FORECASTING PROCEDURE FOR STRENGTH AND DUCTILE PROPERTIES OF ALLOY STEEL PIPES IN PROCESS OF MANUFACTURING AND OPERATION

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Nowadays, the applicable scope of tubular products made of special steels is extended. Tubular products are used for new oil and gas fields development complicated by the presence of carbon dioxide and hydrogen sulfide. Further, pipes of corrosion-resistant and stainless steels are widely used in nuclear industry, aircraft engineering, at liquefied natural gas manufacturing plants and for other knowledge-intensive production branches.

To ensure high-strength and corrosion-resistant properties of steel, a sufficiently large percentage of alloying elements, such as chromium, nickel, molybdenum and etc. are added into steel. However, these elements usually impair steel plastic properties in the process of pipe manufacturing by pressure treatment. Consequently, cracks and breaks may occur on hot-worked pipes. Therefore, the process of pipe manufacture engineering requires reliable information concerning ductility of steels used for pipe production.

When choosing the type of dependence describing the ductility diagram of metals and alloys during hot deformation, its linearization possibility was taken into account to apply the method of least squares when processing the experimental results. As a result, the following formula is proposed:

$$\Lambda_p = a_0 \left(\frac{\theta}{1000}\right)^{a_1 + a_{12}\frac{\sigma}{T}} exp\left(a_2 \frac{\sigma}{T}\right), \qquad (1)$$

where a_0, a_1, a_2, a_{12} – are empirical test factors; θ stands for sample heating temperature; σ – average normal stress; T – shearing stress intensity; Λ_p – ductility of the metal (the degree of deformation accumulated by the metal at the time of destruction).

Using the proposed technique, the ductility of chromium-containing steel types was studied. Examples of the results obtained are presented in the table below.

Table 1. Equations of ductility diagrams of chromium-containing steel types

Steel	Equation
DINX10CrNiMoVNb13-3	$\Lambda_p=0{,}89\left(\frac{\Theta}{1000}\right)^{3{,}35-2{,}02\cdot\frac{\sigma}{T}} \exp\left(0{,}04\cdot\frac{\sigma}{T}\right)$
AISI 321	$\Lambda_p=2{,}55\left(\frac{\Theta}{1000}\right)^{5{,}73-8{,}32\cdot\frac{\sigma}{T}} \exp\left(0{,}3\cdot\frac{\sigma}{T}\right)$
AISI 316 Ti	$\Lambda_p=2{,}61\cdot\left(\frac{\Theta}{1000}\right)^{3{,}51-6{,}01\cdot\frac{\sigma}{T}} \exp\left(0{,}46\cdot\frac{\sigma}{T}\right)$

Pipes for the production and transportation of oil and gas in currently developed fields may be exposed to increased external pressure, which can lead to their flattening. To determine the collapse pressure, physical modeling - Collapse Test - is currently practiced using specially designed test machines.

In order to carry out tests on such test machine, a pipe section with a length of about 1.5 meters is cut from the finished pipe, such test is a destructive examination and leads to additional consumption of metal in the production of pipes. Therefore, using an experimental test machine, it was possible to determine, on the basis of experimentally obtained information, the dependence of the collapse pressure on various factors, such as pipe wall thickness variation, its out-of-roundness, residual stresses values, etc. However, due to insufficient knowledge of the process, we managed to obtain explicit dependences of the collapse pressure on the pipe wall thickness and yield strength of the steel type used for manufacturing. The other dependencies could not be obtained (Figure 1). As shown on Figure 1, the trial values of collapse pressure have a wide dispersion. Therefore, the use of physical simulation to determine patterns and to predict the collapse pressure is quite problematic.

A large amount of input data can be taken into account by neural network modeling. The use of artificial neural networks will reduce the number of trials, reduce costs and increase the number of factors that affect the collapse pressure.

Based on the analysis of the currently known technical information, as well as the results of collapse tests, the following control parameters were selected as the initial data for artificial neural network:

- pipe cross-section OOR;
- pipe cross-section wall thickness variation;
- the ratio of residual stresses in the pipe to the pipe metal yield strength;
- pipe metal yield strength;
- thin-walled D/t index - a value defined as the ratio of the pipe OD to the wall thickness;
- chemical composition of the metal.

Licensed neural network training has been performed using actual data on collapse pressure obtained due to using test unit. Comparison of prediction results and actual test results is given as example on Figure 2. The analysis has shown that results repeatability is rather high. At the same time, the prediction result has turned out to be a little bit overestimated, the maximum error for the represented amount of data is 8.7%. It's recommended to take it into consideration when simulation results are interpreted.

