Ensuring fire safety during the operation of oil and gas equipment based on the results of compact specimens tests

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Abstract. The paper considers the application of the test method of compact specimens to assess the degree of damage of steel elements of oil and gas equipment. According to experimental data, an analytical dependence was obtained linking the degree of damage to the index of the specific fracture work, intended to assess the possibility of safe operation of explosive and fire-hazardous equipment.

Oil and gas equipment is the technical base of the industrial potential of the oil and gas complex of Russia, which ensures uninterrupted supplies of hydrocarbons, gas fuel and oil products for both Russian and foreign consumers. A significant part of process equipment, vessels and pipelines is operated beyond the designed working life, which leads to the presence of active destructive processes that worsen the operational factors of the equipment. The continuous operation schedule necessitates for operating organizations to ensure operability and assess the technical condition, which requires periodic diagnostics. However, the level of accidents and the volume of work on overhaul and reconstruction of oil and gas equipment increasing every year indicate insufficient information on the actual state due to the imperfection of the existing methods of their control [1]. Therefore, the development of new methods for controlling the actual state of the metal without causing significant damage to long-term operating oil and gas equipment, tanks and pipelines is a difficult and urgent task.

One of these new methods currently being developed is the method of analyzing samples with a relatively small size, known as "Small Punch Test" [2]. Despite a number of studies aimed at its development, there are still a significant number of unsolved problems that prevent the introduction of this diagnostic method into industry. One of them is the absence of criteria that allow evaluating the results of determining the strength characteristics of equipment metal from the deformation diagrams of compact specimens.

The solution of these problems, along with the well-known methods of operational assessment of the strength characteristics of structural materials: the Brinell method (HB) [3], in which a steel ball of a certain diameter is pressed into the metal under study, the Rockwell method (HRC) [3], in which a diamond cone is pressed into the surface of the material under study and the Vickers method (HV [3]), based on the indentation of a diamond pyramidal indenter into the material, it will allow obtaining results by direct measurements, in contrast to indirect parameters obtained by hardness testing.
The considered method of using compact samples was developed in Japan and the United States in the 1980s and was proposed to determine the mechanical properties of the material of metal structures of the nuclear industry in operation, since this test method reduces the effect of radiation on personnel, the cost of experiments and the amount of radioactive waste [4]. In the future, the method was developed and today has a fairly wide scope of application, in particular: testing materials available in small quantities, assessing the strength of steel sealed equipment operating under excessive pressure, testing metals that have been under prolonged radioactive irradiation or in a thermal zone, etc.

This method of analysis can be considered as a gentle (quasi-non-destructive) method for monitoring the state of equipment, since the samples taken have miniature dimensions: diameter from 3 to 10 mm, thickness from 0.25 to 2.0 mm [5, 6]. When the punch is pressed into the sample, a deformation diagram is obtained, the abscissa of which is the displacement in mm, and the ordinate is the load in Newtons.

It is generally accepted [7] that in the resulting deformation diagrams it is possible to distinguish zones, each of which corresponds to a certain stage of deformation: the beginning of indentation into the sample and elastic bending, then plastic bending, then stretching of the sample in the membrane mode with crack initiation, after which a crack develops. Final destruction of the sample. To calculate the ultimate strength, empirical relationships between the properties of the material and the characteristic point of the deformation diagram corresponding to the maximum value of the load, given in [7, 8], are used.

Based on the above description of the test method for compact samples, the most common grades of steel St3, 08ps, steel 10 and steel 20 were tested, since they, in the recent past, were the main structural material in the manufacture of technological equipment, tanks and pipelines that have worked out the established service life and need mandatory periodic monitoring. The chemical composition and mechanical characteristics of steels are given in [5]. Static load tests of compact samples were carried out in accordance with the methodology given in [9].

Figure 1 illustrates the test results for compact specimens of various thicknesses.

The above results indicate that the diagrams can be used to determine the specific work of fracture of steel samples, i.e. an objective energy characteristic, which makes it possible to assess the strength of the material before the onset of fracture. It is known [10] that the structural materials from which the technological equipment is made, in the initial state, have a quite definite value of the specific work of destruction, denoted as $W$. This value is defined as the area of the diagram enclosed between the deformation curve (figure 1) and the abscissa axis:

$$ W = \int \sigma \, d\varepsilon, $$

where $\sigma$ is the breaking load; $\varepsilon$ – deformation.

**Figure 1.** Deformation diagrams of compact specimens of steel 08ps with a thickness of 1 mm (1), 1.2 mm (2), 1.5 mm (3).
During the operation of equipment at oil and gas enterprises, due to the negative impact of an aggressive corrosive technological environment, static and cyclic loads, high pressure and temperature in the material, the degree of damage to the material increases. The phenomenon of accumulation of microdamages and defects significantly changes the initial value of the specific work of destruction both upward and downward. It is proved that "... comparative tests of the initial sample and the sample subjected to preliminary loading, during which damage accumulates, makes it possible to determine the potential energy accumulated by the damaged sample as the difference in areas under the corresponding loading curves" [11].

In accordance with the above provisions, experimental tests of carbon steel grades St3, grade 10 and grade 20 were performed (figures 2-4). The dimensions of the compact samples were 10 mm in diameter and 1.0 mm in thickness.

![Figure 2. Test results of compact specimens of steel grade St3.](image)

![Figure 3. Test results for compact specimens of grade 10 steel.](image)
Thus, the presence of a formalized relationship between the degree of damage to the material and the specific energy of destruction of the material, will allow using experimental tests of compact samples to determine the current technical state of the elements of technological equipment. Accordingly, the degree of damage to structural materials was determined as the ratio of the acting mechanical load on the sample to the ultimate strength of steel. The change in the specific work of destruction was carried out according to the root-mean-square deviation from its initial initial value up to the onset of the limiting state of the structural material.

The results of mathematical processing of experimental data are presented in table 1.

**Table 1.** Results of mathematical processing of experimental data on testing compact samples of various steel grades.

| Damage to the material, $J$ | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 |
|-----------------------------|-----|-----|-----|-----|-----|
| Steel St3                   | 0.002 | 0.035 | 0.141 | 0.358 | 0.453 |
| Steel grade 10              | 0.001 | 0.022 | 0.165 | 0.269 | 0.375 |
| Steel grade 20              | 0.002 | 0.039 | 0.176 | 0.298 | 0.451 |

The experimental data made it possible to carry out a regression analysis by the "least squares" method with obtaining the analytical following analytical dependence with the accuracy of the approximation $R^2 = 0.96$:

$$D_j = 0.58J - 0.16$$

where $J$ is the degree of damage to the structural material; $D_j$ is the value of the root-mean-square deviation of the work of destruction.

The presented analytical dependence (2) allows, based on the test results of compact samples, to assess the technical condition of the elements of oil and gas equipment by the value of the root-mean-square deviation of the specific work of destruction. The proposed method for assessing the technical condition of the elements of the oil and gas equipment can be used for the further development and improvement of the currently existing control systems of the condition of the technological equipment.
condition can be used to solve the problems of ensuring the safe operation of technological equipment operated at oil and gas enterprises.

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