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Research Article

Roughness of the nuclear reactor pipe inner surface depending on the reactor operating time*

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Abstract

During operation of nuclear reactors, there are various factors that affect the nuclear plant piping leading to erosion of the pipe inner surface and an increase of its micro-relief (roughness). Metal corrosion occurs and spreads faster on a surface having a higher value of the roughness parameter. Failure through erosive wear of the parent metal takes place predominantly in the pipe bend area. The roughness of the pipe inner surface has a sizeable effect on the signal attenuation in the process of the pipe wall ultrasonic testing. Defective main pipeline segments were cut out during preventive repairs from which samples with different operating times were taken. Five defective pipe segments of the austenitic 12Kh18N10T grade steel cut out of a high-pressure reheater's piping and five defective pipe segments of the perlite-class steel of grade 20, after different operating times, were used to determine experimentally the actual value of the pipe inner surface roughness. Besides, a piece of a new Ø273 × 12 pipe of the 12Kh18N10T steel and a piece of a Ø159 × 6 pipe of grade 20 steel were cut out. The inner surface roughness was measured for different segments. Dependences of the roughness value on the operating time and the pipe segment type have been obtained. Company specimens were fabricated with the inner surfaces having the roughness corresponding to various pipe operating times. This made it possible to take into account the influence of the inner surface roughness on the signal attenuation in the process of the weld integrity ultrasonic testing and during ultrasonic measurements of the weld adjacent zone grain size value following the weld repair.

Keywords

Life extension, surface roughness, metal corrosion, operating conditions, Elcometer 7061 Marsurf PS1 roughness meter, parent metal, preventive maintenance

1. Introduction

Since the mid-1990s, the Russian nuclear power plant operator, jointly with supporting enterprises, has been involved in the efforts to extend the service life of its NPPs considered, in recent years, in the context of a more extensive challenge of the unit life management.

The NPP pipe seam repair requires follow-up flaw inspection and the parent metal grain size control in the weld adjacent zone. Irregularities in the welding process (welding current or welding time increase) lead to a greater grain size, this causing the pipe wall metal strength to decrease and intergranular corrosion to occur which provokes the weld adjacent zone cracking and crack propagation.

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The key ultrasonic grain size measuring technique for the weld adjacent zone parent metal is to measure the signal (amplitude) attenuation which depends to a great extent on the pipe wall surface quality. Whereas the wall outer surface parameters can be either measured or changed in the treatment process, the inner surface is normally inaccessible. Therefore, measurement of the inner surface roughness is the major source of errors in measuring the weld adjacent zone metal grain size. The surface with a higher roughness parameter also tends to develop metal corrosion which spreads faster (Trofimov and Globa 2012, 2014, 2015). One example is a failure of the turbine plant steam line, a high-pressure reheater's piping, etc. The predicted change in the inner surface microrelief over the pipe operating time can be further taken into account in ultrasonic testing.

The purpose of the study is to acquire information on the influence of the NPP pipe operating time on the inner surface roughness. The acquired data can be further used to determine the influence of this parameter on the NPP pipe metal ultrasonic test result for the NPP life extension and for the fabrication of specimens with the estimated roughness parameter.

2. Investigation results

Surface roughness is a combination of the surface irregularities with relatively small pitches identified using the gage length. The surface microrelief is shown schematically in Fig. 1 (GOST 2789-73 2019).

Key: l – gage length; m – profile centerline; S_m – mean profile roughness pitch; S – mean local peak pitch; $H_{i\,max}$ – deviations of the five largest profile maximums; $H_{i\,min}$ – deviations of the five largest profile minimums; $h_{i\,max}$ – distance from the highest points of the five largest maximums to the line that is parallel to the centerline and does not intersect the profile; $h_{i\,min}$ – distance from the lowest points of the five largest minimums to the same line; R_{max} – greatest profile height; y – profile deviations from the line; p – profile section level; b_i – length of segments cut off at the given level p (Bakumenko et al. 1997).

To determine the potential NPP pipe inner surface roughness value, specimens were fabricated from the pipe components cut out in the process of the pipe preventive maintenance (Demkin and Ryzhov 1981; Popov 1987).

The state of the pipe inner surface is influenced greatly by the erosive wear that changes its roughness in the process of operation. The mechanical impact on

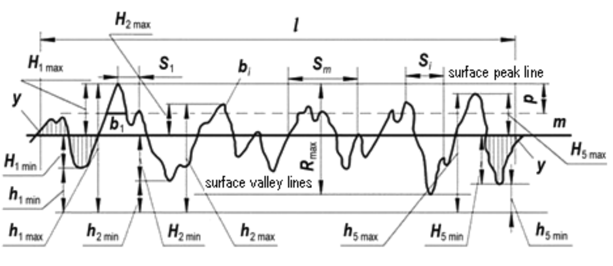

Figure 1. Schematic representation of the surface microrelief.

the inner surface differs depending on the pipe operation area. For instance, due to the surface curvature, the erosive wear in a bent section is greater than in a straight-line section. This may lead to a greater scatter of roughness data for pipelines with similar operating times. The obtained result for the maximum bottom surface roughness value can be therefore considered approximate. However, this is enough to estimate the maximum bottom surface roughness value for the test samples (Krautkremer and Krautkremer 1991; Kretov 1995; Scherbinsky 2005).

