode. Pipe samples with isolated working surface with square of 1 sm^2 are working electrode. Metallographic analysis is carried out by means of optical microscope MIM-7 and raster electron microscope REM-106-I. X-ray analysis of surface coat composition is performed on DRON-2 in Co-K $_{\alpha}$ radiation.

Results and Discussion

The effect of suggested steam-plasma charge technology on condition and corrosion stability of stainless steel pipe internal surface in comparison with effect of lubricant removal technology “Castrol” traditionally used after cold rolling on mill ХПТ-32 is analyzed in the work.

Topography investigation of stainless steel surface (**Figure 1a-c**) showed that there were more defects on the pipe surface produced according to traditional production technology.



a b

c d

Figure 1. Topography of 08X18H10T steel pipe surface after: *a* - rolling and lubricant removal by current technology; *b* – heat treatment with the subsequent straightening and polishing; *c* - passivating treatment process; *d* - steam-plasma charge treatment

So, after rolling there are grooves, grain boundary fracture, microcracks (**Figure 1a**). After polishing there are defects in the form of microgrooves caused by abrasive (**Figure 1a, b**). Use of steam-plasma charge for pipe surfacing depending on current strength and voltage provides smoothed and almost clean surface without visible defects (**Figure 1c**).

Thus, carried out investigations showed that steam-plasma charge provided not only high-quality surface cleaning but also roughness decrease and change of surface coat microstructure morphology.

Some electrochemical characteristics of examined samples are defined for quantitative estimation of pipe surface condition effect on corrosion behavior in the electrolyte.

Stationary electrolytic potential is one of the important functions of metal corrosion condition in the given medium. The results of investigation show (**Table 1**) that electrolytic potential final value in NaCl 3 %-solution of stainless steel samples without further processing (after rolling and lubricant removal) is +0.27 V. Electrolytic potential values after sample heat treatment and also after passivating treatment are +0.28 V and +0.35 V, i.e more positive by 0.01 and 0.08 V, respectively. More considerable change of electrolytic potential after passivating treatment is quite natural as this process makes an oxide layer thicker. Steam-plasma charge processing leads to more considerable change of electrolytic potential towards positive values and makes 0.1 V.

To study the effect of stainless steel pipe surface aftertreatment on corrosion stability increase we analyzed anodic curves that represent a dependence of anode current density of electrode dissolution at shear of electrolytic potential from stationary towards the positive values (**Figure 2**).

Steam-plasma surface cleaning is the most effective which is proved by corresponding anodic curve in **Figure 2** and **Table 1** data. So, there is the widest inactive region (+0.37 - +0.92) on stainless steel sample with steam-plasma aftertreatment. And at further shear of electrolytic potential there is considerably smaller growth of anodic dissolution current.

Table 1. Parameters of anodic polarization curves in NaCl 3%-solution of 08X18H10T steel samples after various heat treatment kinds

				Parameters of anodic polarization curves			
		Initial potential $\varphi_{ст}$, V	Shift $\Delta\varphi$, V	Repassivation potential $\varphi_{переп}$, V	Inactive region width $\Delta\varphi$, V	i, A/m^2 at $\varphi = +1.4$ V	*γ at $\varphi = +1.4$ V
	No treatment	+0.27	–	+0.50	0.23	1124	–
Treatment	Heat treatment	+0.28	0.01	+0.58	0.30	712	1.57
	Passivating treatment	+0.35	0.08	+0.75	0.40	416	2.70
	Steam-plasma charge treatment	+0.37	0.10	+0.92	0.55	242	4.64

* Braking ratio γ is defined from ratio i_o/i_i, where i_o, i_i – metal corrosion rate without and after pipe surfacing

Passive condition on the anodic curve of initial stainless steel sample (after rolling and lubricant removal) is saved in the narrow range of potentials, and repassivation with sharp increase of steel dissolution rate takes place having reached the potential 0.5 V.

Inactive region width on anodic curve is one of the important characteristics of stainless steel. The earlier repassivation process occurs, the less resistant oxide layer on metal surface.

Repassivation potential is approximately 0.75 V on samples passivated in nitrogen-fluohydric acid which is indicative of higher pitting-resistance of oxide layer formed after this treatment. Inactive region width is 0.4 V

Electrochemical behavior of heat-treated pipe samples differs a little. Repassivation process on them also takes place in the area characteristic for passivated pipe sample 0.3 V. However at further shear of electrolytic potential by 0.4 V dissolution currents are at rather low level and vary from 100 to 150 A/m^2. And only having reached 1.1 V, anodic dissolution current sharply increases. This fact shows that oxide film on stainless steel surface after heat treatment (with the subsequent straightening and polishing) is protective in a wide interval of potentials. Thus complete passivation is observed in the range from stationary potential to 0.58 V, and incomplete - before reaching potential 1.2 V. Density of dissolution currents vary from 2 to 120 A/m^2 on the section of anodic curve corresponding to incomplete passivation.