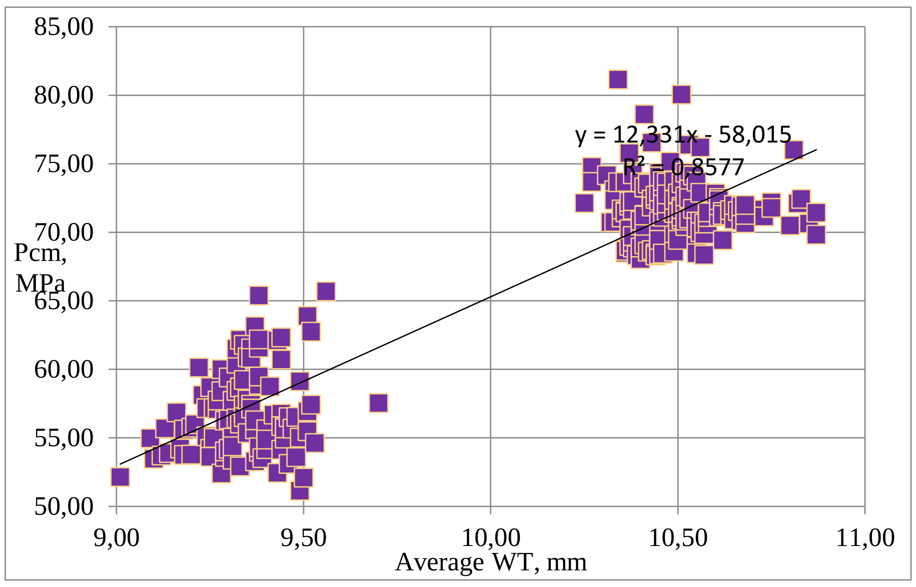

Figure 1 - Dependence of the collapse pressure value on the pipe wall thickness with an OD of 177.8 mm and with a wall thickness of 9.19 mm and 10.36 mm, grade P 110

It should be noted that proposed method of collapse pressure evaluation helps to decrease the quantity of pipes subject to testing at collapse unit significantly and thus to decrease metal consumption. In the future NDT will be carried out only for periodic confirmation of results reliability, obtained using neural simulation.

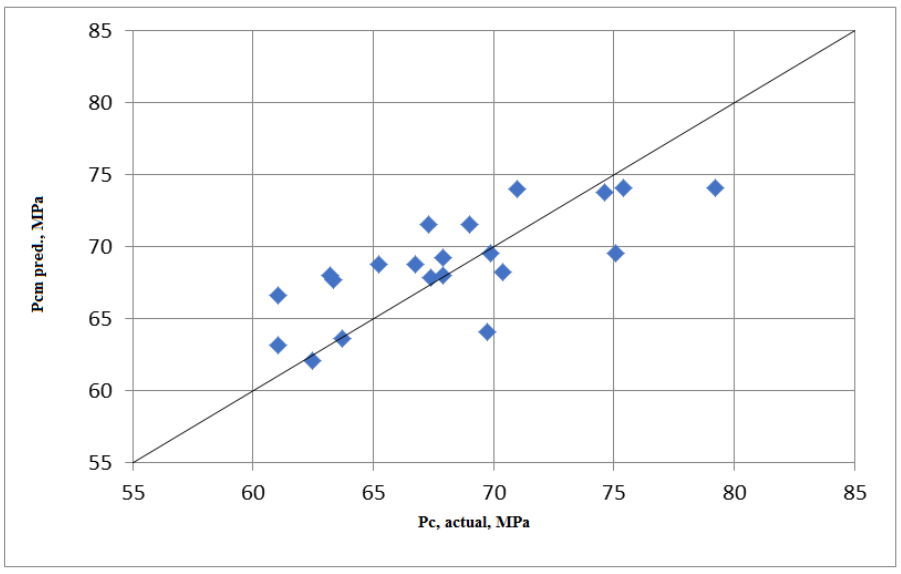

Figure 2 – Comparison of neural network prediction results and the actual tests results

Present-day complicated conditions of oil and gas production require application of tubulars with special properties. To develop the manufacturing process for pipes of this type we propose the following:

1. Proprietary method for determination of steel ductility including high alloyed steels with enhanced anti-corrosion and cold-resistant properties during hot deformation processes which ensures defect-free products manufacture.
2. Application of neural network modeling as the non-destructive method for pipes collapse pressure determination and, on the other hand, for determination of requirements for pipes and pipes manufacturing process that can provide for the specified collapse pressure.