The potential metrology errors that appear when estimating the state of corrosion-resistant pipe surface, namely roughness, indices of general and pitting corrosion are analyzed. It is shown that for determination of technological manufacturability of high-duty pipes with enhanced corrosion resistance it is necessary to follow the possibilities of surface microrelief 3D - analysis. It will enable to describe the surface in the initial state and in the process of service as well as to work out methods to remove disadvantages.

Keywords: PIPE, SURFACE, MICRORELIEF, PITTING CORROSION

Introduction

The problem of limited durability of pipes applied in thermal and atomic engineering becomes more urgent each year. A considerable economic benefit achieved at successful solution of this problem is mentioned in numerous publications on this subject. Many investigations and design projects in this area are focused on raise of durability and operate reliability of pipes used as constructional elements of electric power plants: zirconium alloy covers of fuel elements of atomic furnaces, stainless steel and titanium alloy pipes applied on thermal and atomic power stations for vapor condensation and heating of feed water, various carbon steel boiler tubes.

The patent survey shows that the most of scientific publications are oriented on creation of new corrosion-resistant Zr-alloys [1]. The actuality of this trend is explained by rather early fracture of fuel element covers due to the formation of local corrosion centers. It is assumed that atomic furnace performance and expenditures connected with nuclear-fuel reprocessing can be increased and lowered respectively due to raise of corrosion stability of fuel elements.

The problem issues related to durability of condenser and preheating pipes as well as their economic value are studied in details in [2]. It is noted that in this area the key problem of operate reliability of electrogenerating plants is insufficient operational durability of pipes. And in [3] it is mentioned that corrosion failure is related to the whole complex of technology factors featured for current manufacturing method of these pipes.

Stress corrosion problem in pipes used in various heat exchangers is not solved yet. In particular, the project presented in [4] is devoted to this problem. The authors consider that more thorough knowledge of stress corrosion mechanism in the pipes will allow its effective control. It is reported that implementation of this project will provide only in the USA annual energy saving above 20×10^6 Btu at simultaneous decrease of greenhouse gas atmospheric emissions more than 300 thousand tons [5].

With some share of simplification it is possible to assert that solution of this problem needs a system approach and can be observed as a consecutive solution of the following problems:
- reliable description of initial pipe surface condition and revealing of technological possibilities to improve it;
- estimation of local corrosion center.
topography in the initial stage of formation,
- definition of corrosion change dynamics in a
time while in service;
- forecasting of achievement of critical level
failure value proceeding from service conditions.

The solution of such problems requires proper
measuring devices for collecting and processing
great volumes of information with the use of up-to-
date software. First of all, it is necessary to have
reliable data on topography of surfaces
subsequently subjected to corrosion environments.

Results and Discussion

Method of internal pipe surface microrelief
assessment

When producing high-duty pipes, methods of
their internal surface condition estimation are
crucial. This problem is considered in [6]. There
are a number of contradictions in the present
standards which cast some doubt on reliability of
results of microrelief estimation, and set
parameters of pipe surface condition almost cannot
affect their operational properties, including
corrosion resistance.

Parameter $R_a$ determined proceeding from the
possibilities of pipe production process is taken as
a basis in most present standards and specifications
regulating the condition of pipe internal surface.
As applied to shell-type zirconium alloy pipes, this
parameter is within the limits from 0.3 to
1.5 microns in various standards.

In Ukrainian and Russian specifications on
stainless steel coiled tubing applied in electric
power plants this parameter is at the level
≤ 1.5 microns. At the same time, as applied to stainless
steel pipes used in food, pharmaceutical, semi-
condutor and other industries that require
especially high sterility, this parameter is within
the limits $\leq$ 0.3 microns. It is necessary to note that
such pipes are not produced currently neither in
Ukraine nor Russia. Prescribed parameter $R_a$
defines necessity of using strip chart recording
based on stylus method developed in 30s of the last
century. It consists in the application of thin needle
moving across a surface and observing its
deviations. Subsequently this technique was
essentially improved and applied till now. A
number of additional parameters are obtained at
profile diagram processing.