The comparative analysis of anodic currents of dissolution of researched samples at shear of stationary potential to +1.4 V shows that pipe heat treatment with the subsequent straightening and polishing leads to retardation of anodic dissolution in 1.57 times, passivating treatment operation in nytrogen-fluoric acid is breaking corrosion damage in 2.7 times. While steam-plasma charge treatment promotes lowers anodic dissolution currents in more than 4 times.

Thus, the results of electrochemical corrosion tests show that surface roughness reduction and, as a result, decrease of surface coat structure imperfection promote substantial increase of corrosion-resistance.

To estimate the change of structure-phase composition of surface coat during steam-plasma treatment we carried out X-ray investigation. The fragments of X-ray diffractograms before steam-plasma charge treatment are illustrated in **Figure 3**.

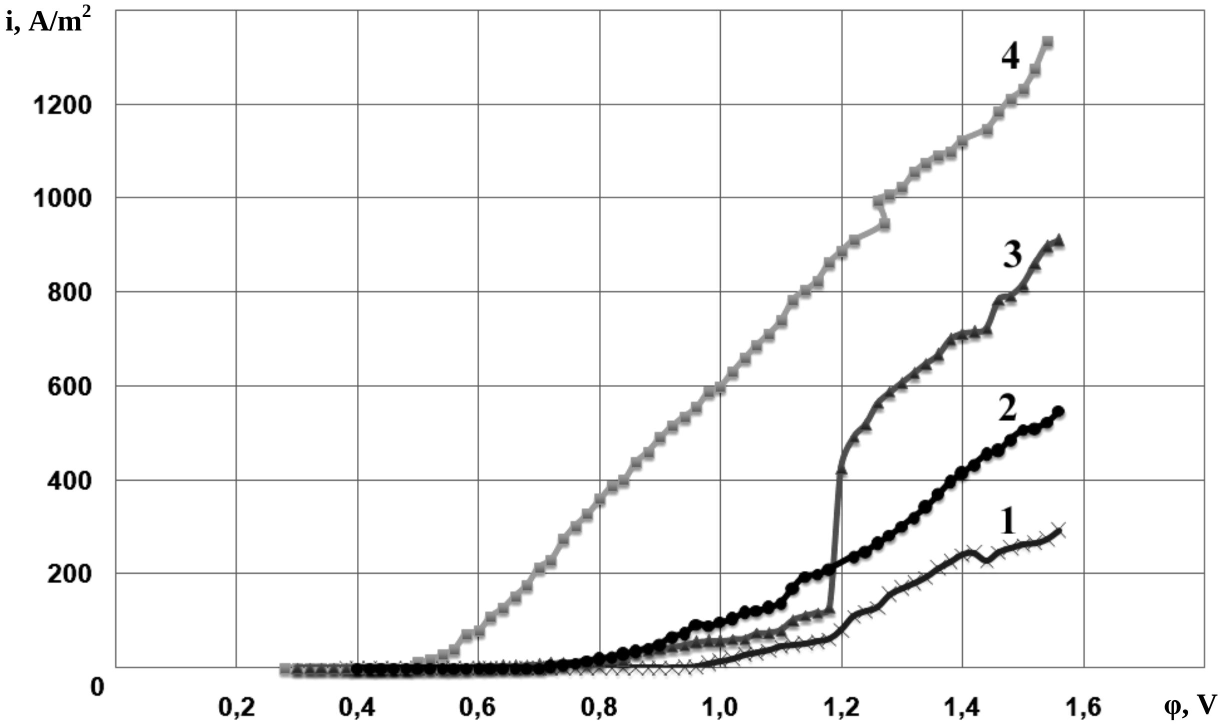


Figure 2. Anodic curves on stainless steel 08X18H10T samples in 3 %-solution of chloride sodium, after: *1* – steam-plasma charge treatment; *2* - passivating treatment process; *3* – heat treatment with the subsequent straightening and polishing; *4* - rolling and lubricant removal according to current technology

