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DETERMINING THE INFLUENCE OF AN ARTIFICIAL DEFECT ON THE MECHANICAL PROPERTIES OF A FLEXIBLE PIPELINE MATERIAL DURING A RUPTURE TEST

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The object of research is the phenomenon of influence of hidden defects on the mechanical properties of the material of flexible pipelines. T-type pressure fire hoses with an inner diameter of 77 mm were used as test samples of flexible pipelines. During the operation of pressurized fire hydrants and their laying on vertical surfaces, they are subjected to significant bursting pressures in their longitudinal direction. That is, such operating modes of the sleeve may occur during its operation. The research was carried out on the FP 100/1 bursting machine, in which the test samples were fixed.

The dependence of the stiffness and normal elasticity of the material of the flexible pipeline on the depth and length of the artificial defect when testing it for breaking has been established. With an artificial defect depth of 0.2 mm and its length from 0 to 40 mm, the stiffness of the flexible pipeline material decreases from 573.812 kN/m to 478.276 kN/m. With the indicated values of the defect, the normal elasticity ranged from 86.46 MPa to 64.567 MPa. When the depth of the defect increases by 0.4 mm, the stiffness of the sleeve material decreases to 432.902 kN/m, and the normal elasticity decreases to 58.442 MPa.

The obtained results are explained by the fact that when the thickness of the threads of the base of the power frame is reduced by 33 %, the longitudinal stiffness and normal elasticity of the material of the flexible pipeline are reduced by 25 % and 26 %, respectively.

The results of these studies are needed in practice because they can make it possible to develop new or improve existing methods of detecting hidden defects in the material from which flexible pipelines are made

Keywords: pressure fire hose, flexible pipeline, normal elasticity, longitudinal stiffness of the material, artificial defect

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1. Introduction

Fires have long been one of the main dangers accompanying human life. The fire extinguishing process is complex and requires certain skills and abilities from firefighters, as well as appropriate technical support. Among various types of fire-fighting equipment, pressure fire hoses, which are actually flexible pipelines, have the lowest level of reliability. At fires, pressure fire hoses are often damaged due to their cuts, punctures, rubbing, burning, and ruptures because of excessive internal hydraulic pressure. When extinguishing fires in buildings and structures, it is necessary to lay hose lines between stairwells or along the knees of mobile ladders if they are involved in this process. Under these conditions and taking into account the fact that the approximate volume of water in a hose with a diameter of 77 mm is 90 l, it is necessary to talk about the occurrence of a significant burst pressure in its longitudinal direction. Because of this, in order to minimize cases of failure of pressure fire hoses in the subdivisions, their hydraulic tests are periodically carried out. The essence of these tests is to create excess pressure in the inner cavity of the sleeve by filling it with water, which makes it possible to detect external damage. At the same time, the resistance of the sleeve to the action of tensile loads in the longitudinal direction is not checked in any way. In the presence of hidden defects or damage in the material from which pressure fire hoses are made, its resistance to the action of tensile loads in the longitudinal direction will usually decrease. Accordingly, in practice, it turns out that the mentioned type of tests is unreliable and does not make it possible to fully detect the existing hidden defects of the material from which pressure fire hoses are made. The material from which pressure fire hoses are made is composite and consists of several layers, because of this it is quite difficult to detect hidden defects in it by known methods. In addition, there are many types of sleeves, and they are made of different materials. In order to detect possible hidden defects in them, it is necessary to know how the physical and mechanical properties of the material from which they are made change as a result of the influence of various factors on it. These factors can also include the effect of loads on the rupture in the longitudinal direction of the sleeve. The consequences of failures in the operation of pressurized fire hoses during a fire are an increase in the level of danger for personnel and an increase in fire extinguishing time. Therefore, it is important to study changes in the physical and mechanical properties of the material from which pressure fire hoses are made under the action of tensile loads in the longitudinal direction. The results of such studies are needed in practice because they can make it possible to develop new or improve existing methods for detecting hidden defects in the material from which pressure fire hoses are made.

2. Literature review and problem statement

The operational readiness indicator makes it possible to assess the effectiveness of firefighting units. This indicator is comprehensive and takes into account many factors, including the probability of trouble-free operation of fire-fighting equipment [1]. Accordingly, the probability of trouble-free operation of pressure fire hoses (PFHs) directly affects the indicator of the operational readiness of fire departments.

As mentioned earlier, PFH is essentially a flexible pipeline at the ends of which connecting heads made of metal, for example, aluminum alloys, are attached. Because of this, its reliability as a whole as a product will also be affected by the reliability of the connecting heads.

In [2], a multi-scale mechanical model was built to predict the behavior of rubber when it is subjected to both uniaxial and biaxial deformation states, which subsequently affect its strength. The mechanical model can be used to predict the moments of onset of limit states of rubber samples. As for composite materials that have rubber in their structure, the application of this mechanical model is limited in such cases. This is explained by the fact that the behavior of a composite material subjected to different states of deformation will differ compared to rubber samples.

