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DETERMINING THE DISSIPATIVE PROPERTIES OF A FLEXIBLE PIPELINE'S MATERIAL AT STRETCHING IN THE TRANSVERSE DIRECTION TAKING ITS STRUCTURAL ELEMENTS INTO CONSIDERATION

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This paper reports an experimental study that determines the dissipative properties of a pressure fire hose, the type of «T», whose inner diameter is 77 mm, under the static load conditions, taking into consideration the structural elements of the hose in the transverse direction. For this study, experimental samples were separated from the different sections of the hose. The study involved both the outer fabric reinforced frame and the internal waterproofing rubber layer of the pressure fire hose. A series of field experiments were carried out while stretching the samples under the conditions of static loading-unloading cycles. The tests included 7 cycles, which were carried out in a two-minute interval for the material of the hose. The study results showed that during the first two to three cycles, the materials manifest a short-term creep that stabilizes under modes 4–7. The results from experimental research were approximated by polynomial trend lines. The deformation of samples demonstrated the curves that, under the conditions of cyclic loading and unloading, formed hysteresis loops. When analyzing the appropriate curves, it was found that, first, during the first two-three loading-unloading cycles the area of the hysteresis loops decreases, second, the inclination angle of hysteresis loops also decreased during each subsequent loading-unloading cycle.

It was established that the dissipation coefficients of the hose material stretched in the transverse direction are significantly reduced under the first three test modes in the range from 0.49 to 0.37. At subsequent tests (cycles 4–7), dissipation coefficients stabilize at the level of 0.18 for the reinforced frame, and 0.316 for the rubber layer

Keywords: deformation, pressure fire hose, hysteresis, dissipative properties, experimental determining, reinforced frame, waterproofing rubber layer

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1. Introduction

An increase in the number of emergencies of anthropogenic nature is associated with the development and growth of the quantity of various industrial enterprises. According to [1], in the structure of calls to emergency rescue units (ERUs), fires still occur more frequently compared to other types of dangerous events and emergencies.

Extinguishing fires is accompanied with air pollution [2] by products of incomplete combustion, destruction of building structures at prolonged temperatures, danger of explosion; it poses a threat to the health and life of people, etc. To extinguish complex fires, such as landscape [3], or at dangerous facilities, ERUs employ a large amount of fire and technical equipment (FTE). Successful operations on the elimination of fires, emergencies of anthropogenic nature depend not only on the time of the concentration of forces and means at a fire site [1] but also on the indicators of FTE failure-free performance [4]. As regards such equipment, fire hoses are characterized by the least reliability. When analyzing the events where fire and technical equipment failed in the western region of Ukraine, it was found that 60 % of failures of the total number of failures (over a month, 20 % of operations involving the failures of fire and technical equipment) accounted for pressure fire hoses. The reasons for the failure of pressure fire hoses (PFH) can be manufacturing defects in their structure, violation of storage conditions and testing. Their sudden failure can cause an increase in the duration of operations to eliminate emergencies. At the same time, PFH can be used not only for the supply of water and aqueous solutions but also to pump hazardous chemicals (HC) whose removal may involve a large number of hoses. Thus, measures aimed at determining the residual resource of fire hoses, the possibility of their repair, their reliability, as well as the safety of their further utilization, greatly contribute to preparing ERUs better to act as intended.

A problematic issue at present is that the PFH testing techniques used by ERUs do not make it possible to diagnose the technical condition of a hose at an early stage of its damage (before the rupture). Therefore, it is a relevant task to devise and improve the PFH testing techniques that could make it possible to determine the presence of a defect before the onset of the limit state (rupture), which could lead to prolonging the time of emergency elimination.

2. Literature review and problem statement

PFHs are essentially flexible pipelines. The destruction of flexible pipelines may occur for various reasons. The types of destruction include a violation of the integrity of the material from which a flexible pipeline is made, as well as the destruction of the connecting valves.

The reasons for the failure of flexible pipelines, which are associated with the destruction of the connecting valves, could be either damage in the places of attachment of the flexible pipeline to the ferrule [5], or the destruction of the fitting itself [6]. The first, according to [5], occurs because the ferrule of the connecting valves may have untreated sharp edges, which cause damage as early as during installation. In addition, over time, there is a loss of elasticity of elastomers, which are part of the material from which flexible pipelines are made, which causes looseness in the places of connection to the fittings. The second reason is associated with possible manufacturing defects of the connecting valves, which, as a result of hydraulic pressure inside the flexible pipeline, causes its destruction [6]. Accordingly, the specified faults of the connecting valves of flexible pipelines are mainly associated with the low quality of their manufacture and production defects. The technical condition of the connecting valves during operation is mainly diagnosed during hydraulic tests.