Five defective pipe segments of the 12Kh18N10T steel and five more segments of grade 20 steel, after different operating times, were used to determine experimentally the actual value of the pipe inner surface roughness. Besides, a piece of a new Ø273 × 12 pipe (12Kh18N10T steel) and a piece of a new Ø159 × 6 pipe (grade 20 steel) were cut out. Both pieces were assigned respective test numbers shown in Table 1.

Table 1. Pipe segment roughness measurement results.

Segment No.	Segment operating time,days	Roughness R_z, μm	
		At measurement points	Average
12Kh18N10T steel			
1	0	32.99; 33.20; 30.15	32.11
2	180	75.36; 73.83; 82.56	77.52
3	360	108.81; 137.00; 120.28	122.03
4	540	164.48; 172.20; 162.93	166.53
5	720	215.71; 219.05; 239.35	224.70
6	900	267.86; 214.08; 208.39	230.11
Grade 20 steel			
7	0	46.80; 44.93; 40.84	44.19
8	180	78.60; 76.20; 81.20	78.67
9	360	159.12; 144.16; 147.84	150.37
10	540	160.20; 167.10; 193.23	173.51
11	720	262.64; 235.81; 274.34	257.60
12	900	245.28; 263.21; 241.35	249.95

For illustration, Fig. 2 shows defective segments of an austenitic 12Kh18N10T steel pipe (Fig. 2a), cut out of a high-pressure reheater's piping, and defective segments of a perlite-class (grade 20 steel) pipe (Fig. 2b), cut out of a turbine plant's steam line.

The inner surface of each defective segment was cleaned and examined visually (GOST 2789-73 2019, GOST 5639-82 2019, GOST R ISO 4287-2014 2019). The surface roughness was measured on the worst-state surface of each segment using an Elcometer 7061 Marsurf PS1 roughness meter of the following performance: measurement range R_z – 350/180/90 μm; measurement accuracy – not more than 15%. The measurement diagram is shown in Fig. 3.

Table 1 presents the pipe segment test numbers, operating times and inner (bottom) surface roughness measurement results for the three points for which the average roughness value was calculated (Saltykov 1976; Gulyaev 1986; Van Der Voort 1999; Muravyev et al. 2013).

Diagrams of the pipe segment bottom roughness dependence on operating time are presented in Fig. 4 (12Kh18N10T steel) and in Fig. 5 (grade 20 steel).

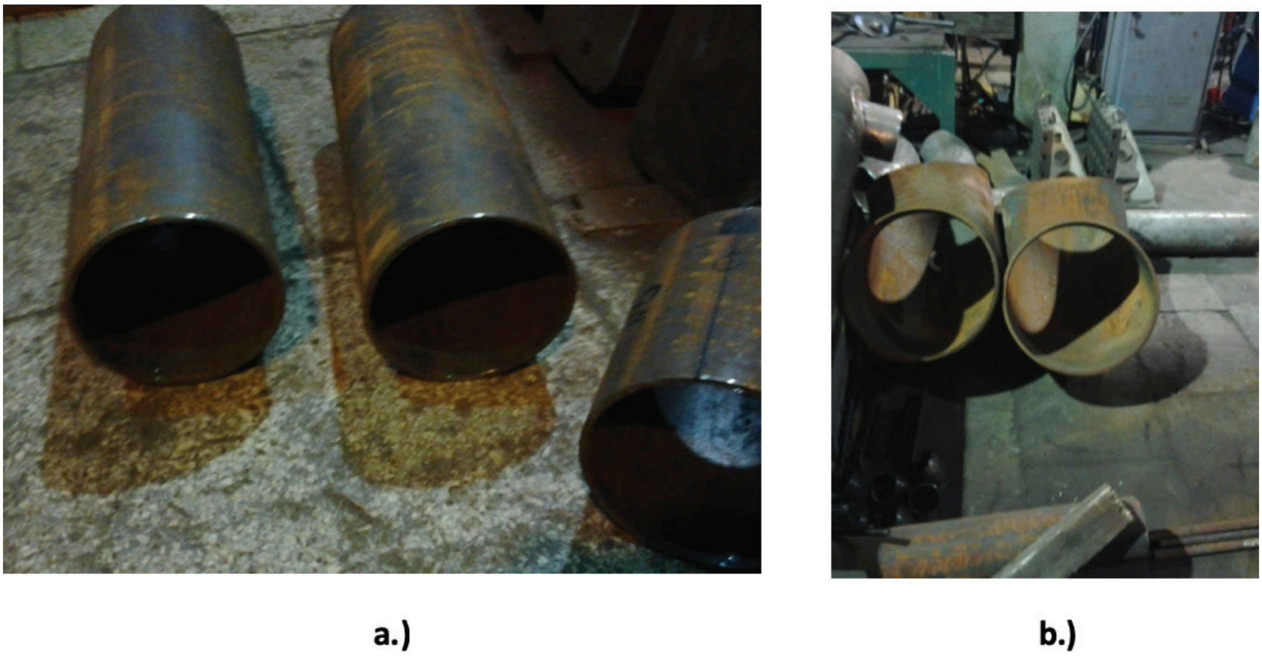

Figure 2. Defective pipe segments cut out of the NPP systems: a) 12Kh18N10T grade steel; b) grade 20 steel.