In [3], the resistance to compression of the reinforcing layer of the unloading hose during the action of an external load on it was investigated. The peculiarity of these hoses is that they are laid under water, and therefore are constantly affected by hydraulic pressure from the outside. A spiral made of composite material or steel is used as a reinforcing layer in hoses. A similar internal structure has a reinforcing layer in PFH, which are designed for supplying fire-extinguishing substances under high pressure, but these sleeves are mostly not affected by external loads during their work.

In [4], the change in the physical and mechanical properties of a marine rubber hose during twisting is investigated depending on the change in the winding angle of the cords and the steps of the spirals of the wire of the reinforcing layer. Research has found that the forces in odd-numbered cord layers and even-numbered cord layers are completely different, and the helix pitches and cord angles have a large effect on the torsional stiffness of the rubber hose. In addition, when the rubber hose is twisted clockwise and counterclockwise, the mechanical properties of the inner reinforcing layers and the outer reinforcing layers are different, and the torsional stiffness shows a non-linear trend. Given the different structure of composite materials from which marine rubber hoses and PFH are made, they will have different physical and mechanical properties when twisted.

In [5], the mechanical characteristics of a glass fiber-reinforced unbonded flexible pipe under the influence of an axial tensile load are studied. It was noted that due to the anisotropy of composite materials, it is difficult to accurately describe the behavior of these pipes during stretching. It was found that due to the reduction of the winding angle of the fibers of the reinforcing layer, the material from which the flexible pipeline is made is able to perceive larger values of the axial load. The stress distribution in the direction of the fibers is relatively uniform along the axial and circumferential directions of the tube, except in the regions near the end sections.

In [6], flexible pipelines are tested for tension in the state when they are bent at a certain angle. It was established that small values of the angle do not affect the rigidity during stretching, but during its increase, an uneven load and stress concentration are created in the reinforcing layer. During the operation of PFHs, their laying is also not always carried out in a straight line, and therefore there are cases when even at the same time several sections of one sleeve are bent at a certain angle. Accordingly, when fire-extinguishing substances are supplied and hydraulic pressure is created in the inner cavity of the sleeve, the amount of stress in the reinforcing layer will increase in these areas. This can increase the probability of destruction of the specified areas of the sleeve if there are hidden defects in them, which also needs to be checked.

In [7], the behavior during stretching and twisting of a flexible pipeline, which had damage to the reinforcing layer in the form of a break from one to ten fibers made of metal, was investigated. Some high-pressure PFH models have a similar structure of the reinforcing layer. In these tests, the pipeline was first subjected to tension and then to clockwise and counterclockwise rotation. The results of the experiments allow one to state that the stiffness of the pipeline decreases with an increase in the number of breaks in the fibers of the reinforcing layer, as well as a significant effect on its tensile and torsional balance. High stress concentrations were observed in fibers close to the damaged ones.

According to [8], the behavior of a flexible pipeline made of composite material will change due to the influence of external loads depending on the characteristics of each layer. A cross-sectional analysis is required to evaluate the behavior of a flexible pipeline. Theoretical, numerical, and experimental approaches can also be used. Testing a flexible pipeline is considered the most reliable way to determine its strength. From the experiments, it is possible to estimate the mechanism of destruction and occurrence of stresses in each layer depending on the loads created during stretching. As mentioned above, it is possible to estimate the breaking strength of flexible pipelines using numerical methods. One of such methods is proposed in the cited work. But it does not provide an opportunity to establish the locations of hidden defects in the material from which the flexible pipeline is made during its operation.

In [9], a study of the mechanical properties of a flexible pipeline during its stretching was carried out. According to its results, the curves of the tensile forces and the load applied to the end of the test sample were constructed. In addition, test samples of the flexible pipeline were tested by creating hydraulic pressure in their internal cavity. Under the action of internal pressure, the axial tension of the material from which the flexible pipeline is made increased from the inner to the outer layer, and the destruction of these layers occurred in the same order until their complete failure.

In [10], the stiffness and modulus of elasticity of the material of a high-pressure fire hose type 1 ST with a diameter of 19 mm were investigated. The limit loads that act on the material of a high-pressure fire hose when testing it for rupture, as well as the relative elongation of the material at the same time, are established. The study was limited by the fact that the sleeve properties of only one type and diameter of the sleeve were investigated. In addition, hoses of this type are rarely used when extinguishing fires. The test samples used in the research were undamaged.

In [11], the change in physical and mechanical properties of PFH with a diameter of 66 mm was studied. Studies were conducted with PFH samples that did not have any damage. These samples were subjected to cyclic tensile loads, and periodic force and deformation measurements were taken. The determined experimental data made it possible to calculate the modulus of elasticity when stretching the material of the sleeve in the longitudinal direction. Studies with PFH samples with existing damage to compare the values of their physical and mechanical properties with PFH samples without damage were not conducted in the cited work.