Violation of the integrity of the material from which flexible pipelines are made could occur for many reasons. The process of assessing the maximum strength of flexible pipelines is complex. This is because they are made of composite materials and could consist of several layers, which are combined differently [7]. When evaluating the maximum strength of flexible pipelines, it is necessary to take into consideration their internal structure and many other factors, which explains the complexity of the mathematical models used for this.

Work [8] investigated a change in the physical properties of the material of flexible pipelines, namely elastomers, as a result of their exposure to liquid fuels. This effect could occur either from the inside, which is possible when pumping liquid fuel through flexible pipelines, or even externally if its spill occurred. Such physical properties as weight and volume, as well as hardness and tensile strength, were studied. It was established that different elastomers, which are part of the material from which flexible pipelines are made, interact differently with liquid fuels. Some elastomers interact actively and, therefore, quickly change their physical properties, while some show a slight interaction.

The destruction of the material from which flexible pipelines are made is facilitated by the appearance of microcracks on its surface, which, according to [9], could appear as a result of tension and cyclic deformations. The process of predicting the duration of operation of a flexible pipeline before damage appears in it is complicated by the fact that it is made mainly of composite material. The complexity of the internal structure from which the pipelines are made causes the need to adopt certain simplifications in the process of their research, which causes significant errors. Study [9] assesses the fatigue process of elastomers only, which are part of the material from which a flexible pipeline is made. At the same time, the condition of the fabric reinforced layer was not considered.

In order to conduct a numerical analysis of the probable deformations of the flexible pipeline, homogenization and interpolation methods [10] could be applied. The use of these methods predetermines the adoption of some simplifications when considering the structure of the material, as well as certain averaged values of parameters, which also cannot ensure the necessary reliability of the results.

Work [11] proposes a system of nonlinear equations, which makes it possible to estimate the probable deformation, as well as the loads that occur in the reinforced layer of flexible pipelines. This model could be used to assess the pressure limit in the middle of the pipeline at which its destruction could occur. Fatigue of elastomers, which are part of the material from which flexible pipelines are made, is not considered in the cited work.

According to [12], when establishing the breaking pressure of flexible pipelines, specifically PFH, it is necessary to take into consideration many different factors. These factors include the breaking force of weft threads, a hose radius, the geometric density on the base and weft, the diameters of the base and weft threads, the coefficients of vertical crumpling of the base and weft threads. Work [12] proposed a mathematical model was, which, while including the previously mentioned factors, makes it possible to assess the breaking pressure of PFH. At the same time, this mathematical model does not take into consideration any properties of elastomers that are part of the material from which the PFH is made.

Study [13] suggests a mathematical model that makes it possible to evaluate the process of fatigue damage in rubber-like materials. This mathematical model was built on the basis of the experimental study into the process of accumulation of fatigue by various rubber samples. This mathematical model does not make it possible to establish the probable place of destruction of a flexible pipeline made of the material that is structurally a rubber-cord composite.

Under the action of cyclic loads, according to [14], there is a change in the dissipative properties of rubber-cord composites, in particular, their self-heating. The experimental samples were flat fragments that were made of rubber-cord composites and had all the same geometric dimensions. During full-time experiments on stretching the experimental samples along the reinforced fibers, it was possible to acquire data on changes in their characteristics, which made it possible to build deformation curves, that is, the process was described. Accordingly, it could be assumed that under the influence of cyclic loads an experimental sample that has a hidden defect would demonstrate that its dissipative properties are different from those of a similar sample that has no defect. This assumption was not tested in the cited study.

One of the methods for diagnosing the technical condition of flexible pipelines is the method of industrial computer tomography. According to [15], the specified method makes it possible to obtain sufficiently accurate results but requires, before applying, the analysis of the composition of the material from which the flexible pipeline is made. If the pipeline is made of the composite material of a certain composition, this method may not be applied, which limits its application.

In work [16], the mechanical properties of the «T» type PFH with an inner diameter of 66 mm were investigated under static load conditions. During the experiment, a certain standard effort was applied to the PFH experimental sample, which allowed it to be stretched by a certain length, which was subsequently measured. Taking into consideration the acquired experimental data, the value of the elasticity module was established when stretching the hose material.

According to [17], the mechanical properties of flexible pipelines could also change when they are twisted at a certain angle. This paper investigated the mechanical properties of the «T» type PFH experimental samples with an inner diameter of 77 mm, which accepted different values of internal hydraulic pressure when changing the angle of twisting. The dependences that had been established in the course of the experimental study were approximated by trend lines.