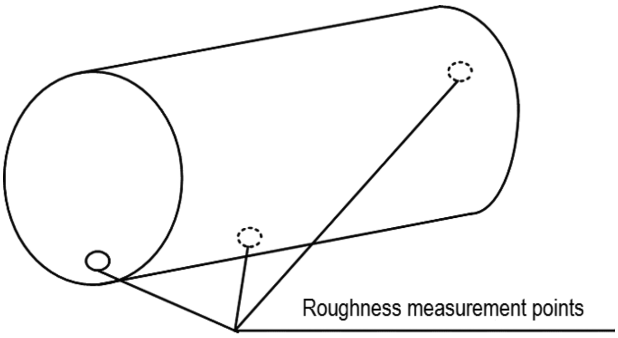

Figure 3. Pipe roughness measurement diagram.

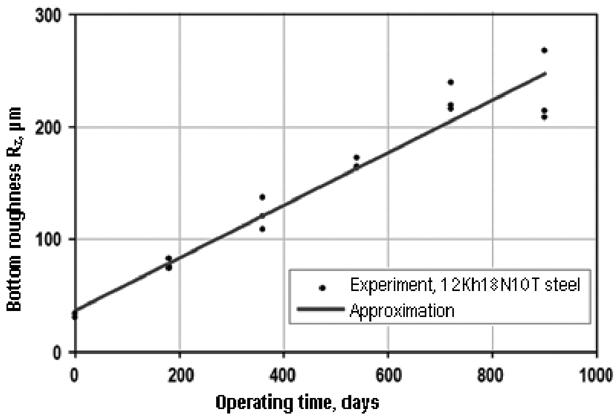

Figure 4. Bottom surface roughness of a high-pressure reheater's piping as a function of operating time.

Least square method was used for the linear dependence approximation with mathematical processing of data using the SigmaPlot code. The results obtained are as follows:

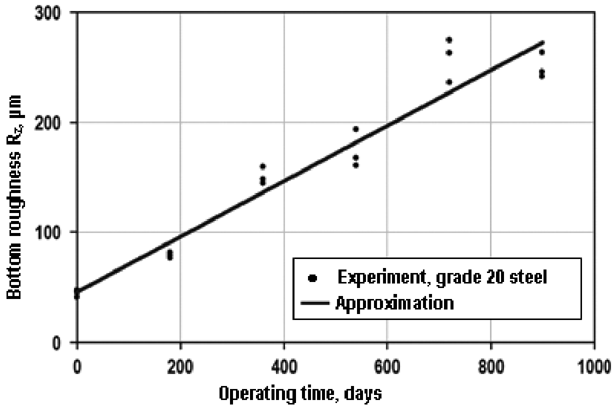

Figure 5. Turbine plant steam line bottom surface roughness as a function of operating time.

- 12Kh18N10T steel: $R_z = 36.6 + 0.234 \times t$; $R^2 = 0.97$,
- grade 20 steel: $R_z = 45.6 + 0.252 \times t$; $R^2 = 0.97$,

where t is the operating time, days; and R^2 is the approximation confidence factor.

It has been obtained experimentally (see Table 1) that the maximum roughness R_z is recorded at a level of 230 µm for the 12Kh18N10T steel and at a level of 258 µm for grade 20 steel. Three years were assumed to be the operating time for the systems since, as shown by observations, the pipe inner surface roughness R_z changes insignificantly after this time.

The three-year prediction (3×365 days) for the obtained relations leads to the roughness value R_z = 293 µm for the 12Kh18N10T steel and R_z = 321 µm for grade 20 steel. The maximum roughness level on the specimen bottom surface is R_z = 313 µm for the 12Kh18N10T steel and R_z = 337 µm for grade 20 steel (see Table 1). Therefore, the specimens fabricated for the experiments to determine the dependence of the amplitude signal on the bottom surface roughness cover the three-year operating time of the NPP pipelines (Chernyavsky 1977; Anurev 2001).

3. Conclusions

The microrelief of the pipe inner surface changes in the process of the NPP pipeline operation leading to a change in the inner surface roughness parameter. The pipe inner surface roughness change is capable to distort substantially the ultrasonic grain size measurement data for the weld adjacent zone metal following the NPP pipe weld repair.

The maximum roughness R_z obtained experimentally for the 12Kh18N10T steel is 230 µm and that for grade 20 steel is 258 µm.

Dependences of the bottom surface roughness on the operating time of pipelines manufactured out of the 12Kh18N10T steel and grade 20 steel have been found.

Company specimens were fabricated for the ultrasonic inspection making it possible to take into account the attenuation of the signal from the pipe inner surface with different roughness values (Van Der Voort 1999; Trofimov and Globa 2012, 2014, 2015).

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