In [12], the dependence of changes in the physical and mechanical properties of PFH with a diameter of 77 mm was investigated in the inner cavity of which hydraulic pressure was created during their twisting to a certain angle. At the same time, the experimental samples of PFH had no damage. The data of these studies can be used for the purpose of comparison with similar characteristics of the physical and mechanical properties of PFH with existing damage to establish possible changes.

In [13], experimental studies were conducted to determine the dependence of changes in the physical and mechanical properties of PFH with a diameter of 77 mm in the inner cavity of which hydraulic pressure was created during their stretching in the transverse direction. As a result of these studies, curves were obtained that reflected the deformation of the samples under conditions of cyclic loading and unloading and formed hysteresis loops. The experimental samples of PFH that were used in the work had no damage, and the change in their physical and mechanical properties in the presence of material damage was not considered.

In [14], the dependence of the change in the strength indicators of the PFH material with a diameter of 77 mm during their stretching in the transverse direction was investigated. The test samples that were used during the research had single damage in the form of cuts of a certain fixed depth and length. As a result of the research, it was established that the change in the strength of the PFH material depends almost linearly on the specified damage parameters. As damage increases, the strength of the PFH material decreases significantly.

In [15], a plan for conducting an experiment was drawn up, the purpose of which was to establish the dependence of change in the values of the twisting angle of a 77 mm diameter PFH on the internal water pressure and the length of the defect. The defect on the test sample was applied along and across the axis of the PFH. The length of the defect was 50 and 100 mm. The values of the pressure in the middle of the sleeve were 0.2, 0.4, and 0.6 MPa. The work also derived regression equations whose adequacy was checked according to Fisher's test, analyzed the results of research, and determined the numerical values of the factors that have the greatest influence on the change in the value of the twisting angle of the sleeve.

Different methods can be used to identify hidden defects that may be present in the material from which flexible pipelines are made.

The authors of [16] proposed a numerical method for predicting the deformation and fatigue damage of a rubber hose by using nonlinear finite element analysis of large deformations. The complex braided layers in the rubber hose microstructure are modeled as an orthotropic solid using the homogenization method, and the deformation is analyzed by the updated Lagrange method. Fatigue damage in the proposed numerical method was evaluated using the modified Morrow fatigue model and Minor's rule. A special feature of this numerical method is that it was developed for hoses used in the hydraulic braking system of vehicles. These hoses are subjected to constant cyclic tensile and compressive loads, and therefore their mode of operation is different from the mode of operation of PFH. In addition, this method cannot be used to determine hidden defects in the material from which flexible pipelines are made during their operation.

In [17], the use of the computer industrial tomography method is proposed for diagnosing the technical condition of rubber hoses in operation. This method can be used to analyze even high-pressure hoses. One of the main limitations regarding the practical application of the method is diagnosing the technical condition of rubber hoses with an internal reinforcing layer made of metal. The specified structure, for example, is in some varieties of high-pressure PFH.

In [18], for the purpose of diagnosing the technical condition of pipelines, the use of a resonator with a separating ring is proposed. This method can be used to check the integrity of pipelines that are laid in the middle of the casing pipe. This resonator is tuned to a resonant frequency of 6.1 GHz and makes it possible to determine the places of damage to the pipeline during the pumping of liquid through it. Due to the fact that the operating conditions of PFH differ from the operating conditions of pipelines for which the specified method was developed, this usually limits its application.

In [19], a review of known external and internal methods of pipeline damage detection was carried out. As for external methods, they are based on several main approaches. The first consists in a visual inspection of the pipeline in order to detect its damage, in particular, with the help of various technical devices. The second method implies the detection of foreign substances in the atmosphere, which get there through damaged sections of the pipeline, which can be determined with the help of trained animals or, for example, gas analyzers. The third method involves laying a fiber-optic cable along the pipeline to record the change in temperature along its entire length. In the event of damage to the pipeline and leakage from it, a temperature change occurs near these places, which makes it possible to detect the cable laid nearby. The fourth method consists in the use of various acoustic systems, which allow recording an increase in the level of the sound signal in places of damage to the pipeline. One of the internal methods consists in fixing the pressure or flow at the inlet and outlet of the pipeline and detecting damage by reducing the specified values. Another method is the magnetic induction method, which implies the use of sensors both inside and outside the pipeline. Sensors inside measure the pressure and velocity of the fluid being transported, as well as acoustic vibrations caused by leaks. Sensors placed outside measure the temperature, humidity, and properties of the soil around the pipelines. Accordingly, all of these methods make it possible to determine only damage to pipelines through which substances leak, and they do not make it possible to detect hidden defects that may, under certain conditions, cause this in the future.In [20], in addition to the previously analyzed methods, MAPS rarefaction measurement technology was also considered. The essence of this technology is the introduction of MAP sensors into the flexible pipeline, which allow continuous monitoring of the occurrence of rarefaction in the internal cavity of the flexible pipeline. Rarefaction in the internal cavity of the flexible pipeline can occur when it is damaged and the substance leaks. This method does not make it possible to establish the presence of a hidden defect in the material from which the flexible pipeline is made.