The experimental samples investigated in studies [16, 17] had no damage before the experiments. These studies did not consider changes in the parameters of the mechanical properties of PFH experimental samples that had a certain defect compared to samples without defects. In addition, work [16] investigated the mechanical properties of the «T» type PFH with an inner diameter of 66 mm, which is quite rarely used by ERUs. It should also be noted that study [16] performed the tests involving the material of the hose in a longitudinal (along the base) direction.

The authors of [18] considered the strength and improvement of the structure of the force frame (weaving cover) of pressure fire hoses. It was established that the calculations of the strength of the force frame do not take into consideration the difference in the fiber composition of the material, the density and diameter of the threads, both on the base and weft. That necessitated a more detailed study of this issue. Thus, they investigated the issue of improving the structure of the reinforced frame of the hose by changing the diameter of the threads, the geometric density of the fabric (base and weft) depending on breaking pressure. It was established that, first, with an increase in the geometric density of the reinforced frame both on the base and weft, the breaking pressure decreases; the most effective density of the material was determined. Second, with an increase in the diameter of the base threads (weft), the breaking pressure increases (decreases). Third, the breaking pressure of the fire hose is directly proportional to the breaking effort of the weft threads and is inversely proportional to the radius of the fire hose while all other parameters are constant (material density, thread diameter). The cited work is aimed at improving the PFH structure. In turn, those results prove that different diameters of the main and weft threads are used in the PFH design. The existence of different thread diameters leads to orthotropy of the viscous-elastic properties of the hose material. To determine the orthotropy constants of the hose material, computer modeling methods or experimental testing of the relevant characteristics of the material are used. Therefore, there was a need to determine the mechanical properties of the hose material in the transverse direction by experimental testing. And, taking into consideration that PFH includes a composite material, it is necessary to determine the mechanical properties of the hose taking into consideration their structural elements, both the reinforced frame and the waterproofing layer of the hose.

Thus, after analyzing the scientific literature [5–18], it was found that most studies address changes in the properties of materials from which flexible pipelines are made, exerted by various influences [5–16, 18]. In order to diagnose the technical condition of flexible pipelines, the industrial computer tomography method could be applied [15]; however, the complexity of the structure of the material from which they are made limits its application. Given the complex structure of flexible pipelines, a series of works [8–14] investigated changes in the properties of individual layers only, which make up the material for pipelines. A comprehensive estimation of changes in the mechanical properties of the material from which flexible pipelines are made when it is exposed to various influences was reported in works [16, 17]. Those studies found that intense fatigue contributes to a change in the properties of the PFH material, the occurrence and propagation of cracks, and, after a certain time, causes their failure. The failure of PFH prolongs the period of fire elimination, which, in turn, could lead to significant losses, and, sometimes, catastrophic consequences. Therefore, there is a need to determine the PFH mechanical properties taking into consideration their structural elements. When these properties are investigated, it will become possible to compare them with the mechanical properties of samples that have defects and, on this basis, to draw a conclusion about their technical condition.

3. The aim and objectives of the study

The aim of this study is to determine the dissipative properties of a flexible pipeline using the «T» type PFH as an example with an inner diameter of 77 mm at stretching in the transverse direction, taking into consideration its structural elements for subsequent calculations of their reliability.

To accomplish the aim, the following tasks have been set:

– to perform an experimental study to determine the dissipative properties of a fabric reinforced frame of fire hoses;

– to perform an experimental study to determine the dissipative properties of an inner waterproofing rubber layer of fire hoses.

4. Materials and methods of experimental studies to determine the dissipative properties of materials for the «T» type pressure fire hose

In order to determine the dissipative properties of the material for a «T» type PFH with an inner diameter of 77 mm, we performed a series of full-time experiments on stretching under the conditions of static loading-unloading cycles, followed by treatment of results.

The PFH structure was considered in work [16]. It established the elasticity modules and dissipative properties of the «T» type PFH with an inner diameter of 66 mm in the longitudinal direction (along the axis of the hose).

The experimental installation DM-30M (made at the Factory of testing machines, USSR) was used for the tests, in which a hose sample was fixed with a mechanical clamp. We set the fixed values of sample deformation. A regular mechanical dynamometer was used as a measuring base. Experiments were carried out to determine the dissipative properties of the fabric reinforced frame, the inner waterproofing rubber layer, as well as define the viscoelastic properties of the hose, in the transverse direction. The research was carried out with nine samples that were separated from different sections of the new 77-mm-diameter PFH; the samples were loaded at a constant elongation of the sample ($\Delta=0.5$ mm).

