Justification of indirect methods of bending stresses polyethylene pipes evaluation

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Abstract. The world and Russian companies have a long experience of the polyethylene pipeline installation and operation. At the same time, the significant attention is paid to the improvement of the relevant machines and the production technology. The polyethylene pipeline installation experience proves that its operation properties (reliability and durability) depend on physical and mechanical characteristics of polyethylene, which should be saved during its installation. Defects can occur, including in cases when the pipe is subjected to the significant bending stresses during installation. To evaluate these stresses, including when exposed to cold weather conditions, an indirect method based on the relationship between strength characteristics and occurred deformations is proposed.

1. Introduction
Modern construction and development of cities and other populated areas are impossible without a stable functioning of the infrastructure and basic life support systems (engineering communications for various purposes). In these cases, the polyethylene pipelines are getting more and more widespread. Due to its characteristics (elasticity, flexibility, impact resistance, neutrality to a number of pump products), polyethylene pipelines are widely used in the constructions of pressure and drain water systems, in the constructions of gas networks, cabling and others.

The specialists from different countries recognized that polyethylene pipeline breakages in operation typically occurred due to defects in the material, caused by the pipeline installation technology violations, and damages during transport and storage.

Such defects can occur, including in cases when the pipe is subjected to the significant bending stresses during installation. It is proved that the ratio of the pipe bend diameter to the pipe diameter should fit a certain normed ratio [1]. In cases of out of this ratio, the irreversible deformations will be in the polyethylene and its physical and mechanical characteristics will be violated.

Such countries as Russia, Canada, USA and others with the long cold weather period, are interested in development of the polyethylene pipeline installation technologies applied to the cold weather conditions.

Application of laying equipment at cold weather conditions are regulated by the normative documents. However, the influence of negative temperatures on the strength and deformation characteristics of polyethylene during bending remains little studied. Special investigations of stress-deformed state of polyethylene pipes at installation with bending will allow establishing limiting temperature conditions [2, 3].
The complexity of the research consists in the fact that to measure the stresses at the point of bending is difficult, due to large measurement error at low temperatures.

2. The working hypothesis personal research experience

The authors proposed an indirect evaluation system based on the relationship between the strength characteristics and deformations, occurring in polyethylene pipe at bending [4].

The working hypothesis is: if the listed below requirements are carried out in the complex, the irreversible changes of the physical and mechanical pipe characteristics do not occur:
1) after loading of the bending load, the ratio of the diameter of the pipe bend to the pipe diameter should be at least 20, which corresponds to the design and construction rules ("Design and construction of gas-pipelines from polyethylene pipes and reconstruction of worn-out pipelines");
2) after loading of the bending load, the pipe ovality is not exceed the maximum allowable values as defined by the Russian Federation national standards (ГОСТ Р 50838-2009 "Polyethylene pipes for gas-pipelines").

The pipe samples made from PE80 polyethylene have been tested. The ratio of the outer pipe diameter to the pipe wall thickness equals 11 (Standard Dimension Ratio - SDR 11). The pipe samples were supplied by manufacturers on the spools (with diameters up to 110 mm) and had a quality certificates.

The bend diameters were set with five values. The maximum bend diameters were close to ratio \(D_{\text{bend}} \geq 20d_{\text{pipe}}\) and ensured this ratio after unloading. On the other hand, the minimum value of the bend ensured the deformation of the pipe samples to a state in which the return to the required ratio was impossible.

The pipe samples were bended with certain radius (Figure 1). After removal from the bending device, the distance between the pipe ends (a) and the pipe cross-section ovality (\(\Delta d\)) were measured on the fixed distances (Figure 2).