Thus, most methods [16–20] that could be used to diagnose the technical condition of flexible pipelines do not allow detecting hidden defects in the material. Only the computerized industrial tomography method [17] allows this to be done, but it has certain limitations in its application. In order to predict the behavior of materials from which flexible pipelines are made from various factors that affect them during their work, it is necessary to conduct research into their physical and mechanical properties. Several authors [2–15] report these studies. The study of the physical and mechanical properties of pressurized fire hoses under the influence of various factors is complicated by the fact that the material from which they are made is composite and anisotropic. In [10–15], studies of changes in the characteristics of the physical and mechanical properties of the material from which pressure fire hoses are made as a result of external influences on it were carried out. Some of them [14, 15] consider the study of the physical and mechanical properties of samples of pressure fire hoses of the «T» type, which had an internal diameter of 77 mm with existing material damage. At the same time, they considered only the dependence of the change in the strength of the pressure fire hose material depending on the nature of the single damage and the change in its twist angle on the internal water pressure and the length of the defect. The dependence of the stiffness and normal elasticity of the material from which the pressure fire hose is made on the depth and length of the artificial defect when testing it for rupture in the longitudinal direction remains unexplored. As it was indicated above, during the operation of pressurized fire hoses and their laying on vertical surfaces, they are subjected to significant bursting pressures in their longitudinal direction. That is, such operating modes of the sleeve may occur during its operation.

3. The aim and objectives of the study

The purpose of this study is to determine the dependence of change in the stiffness and normal elasticity of the material from which the flexible pipeline is made on the depth and length of an artificial defect when testing it for rupture in the longitudinal direction. The results could be used when solving problems in modeling the stress-strain state of the flexible pipeline material using the finite element method.

To achieve the goal, the following tasks were set:

– to conduct experimental studies to determine the stiffness index of the material of the flexible pipeline;

– to determine the patterns of changes in the normal elasticity of the material of the flexible pipeline.

4. The study materials and methods

The object of our research is the phenomenon of influence of hidden defects on the mechanical properties of the material of flexible pipelines. The research hypothesis assumes that the presence of hidden defects in the material of the flexible pipeline affects the change in its stiffness and normal elasticity. The tests carried out in the work were limited to the study of only two factors, while the degree of wear, the type of sleeve, and the effect of several defects on test length were not taken into account.

As experimental samples of flexible pipelines, «T» type PFH with an internal diameter of 77 mm were used [11]. In order to initially check the integrity of the sleeve, its hydraulic tests were carried out. After that, it was dried. Further, experimental samples were separated from this pressure sleeve for research. The test samples were separated from different parts of the sleeve in the longitudinal direction. The length of the working zone was $l=100$ mm, the width of the working zone was $S=50$ mm, and the material thickness was $\delta=2.7$ mm (taking into account the thickness of the power frame $\delta_f=1.2$ mm).

The tests were carried out on a FP 100/1 burst test machine («VEB MWK Fritz Heckert», Germany) in which the test samples were fixed using self-tightening clamps. The load was measured with a standard dynamometer, and the deformation curve of the sample was recorded on indicator paper. The tests were carried out at a temperature of 20–22 °C. After fixing the test sample in the burst test machine, loads were gradually created, which caused the onset of the limit state, namely rupture. The general view of the experimental setup with a fixed experimental sample is shown in Fig. 1.

During PFH operation, it was found that the most characteristic defects are bends, cracks, tears, and abrasions. Each of these defects can be modeled by making cuts of different depth, width, and direction.

Due to the fact that the power frame fully perceives the forces caused by the presence of internal fluid pressure in the middle of the sleeve, according to [23], it was decided to apply an artificial defect to the power frame. The artificial defect was applied in the central part of the working area, across the test sample, that is, along the base, as shown in Fig. 2. In appearance, it was similar to abrasions that can occur during the operation of sleeves. The length of the artificial defect varied from 20 to 40 mm, and the depth was 0.2 and 0.4 mm. The defect was applied using a blade with a width of 0.1 mm. The length and depth of the defect were determined visually using an MBS-9 microscope (USSR). If the damage deviated from the specified parameters, the sample was not accepted for testing.

Fig. 1. Fixation of prototypes in a burst test machine

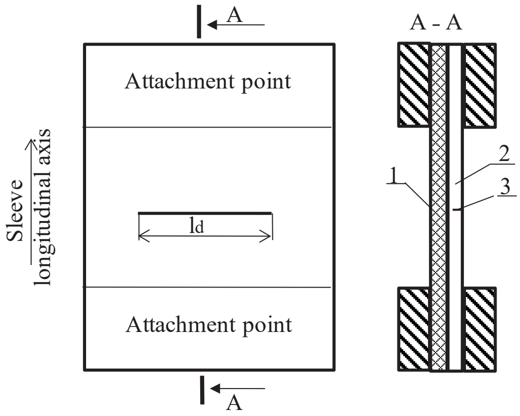

Fig. 2. Location of damage on the sleeve [14]: 1 – waterproofing layer; 2 – power frame; 3 – place of damage

The experiments were carried out in two separate variants. Experiments were first conducted to determine the stiffness of the material in the longitudinal direction with variation in the size of the artificial defect. The second variant of the experiments were tests to determine the normal elasticity of the material, also with varying the size of the artificial defect. Efforts were created by the burst test machine.