Experimental samples (fragments) of the material (Fig. 1), which were separated from the «T» type fire hose with a diameter of $d=77$ mm, had the following dimensions:

– test length $l=75$ mm;
– width $b=100$ mm;
– the thickness of the outer fabric frame $\delta_f=1.2$ mm;
– the thickness of the inner rubber layer $\delta_w=1.5$ mm.

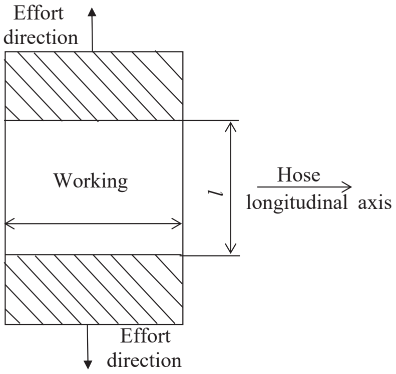

Fig. 1. Test sample of a fire hose material

To check their repeatability, each experiment was conducted 9 times. The samples were separated from different sections, different hoses, with the following statistical treatment of results.

5. Results of the experimental study of the dissipative properties of hoses in the transverse direction taking into consideration their structural elements

5. 1. Results of the experimental study of the dissipative properties of a fabric reinforced frame of hoses

The results from our experiment to study the material of an outer fabric reinforced frame have been statistically treated: they are given in Table 1.

Table 1

Results from the experimental tests of the material of the outer fabric reinforced frame

Deformation, mm	Load, *N*							
	Cycle 1		Cycle 2		Cycle 3		Cycle 4–7	
	L	*U*	*L*	*U*	*L*	*U*	*L*	*U*
0	0	–	–	–	–	–	–	–
0.5	456	–	–	–	–	–	–	–
1.0	876	–	–	–	–	–	–	–
1.5	1,224	0	0	–	–	–	–	–
2.0	1,440	192	204	0	0	–	–	–
2.5	1,848	600	744	96	168	0	0	–
3.0	2,136	768	1,332	408	684	408	408	0
3.5	2,400	1,440	2,040	960	1,104	768	864	528
4.0	2,760	1,560	2,388	1,200	1,752	1,080	1,344	1,128
4.5	3,192	1,968	3,120	1,680	2,400	1,680	2,040	1,800
5.0	3,420	2,880	3,360	2,208	3,120	2,304	2,880	2,160
5.5	3,698	3,240	3,600	2,904	3,456	3,096	3,240	2,880
6.0	4,164	4,164	3,864	3,864	3,720	3,720	3,600	3,600

The results from the experimental study of the fabric reinforced frame of pressure fire hoses (Table 1) have been approximated by the relevant trends: their charts are shown in Fig. 2–5.

The charts in Fig. 3 correspond to the polynomial trends of cycle 3 during the loading-unloading the PFH material fragments.

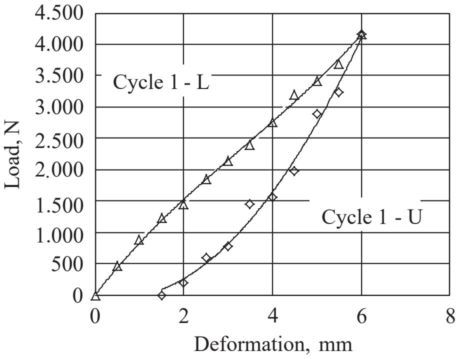

Fig. 2. Deformation curve of the reinforced frame sample. Cycle 1: *L* — loading; *U* — unloading

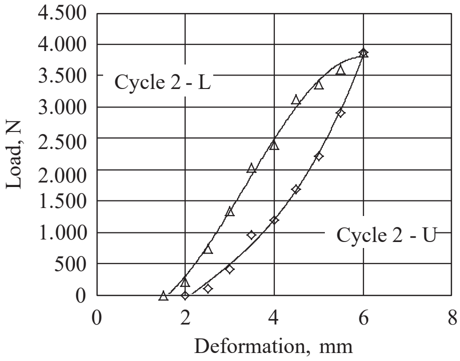

Fig. 3. Deformation curve of the reinforced frame sample. Cycle 2: *L* — loading; *U* — unloading

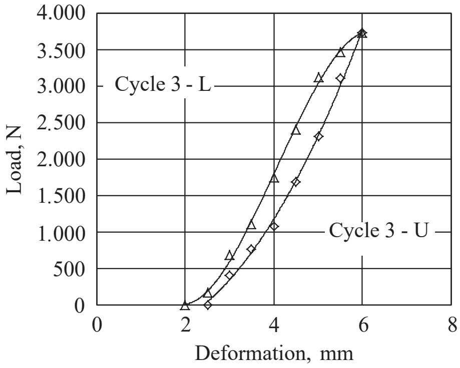

Fig. 4. Deformation curve of the reinforced frame sample. Cycle 3: *L* – loading; *U* – unloading

