Modeling a composite assembly for repair of trunk pipelines

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Abstract. The article considers the issue of the efficiency of the use of composite materials in the repair of trunk pipelines. During the study, simulation experiments were carried out using the Solidworks program for the main product pipeline under excess pressure $P = 4$ MPa. Altogether, eight situations were studied that differed in the amount of composite material applied to the defect. The criterion for determining the number of situations was determined by the number of layers of the composite material at which a favorable situation for the operation of the pipeline occurs. As a result of the experiments, the dependence of the stress-deformed state on the number of layers of the composite material deposited at the defect site is obtained. This dependence allows us to recommend a certain composition of the composite unit for repair of trunk pipelines. The research results obtained have the prospect of their further application in the development of a standard program for the repair of trunk pipelines using composite materials.

1. Introduction
Trunk pipelines are the most economical type of transport for oil, gas, oil products, and pipeline systems are an essential part of the energy complex, the uninterrupted functioning of which is of exceptional importance for the state economy. The total length of trunk pipelines in Russia exceeds 200 thousand km. currently, 37% of pipelines have been in operation for more than 20 years, which requires increased attention to their operational reliability and technical safety [1-5].

Operating experience of trunk pipelines shows a direct dependence of their reliability on timely and effective repair work on the linear part [6-10].

Currently, the most widely used steel repair systems and their application remains relevant until now. The mentioned repair systems have a number of disadvantages. These methods are generally suitable for straight pipe sections, but not for joints or bends. Besides, welding of pipelines is an expensive and time-consuming operation, especially if the pipelines are underground. In most cases, heavy equipment is required to complete this work. In addition, welding requires work that could lead to an explosion.

In global practice, one of the most common methods for repairing pipelines without stopping pumping is repair methods using steel welded couplings (crimp and non-crimp, welded and non-welded), winding repair structures made of composite materials and couplings installed using composite-coupling technology [11-13].

The second method is the most promising, as it is implemented using lightweight and inexpensive composite materials. This method has shown its advantage, due to the importance of repairing not only straight sections of pipelines, but also welds or bends [14-17].
However, along with this, there is the problem of determining the most optimal and rational quantitative structural composition of a composite material acceptable for use in certain production conditions.

From here, one can formulate the objective of the work, which is to simulate the site of applying the repair composite material, which allows restoring the design operational parameters of the main pipeline.

2. Modeling the application of the composite material

There are several types of repair structures, traditionally called “composite couplings”. It is necessary to distinguish structures with bolted joints from adhesive couplings, forming a single whole with the pipeline wall. Such systems are designed to repair external defects caused by corrosion manifestations, pitting, groups of longitudinal and single cracks, scratches, nicks, dents, burrs, backfins on trunk, distribution and other pipelines (Figure 1).

The types and kinds of adhesive couplings differ, differing both in polymer binder materials and in many other basic operational characteristics.

To study and solve the problem stated in the article, simulation experiments were carried out using the Solidworks program, modeling a main product pipeline under excess pressure $P = 4$ MPa, with geometric characteristics and defect parameters shown in Table 1.

**Table 1.** Parameters of pipeline and defect.

| Inner diameter, $D_{in}$, mm | Thickness, $s$, mm | Pipeline length, $L$, mm | The length of repairing area, $l$, m | Maximum thickness, $s_{max}$, mm |
|------------------------------|--------------------|--------------------------|-------------------------------------|----------------------------------|
| 1000                         | 10                 | 10000                    | 1500                                | 5                                |
The indicators necessary for modeling using the Solidwork software product are given in Table 2.

Figure 2 shows the result of experiment No. 1 in the absence of a composite material and, accordingly, a repair unit. The figure shows that when the pipe is loaded in the defect zone, stresses arise above the yield strength precluding the operation of the main pipeline. Altogether, eight situations were studied that differed in the amount of composite material applied to the defect. The criterion for determining the number of situations is the number of layers of the composite material, in which there is a favourable situation for the operation of the pipeline. According to the results of experiment No. 8, the optimal number of layers of the composite material was revealed at which the stress-deformed state at the place of application of the repair unit allows operation of the main pipeline under excess pressure $P = 4$ MPa (Figure 3).

**Table 2.** Characteristics of pipeline materials and composite material.

| Material property | 09G2S         | Composite   |
|-------------------|--------------|-------------|
| Elastic modulus   | 200000, MPa  | 50000, MPa  |
| Poisson's ratio   | 0.29         | 0.3         |
| Mass density      | 7900, kg/m³  | 2100, kg/m³ |
| Tensile strength  | 405, MPa     | 1750, MPa   |
| Yield strength    | 295, MPa     | 3000, MPa   |

According to the results obtained during the experiment, the dependence of the stress-deformed state on the number of layers of the composite material deposited at the defect place is constructed (table 3, figure 3).
Table 3. Results of the simulation experiment.

| Number of layers | Stresses on the pipe, MPa | The stress on the composite, MPa |
|------------------|---------------------------|----------------------------------|
| 0                | 368.5                     | -                                |
| 1                | 378.9                     | 94.7                             |
| 3                | 320.6                     | 80.16                            |
| 5                | 282.4                     | 76.4                             |
| 6                | 280.9                     | 70.2                             |
| 7                | 264.3                     | 66.07                            |
| 8                | 262.8                     | 62.6                             |
| 9                | 262.6                     | 59.18                            |
| 10               | 225.6                     | 48.58                            |
| 11               | 190.3                     | 42.15                            |

Figure 3. Experiment No. 8 (10 layers of composite (10 mm)).
3. Conclusion

Thanks to the obtained graphs of the dependence of the stress-deformed state of pipelines on defect location and the surface of the composite material on the number of layers, it is possible to obtain the recommended quantitative composition for repairing pipelines with known operating parameters and defects, including dimensions.

The choice of the boundary point of the experiment, denoting 11 layers of the composite, is explained by the fact that the stress value in the defective pipe is 190.3 MPa, while the stress in the pipe without a defect is 176-185 MPa. This means that the task of coordinating the strength characteristics of the repair unit and a trouble-free pipeline has been achieved.

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