Fig. 3 shows the general view of experimental samples after testing them for rupture in the longitudinal direction.

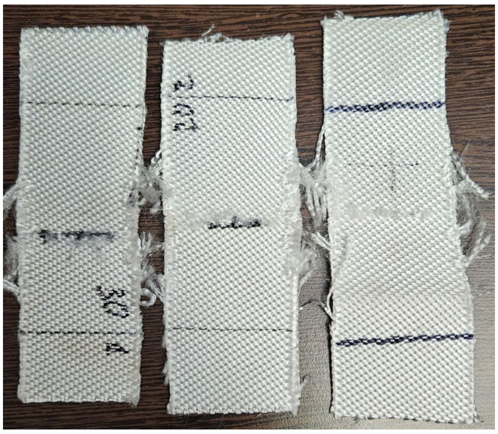

Fig. 3. Test specimens after sleeve material tensile test

After the tests on the samples, it was found that the warp threads were broken in the middle of the cord. At the edges of the samples, tears and torn threads of the base were observed. A test sample that broke at the point of fixation was not accepted for testing. The test sample kept its shape due to the waterproofing layer and weft threads.

5. Establishing the dependence of changes in longitudinal stiffness and normal elasticity of the flexible pipeline material

5. 1. Experimental studies of the longitudinal stiffness of the flexible pipeline material

The results of our experimental studies to determine the longitudinal stiffness of the sleeve material depending on the depth and length of an artificial defect are characterized by the curves shown in Fig. 4–10.

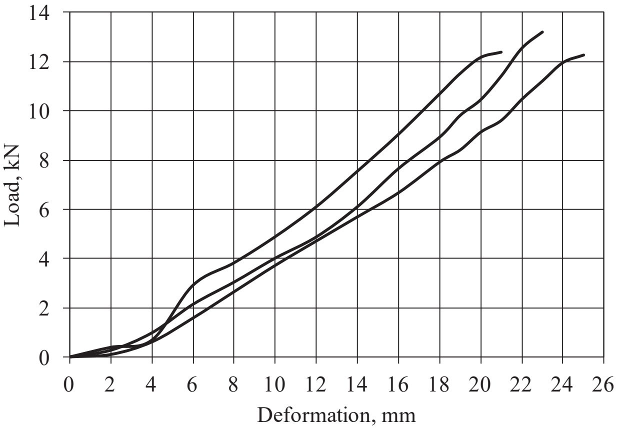

Fig. 4. Experimental studies of a non-deformed specimen

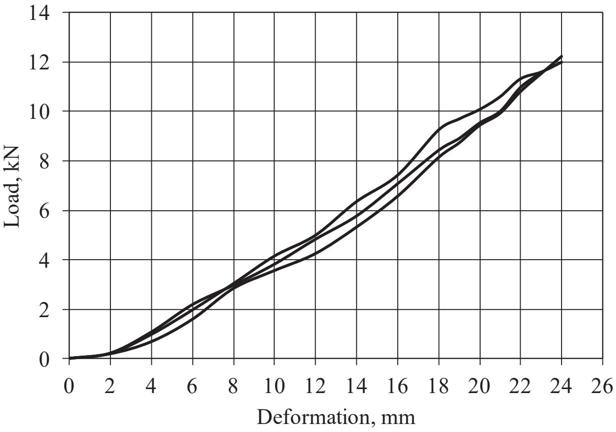

Fig. 5. Experimental studies of a sample with an existing artificial defect 20 mm long and 0.2 mm deep

Fig. 4 shows the results of experimental studies on a non-deformed sample. The maximum load and deformation of the sleeve material.

Fig. 8, 9 show the results of experimental studies on a sample with an existing artificial defect 20 mm long and 30 mm deep with a depth of 0.4 mm. The maximum load and deformation of the sleeve material.

The load and deformation of test samples of fire hoses make it possible to determine the stiffness (C) of its material in the longitudinal direction.