Not talking about adequacy of parameter $R_a$,
we note that this parameter is mentioned not to
cover corrosion resistance of metal surfaces as well
as potential errors which can appear as a result of
wrong measurement direction in a number of
publications. In particular, necessity to choose
measurement orientation which should be carried
out perpendicularly to direction of the main
deviations of surface is ignored when estimating a
microrelief of internal pipe surface. However, in
many cases scanning is carried out in the
longitudinal direction. As a result, there are
significant errors. They are caused by longitudinal
topography clearly observed in hard-wrought pipes
shown in Figure 1. In these cases the measurement
path passes through crests or dimples of surface,
and the real results are distorted and do not cover
its real structure.

At the same time, the measurements in the
transverse direction showed that $R_a$ values exceed
this parameter stipulated in current specifications
in more than 10 times, and electrolytic potential
measurements of stainless steel pipes from such
surface are close to carbonaceous grades [3].

Figure 1. Dot area of cold-rolled pipe internal surface, size 48×5.0 mm, ×500 (black dotted line - longitudinal
orientation of measurement path, white dotted line - transverse orientation)
Other potential reason of metrological errors is selection of measurement path length, cut-off step and characteristics of filters.

The standardized values of these parameters are formulated as applied to stationary profiles with clear-cut components formed mainly during mechanical operation - machining, milling, polishing. Plastically deformed surfaces have absolutely other structure of deviations, a considerable amount of casual components in the form of local ravines which can become the potential corrosion centers and further fracture. Out-of-roundness profile of pipe internal surface presented in Figure 2 is indicative of this.

One more serious lack of strip chart recording is impossibility to reveal the local pits which are the elements of pitting corrosion. It is caused by sizes of contact sensor (needle) and software used in up-to-date profilographs.

Potential errors of corrosion parameters and corrosion stability evaluation

Methods of corrosion parameters and corrosion stability evaluation are defined by standard GOST 9.908-85.

In this document, the continuous corrosion value is recommended to define as weight loss per unit surface area. However, it is well-known that at action of corrosion environments the surface peaks are intensively etched at the initial stage and only after a while local pits appear. It is still not clear how to divide these components as applied to the surfaces with casual components, for example characteristic for pipe internal surface. This moment is a potential source of metrological error.

Other reason of potential errors is corrosion spot square definition method. It is recommended to apply planimeter for these purposes, and if such measurement is impossible, a square of corrosion spot is computed. At the same time, evaluation of corrosion spot square in the internal pipe surface by means of the planimeter is completely eliminated due to profile cross-section curvilinearity. And generally corrosion spots have a free shape and their approximation will inevitably lead to significant errors.

Recommendations on pitting corrosion evaluation also have problems. In particular, it is underlined that the maximum depth of pitting corrosion is defined by:

- “measurement of the distance between plane of mouth and bottom of pitting after removal of corrosion products by mechanical indicator with mobile needle-shaped stylus in cases when pitting size allow stylus to reach pitting bottom”.

Permissible dimensions of the indicator are not specified.

- “microscopically, measuring the distance between plane of mouth and pitting bottom (double focusing method) or on the crosscut metallographic specimen at corresponding amplification”.

In this case, estimation error will be related to pitting sampling subjected to measurement. Cross profile of cold-wrought pipe internal surface is illustrated in Figure 3. Other sections of the standard also have such drawbacks. Out-of-date requirements of pitting corrosion resistance test methods of corrosion resistant steel and alloy

![Figure 2. Out-of-roundness profile of cold-rolled pipe cross-section 25x1.65 mm, steel X18H10T](image-url)
of current standard 9.912-89 are also beneath criticism. It is recommended to use the average conditional rate of pitting corrosion as evaluation method in given GOST. This rate is defined as a change of metal weight from sample surface unit per time unit. At the same time, it is not clear what is better at equal rate: a great number of small pittings or less of deep pittings? All mentioned conditions are often not considered [7] which can inevitably lead to erroneous results.