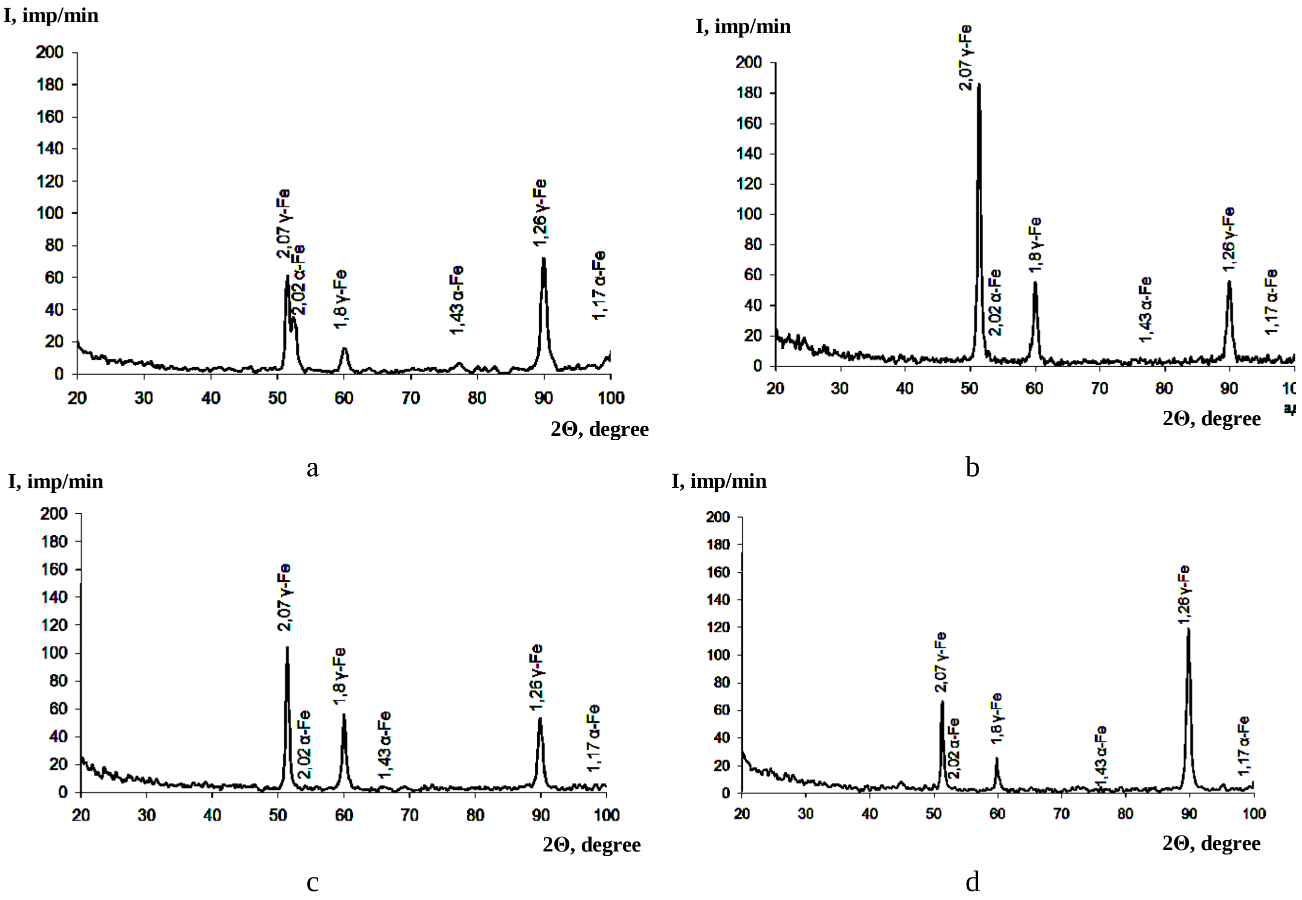


Figure 3. X-ray diffractograms of 08X18H10T steel pipe surface, (radiation Co-K $_{\alpha}$) after: a - rolling and lubricant removal according to current production technology; b – heat treatment with the subsequent straightening and polishing; c - passivating treatment process; в - after steam-plasma charge treatment

Qualitative analysis of diffractograms showed decrease of diffractional peaks 2.02 α-Fe (110), 1.43 α-Fe (200) and 1.17 α-Fe (211) and increase in peaks 2.07 γ-Fe (111), 1.8 γ-Fe (200) and 1.26 γ-Fe (220). So, before treatment steel surface coat contained 70 % γ-Fe and 30 % α-Fe, and after treatment 97 % γ-Fe and 3 % - α-Fe. Hence, steam-plasma charge treatment of corrosion-resistant pipe leads to change of surface coat phase composition. As a result, the content of α-Fe drops and γ-Fe increases.Reduction of α – phase concentration or its total absence in metal surface coats provides necessary technological properties at rolling and piercing. The increase of γ - phase content - one of the most important phases of stainless steel - increases impact strength of material at room temperature [4] that makes steel stronger, softer and more corrosion resistant [5].

Conclusions

It is determined that steam-plasma charge treatment of stainless pipe surface unlike other treatment kinds (rolling, polishing, passivating treatment), leads to considerable change of topography and structural composition of surface coats.

Content of α – phase is decreased and γ - phase is increased after steam-plasma treatment in stainless pipe surface coat. As a result, steel ductileness and crack resistance increase.

It is determined that defect-free structure of stainless steel pipe surface coat ensures considerable increase of corrosion resistance in corrosive environments. Investigations of stainless steel electrochemical behavior in 3 %- solution of chloride sodium showed that steam-plasma treatment promotes electrolytic potential shear by 0.1 V towards positive values with simultaneous spreading of inactive region area and breaks anodic dissolution at shear of electrolytic potential to +1.4 V in more than 4 times.

Steam-plasma charge technology can be successfully applied for the purpose to produce qualitative internal and external surface of stainless pipe.

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Влияние обработки пароплазменным разрядом поверхности трубы из нержавеющей стали на стойкость к коррозии

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Изучено влияние обработки пароплазменного разряда на коррозионную стойкость нержавеющей трубы. Установлены особенности электрохимического поведения образцов нержавеющей стали в агрессивной среде раствора хлористого натрия, а также топография и структурно-фазовый состав ее поверхностного слоя после традиционной и пароплазменной обработки.