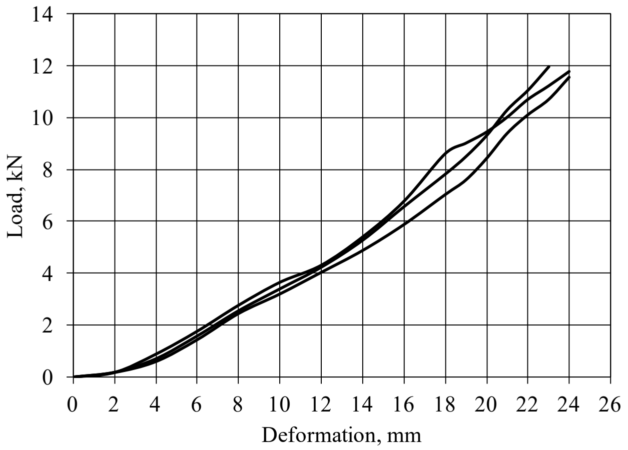

Fig. 6. Experimental studies of a sample with an existing artificial defect 30 mm long and 0.2 mm deep

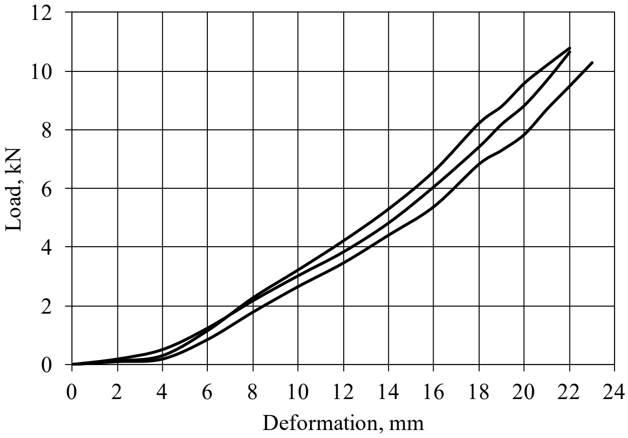

Fig. 7. Experimental studies of a sample with an existing artificial defect 40 mm long and 0.2 mm deep

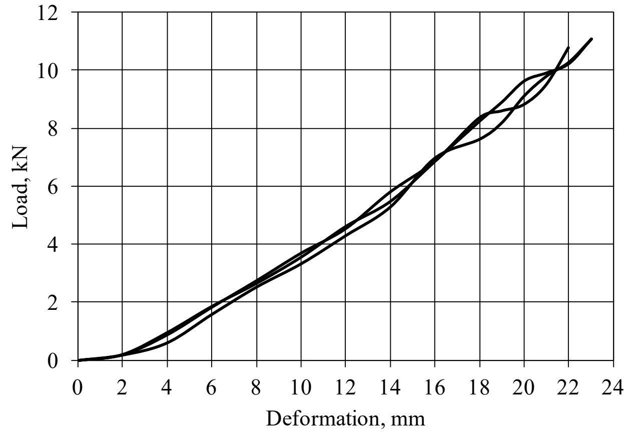

Fig. 8. Experimental studies of a sample with an existing artificial defect 20 mm long and 0.4 mm deep

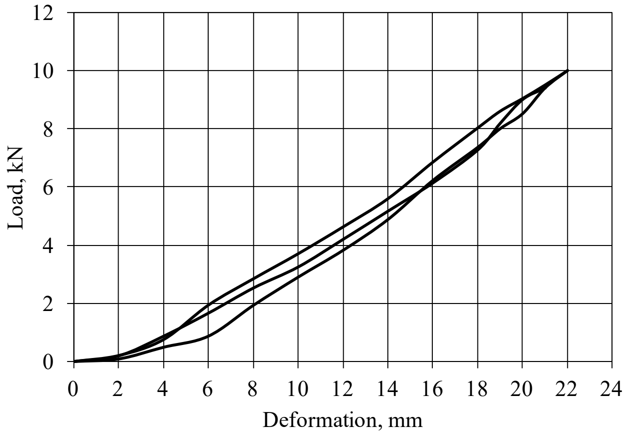

Fig. 9. Experimental studies of a sample with an existing artificial defect 30 mm long and 0.4 mm deep

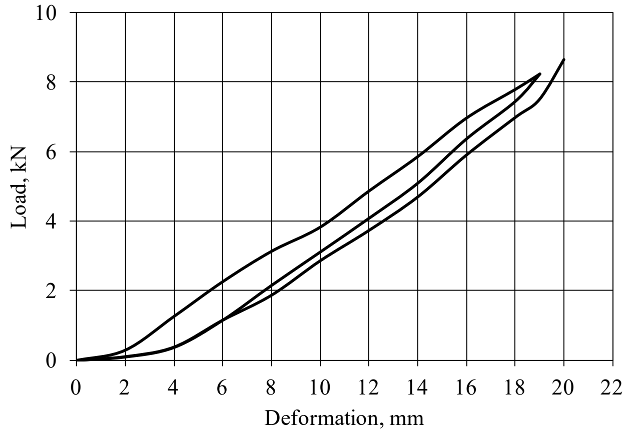

Fig. 10. Experimental studies of a sample with an existing artificial defect 40 mm long and 0.4 mm deep

Formula (1) is used to determine the stiffness of the flexible pipeline material. Tables 1, 2 give the results of calculations of sleeve material stiffness indicators, both for a sleeve without a defect and for a sleeve with an artificial defect of the appropriate depth and length:

$$C_i = \frac{F_i^{\max}}{\Delta l_i^{\max}}, \qquad (1)$$

where C_i is the stiffness determined for the i-th sample; $F_i^{\max}$ – maximum load of the i-th sample; $\Delta l_i^{\max}$ – maximum elongation of the i-th sample before the break.