Possibilities of 3D – surface analysis
Every year 3D – surface analysis becomes more widespread. The international standard “Surface texture: Terms, definitions and surface texture parameters” has been put in action recently. This standard is necessary because of rapid development of nanotechnologies that need high accuracy evaluation. At the same time, mass production of optical profilographs and corresponding software capable to process great volumes of measuring information has been started.

Standard ISO/25178-2 regulates: signs of surface structure, terms used for its parameters definition, classification of measurement methods, nominal performance of contact and contactless measurement. This standard introduced new parameters.

Examples of using pipe internal surface 3D - analysis
Some examples of using 3D - analysis as applied to estimation of high-duty pipe quality are presented below.

Estimation of surface uniformity
Pipe making methods from zirconium alloys provide application of spray acid etching at the final stage of the process. Defects formed in the internal surface during rolling are removed. To estimate its efficiency the microscope pictures of Zr1Nb alloy pipe internal surface are made at different amplification.

Processing of obtained pictures provided determination of entropy values of gray-scale pictures. According to [8] entropy is a statistical characteristic of random nature which can be used to describe the structure of image. Entropy value was defined using expression - sum (p.*log2 (p)), where p - bar diagram of picture deviation.

Obtained results are presented in Table 1. It is possible to draw a conclusion that noticeable change

![Figure 3. Deviation of cross profile of pipe internal surface 25×1.65 mm](image)

Table 1. Entropy of pipe internal surface 17 x 1.9 mm, alloy Zr1Nb

<table>
<thead>
<tr>
<th>Surface characteristics</th>
<th>Surface condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>After rolling</td>
</tr>
<tr>
<td></td>
<td>× 200</td>
</tr>
<tr>
<td>Measurement</td>
<td>0.65</td>
</tr>
<tr>
<td>Image size, mkm</td>
<td>345×546</td>
</tr>
<tr>
<td>Entropy</td>
<td>55.9</td>
</tr>
</tbody>
</table>
of surface inhomogeneity occurs in macroareas and is almost constant on the local sections.

Interconnection between microrelief and microstructure

Other instance of successful 3D-analysis application is interconnection between microrelief of pipe internal surface and metal microstructure. A number of publications cover interconnection between metal microstructure and its corrosion properties, including [9]. The pictures of microrelief and microstructure of Zr1Nb alloy pipe 9.1×0.7 mm are shown in Figure 4 to understand the mechanism of such regularity as applied to zirconium alloy.

Further we estimated the standardized autocorrelation functions (ACR) for deviations relating to both secants. ACR diagrams are illustrated in Figure 5. ACR pattern shows the periodicity of microstructure and microrelief. Spectral concentrations shown in Figure 6 are defined to determine amplitude-frequency characteristics of deviations.

Determination of contact areas

At metal flow the formation of surface microrelief depends on the contact between tool and deformable metal. In general, the formulation this problem is similar to determination of corrosion center square.

Initial picture of pipe internal surface in the grey shade scale obtained by means of scanning microscope is shown in Figure 7 at amplification × 1000. The size of analyzed section is 90×122 micron.

The same section is shown in Figure 7 a in binary aspect with white contact zones. Digital processing of binary image showed that the contact area was approximately 37 % from the total surface of analyzed section.

It is quite obvious that estimation of total square of contacts using GOST 9.908-85 is not real in similar cases.

![Figure 4](image), ![Figure 5](image), ![Figure 6](image), ![Figure 7](image)
Conclusions

The estimation method of high-duty pipe internal surface microrelief applied today is associated with considerable metrological errors. Estimation methods of total corrosion resistance and parameters of pitting resistance based on GOST 9.908-85 and GOST 9.012-89 are out-of-date and do not meet the modern requirements.

To increase qualitative level of investigations in this area, it is necessary to follow the standard ISO/25178-2 that recommends surface microrelief 3D analysis.

References

4. Singh Preet M., Pawel Steven J., Yang Dong,


* Published in Russian

Received October 26, 2010