![Figure 1. A general view of the polyethylene pipe under load](image)

![Figure 2. The scheme of the pipe deformation measurements: \(d_1\) and \(d_2\) are minimum and maximum diameters of the pipe; ‘a’ is the length of the chord.](image)

The evaluation of the elastic properties was performed by measuring the (a) value, which in itself
did not characterize the admissibility or inadmissibility of the pipe bending. The above-mentioned requirement may be as evaluation criteria \( D_{\text{bend}} \geq 20d_{\text{pipe}} \).

In order to evaluate the specified requirements for the diameters ratio, the problem of the relationship between the measured length \((a)\) and the pipe bend radius after unloading was solved [5].

The measurement results were processed by using known statistical methods.

As a result of the bending test, the pipe ovality and the \(d/D\) ratio after the bending unloading was determined.

3. **Verifying working hypothesis**

   To verify the working hypothesis the polyethylene pipe strength properties were studied by a tensile test in accordance with the standard of the Russian Federation (GOST 11262-80 "Plastics. Tensile Test Method").

   The verification was conducted in accordance with the following criterion: if the yield strength of the pipe material which subjected to bending load was not reduced compared to the yield strength of the pipe material which was not subjected to bending load, then the deformation occurred within acceptable limits. Otherwise - the deformation occurred at the bend that led to the unacceptable violations of the strength characteristics. Tensile tests were carried out in a certified research laboratory of “Sibgazapparat” (Russia, Tyumen) on certified tensile testing machine.

   The pipe samples were cut of the polyethylene pipes and were subjected to the tension in the tensile testing machine (Figure 3).

   ![Figure 3](image)

   **Figure 3.** The general view of the tensile testing machine and samples before and after testing

   As a result, yield strengths were determined during tension of samples exposed and not exposed to the bending load.

   The typical diagram of the results are presented in Figure 4.
The minimum value of the pipe tensile yield strength not subjected to bending was $19.5 \pm 0.17$ MPa. Therefore, it can be argued that if the pipe yield strength subjected to bending is not less than this value, the bending is made in the acceptable limits. If this value is less, the pipe strength characteristics is violated and the bending is made in unacceptable limits (see Table 1 - Gray background).

Table 1. The pipe samples yield strength after the bending

| $d_{\text{pipe}}$ mm | $D_{\text{bend}} < 20d_{\text{pipe}}$ | $D_{\text{bend}} > 20d_{\text{pipe}}$ |
|----------------------|----------------------------------|----------------------------------|
| 20                   | 19.2 ±0.11                       | 19.5 ± 0.17                      |
| 25                   | 19.3 ± 0.13                      | 19.6 ± 0.13                      |
| 32                   | 19.3 ± 0.18                      | 19.7 ± 0.13                      |
| 40                   | 19.1 ± 0.13                      | 19.5 ± 0.11                      |
| 63                   | 19.3 ± 0.13                      | 19.6 ± 0.08                      |
| 110                  | 19.2 ± 0.13                      | 19.5 ± 0.11                      |

4. The results, conclusions and recommendations

The experimental researches complex of observation of the polyethylene pipes deformations at various temperatures (from 20°C to minus 20°C) It is proved that the deformation changes occurred at bending in this temperature range affect the strength properties.

The proven hypothesis confirms that the condition for a circular cross section stability and the condition of a maximum permissible pipe cross-section ovalization have to be used in the polyethylene pipelines calculation in the strength and load-bearing capacity.

Experiments confirmed that the condition of no violations of physical and mechanical properties of polyethylene pipe is the complete deformation reversibility after the bend loading.

Experiments have confirmed theoretical calculations [5] that allow establishing the radii of possible bends of polyethylene pipes (Figure 5).
Figure 5. Pipe stress as function of pipe diameter (d) and bending radius (R)

The analysis of the results shows that if the bended pipes have bend radiuses less than the permissible minimum, the yield strength decreases. Thus, samples deform in unacceptable limits. The pipe material retains its strength characteristics when bended pipes have bend radiuses more than the permissible minimum.

As a result, the experimental researches complex has proved that the proposed experimental research method has been verified.

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