Fig. 11 shows the plots of dependence of the stiffness of the sleeve material on the length and depth of the defect, taking into account the results of the calculations in Tables 1, 2.

The dependences obtained by using the spreadsheet editor Microsoft Excel 2007 were approximated by a trend line. Types of trend lines were chosen based on the calculated value of the coefficient of determination, which characterizes the degree of closeness of the specified lines to the original data.

Table 1

Results of calculating the stiffness of the sleeve material without a defect

Parameter values	Prototype number			Average design stiffness, kN/m
	No. 1	No. 2	No. 3	
Stiffness value of the hose material, kN/m	559.4	588.9	573.1	573.8

Table 2

Results of calculating the stiffness of the hose material with an artificial defect

Parameter values	Defect depth, mm							
Defect length, mm	0.2				0.4			
	Prototype number			Average design stiffness, kN/m	Prototype number			Average design stiffness, kN/m
	No. 1	No. 2	No. 3		No. 1	No. 2	No. 3	
	Stiffness value of the hose material, kN/m				Value of hose material stiffness, kN			
20	503.2	508.4	502.3	504.6	490	481.5	481.1	484.2
30	481.8	490	498.5	490.1	454.4	454.4	448	452.2
40	460.2	484.7	490	478.3	433.3	432.2	433.3	432.9

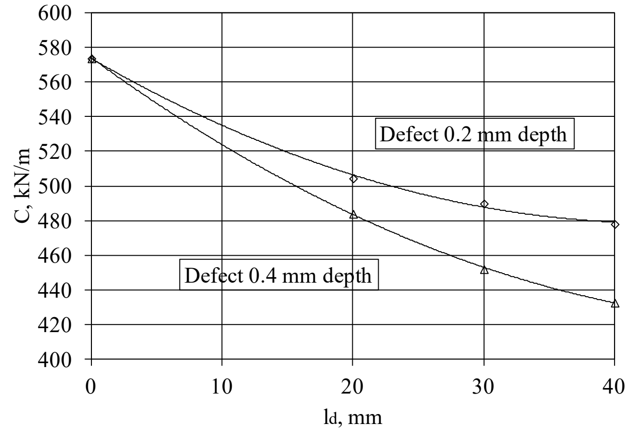

Fig. 11. Plot of the dependence of stiffness of the sleeve material on the length and depth of the defect

The resulting trend lines describe the corresponding equations:

– for a defect depth of 0.2 mm:

$$Y_i = 0.0499 \cdot X_i^2 - 4.3557 \cdot X_i + 573.52; \qquad (2)$$

– for a defect depth of 0.4 mm:

$$Y_i = 0.0493 \cdot X_i^2 - 5.5063 \cdot X_i + 573.92, \qquad (3)$$

where Y_i is the predicted stiffness value of the sleeve material of the i-th sample; X_i is the defect length of the i-th sample.

The value of the coefficient of determination for regression equation (2) is 0.9983, and for regression equation (3) – 0.9999.

5. 2. Determination of the values of normal elasticity of the material of the flexible pipeline

The established almost linear relationship between load and deformation (Fig. 4–10) of sleeve fragments allows us to determine the modulus of elasticity (E) of its material in the longitudinal direction:

$$E_i = \frac{F_i^{\max} \ell}{\left(\Delta\ell_i^{\max} - \Delta\ell_{i-1}^{res}\right)\delta S}, \qquad (4)$$

where E_i is the modulus of elasticity determined for the i-th sample; $F_i^{\max}$ – maximum load of the i-th sample; ℓ – length of the working area; $\Delta\ell_i^{\max}$ – maximum deformation of the i-th sample; $\Delta\ell_{i-1}^{res}$ – maximum elongation of the i-th sample before the break; δ is the thickness of the sample material; S is the width of the working area of the fragment.

Table 3 gives the results of calculating the normal elasticity of the sleeve material without a defect.

Table 4 gives the results of calculating the normal elasticity of the sleeve material with an artificial defect.

Fig. 12 shows dependence plots of the normal elasticity of the sleeve material on the length and depth of the defect, taking into account the results of the calculations in Tables 3, 4.

Table 3

Results of calculation of normal elasticity of sleeve material without defect

Parameter values	Prototype number			Mean calculated value of normal elasticity, MPa
	No. 1	No. 2	No. 3	
Value of normal elasticity, MPa	72.5	79.5	77.37	76.46

Table 4

Results of calculation of normal elasticity of hose material with artificial defect

Parameter values	Defect depth, mm							
Defect length, mm	0.2				0.4			
	Prototype number			Average design value of hose material elasticity, MPa	Prototype number			Mean calculated value of normal elasticity, MPa
	No. 1	No. 2	No. 3		No. 1	No. 2	No. 3	
	Value of normal elasticity of sleeve material, MPa				Value of normal elasticity of sleeve material, MPa			
20	67.93	68.63	67.8	68.12	66.15	64.99	64.94	65.36
30	65.04	66.15	67.3	66.166	61.34	61.34	60.48	61.05
40	62.12	65.43	66.2	64.57	58.49	58.34	58.49	58.44

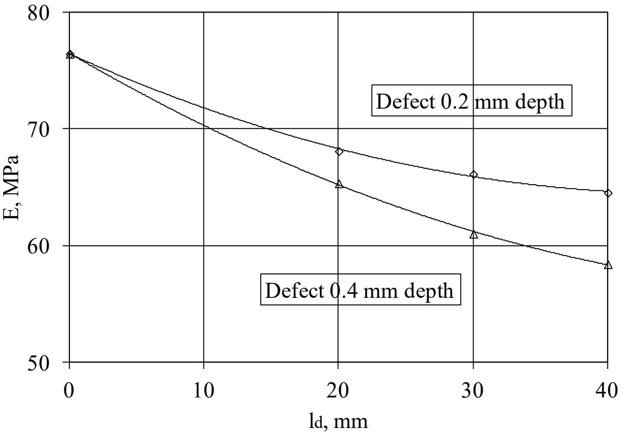

Fig. 12. Dependence plot of the normal elasticity of the sleeve material on the length and depth of the defect

The dependences obtained by using the spreadsheet editor Microsoft Excel 2007 were approximated by a trend line. Types of trend lines were chosen based on the calculated value of the coefficient of determination, which characterizes the degree of closeness of the specified lines to the original data.

The resulting trend lines describe the corresponding equations:

– for a defect depth of 0.2 mm:

$$Y_i = 0.0056 \cdot X_i^2 - 0.5182 \cdot X_i + 76.43; \tag{4}$$

– for a defect depth of 0.4 mm:

$$Y_i = 0.0055 \cdot X_i^2 - 0.6735 \cdot X_i + 76.484, \tag{5}$$

where Y_i is the predicted stiffness value of the sleeve material of the i-th sample; Y_i is the defect length of the i-th sample.

The value of the coefficient of determination for regression equation (4) is 0.9988, and for regression equation (5) is 0.9997.

6. Discussion of results of investigating the longitudinal stiffness and normal elasticity of the material of a flexible pipeline

During our experiment (Fig. 4–10), the stiffness (Tables 1, 2) and normal elasticity (Tables 3, 4) of the material of the flexible pipeline were determined from the depth and length of the artificial defect when testing it for rupture in the longitudinal direction. It was found that when the length and depth of the artificial defect increases, the stiffness (Fig. 11) and normal elasticity of the sleeve material (Fig. 12) decrease. It was determined that when the artificial defect increases in length from 0 to 40 mm and a depth of 0.2 mm, the stiffness and normal elasticity of the sleeve material decrease by 17 % and 16 %, respectively. When the artificial defect increases in depth by 0.4 mm, the stiffness and normal elasticity of the sleeve material decreases by 24 % and 25 %. This can be explained by the decrease in the diameter of the threads of the power frame.

The tests conducted were limited to the study of only two factors, while not taking into account the degree of wear, the type of sleeve, and the effect of several defects on the test length. These limitations can be overcome by investigating the pressure sleeve with an arbitrary period of use and by conducting additional studies.

The disadvantage of these studies is that the results were obtained when a defect was applied to the material. In practice, cuts can be placed on flexible material not only lengthwise. In addition, they can also be through. Under the specified conditions, the results obtained during similar studies may differ significantly from those obtained in this work.

The further development of our research is the experimental analysis of the effect of different directionality, shape, and direction of the defect on the sleeve, as well as the effect of several defects on the test length of PFH.

Such studies require the development of a new plan for the experiment and its methodology.

7. Conclusions

1. Experimental studies were carried out and the dependence of the stiffness index of the flexible pipeline material on the depth and length of the artificial defect during the rupture test was established. At a depth of 0.2 mm and the length of the artificial defect from 0 to 40 mm, the stiffness of the sleeve material decreases from 573.812 kN/m to 478.276 kN/m. When the depth increases by 0.4 mm, the stiffness of the sleeve material decreases from 573.812 kN/m to 432.902 kN/m. According to the research results, dependences were obtained for the depth of the defect of 0.2 mm and 0.4 mm with its length from 0 to 40 mm.

2. The dependence of the normal elasticity index of the material of the flexible pipeline on the depth and length of the artificial defect during its tear test was established. At a depth of 0.2 mm and the length of the artificial defect from 0 to 40 mm, the normal elasticity of the sleeve material decreases from 86.46 MPa to 64.567 MPa. When the depth increases by 0.4 mm, the normal elasticity of the sleeve material decreases from 86.46 MPa to 58.442 MPa. According to the research results, dependences were obtained for the depth of the defect of 0.2 mm and 0.4 mm and for its length from 0 to 40 mm.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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