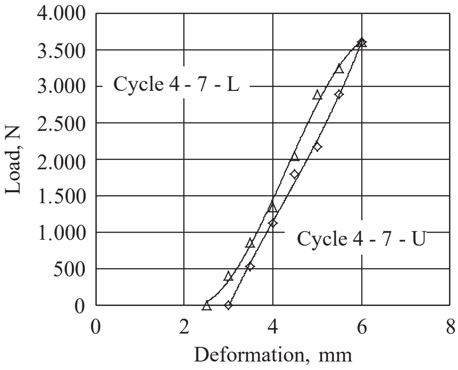

Fig. 5. Deformation curve of the reinforced frame sample. Cycles 4–7: *L* – loading; *U* – unloading

The resulting dependences were approximated with the trend line by using the Microsoft Excel 2007 tabular processor. The types of trend lines were chosen on the basis of the calculated value of the determination coefficient, which characterizes the degree of proximity of the specified lines to the source data.

The possible types of trend lines considered were polynomial, exponential, linear, logarithmic, and power. Thus, for the linear and logarithmic trend lines, the determination coefficient ranged from 0.5315 to 0.9264 for all test cycles; for the exponential and power trend lines, the determination coefficient ranged from 0.83535 to 0.9664. The highest value approaching unity was obtained for the polynomial trend line.

The resulting trend lines describe the corresponding equations that are given in Table 2.

Equation (1) is used to determine the energy (A_D) that accumulates in a sample:

$$A_D = A_L - A_U = \int_{\Delta\ell_{LI}}^{\Delta\ell_{LF}} F_L(\Delta\ell)\,\mathrm{d}(\Delta\ell) - \int_{\Delta\ell_{UF}}^{\Delta\ell_{UI}} F_P(\Delta\ell)\,\mathrm{d}(\Delta\ell), \qquad (1)$$

where $F_L(\ell)$ is the equation of the applied force dependence on sample deformation under loading; $F_U(\Delta\ell)$ is the equation of the applied force dependence on sample deformation under unloading; $\Delta\ell_{LI}$ $(\Delta\ell_{LF})$ is the lower (upper) integration limit corresponding to the initial (final) loading point; $\Delta\ell_{UI}$ $(\Delta\ell_{UF})$ is the lower (upper) integration limit corresponding to the initial (final) unloading point.

The energy (A_D) corresponds to the dissipative properties of the hose material determined by the area of the hysteresis loop as the difference between work spent on loading (A_L) and subsequent unloading (A_U) of the sample. Equation (2) determines the dissipation coefficient (β):

$$\beta = \frac{A_D}{A_L}. \qquad (2)$$

The results of the corresponding calculations are given in Table 3.

Table 2

Regression equations and degree of reliability of the reinforced frame material's processes

Cycle No.	The equation of the operating load (y) dependent on deformation (x)	Degree of reliability
1-*L*	$y = 8.8596x^3 - 88.167x^2 + 901.6x$	$R^2 = 0.9984$
1-*U*	$y = -1.3092x^3 + 148.59x^2 - 163.34x$	$R^2 = 0.99$
2-*L*	$y = -56.597x^3 + 570.35x^2 - 745.21x - 39.345$	$R^2 = 0.9961$
2-*U*	$y = 30.707x^3 - 197.99x^2 + 959.41x - 1439.2$	$R^2 = 0.9964$
3-*L*	$y = -96.081x^3 + 1172.4x^2 - 3453.5x + 2995$	$R^2 = 0.9986$
3-*U*	$y = 0.9697x^3 + 143.06x^2 - 206.84x - 351.48$	$R^2 = 0.9976$
4–7-*L*	$y = -104.24x^3 + 1345.7x^2 - 4450.7x + 4387$	$R^2 = 0.9966$
4–7-*U*	$y = 48x^3 - 603.43x^2 + 3612x - 6725.1$	$R^2 = 0.9974$

Table 3

Results from calculating the experimental tests of the material of an outer fabric reinforced frame

Characteristic, designation, dimensionality	Cycle 1	Cycle 2	Cycle 3	Cycles 4–7
Energy at loading, A_L, J	12.76	9.4	7.26	6.29
Energy at unloading, A_U, J	7.41	5.69	5.55	5.15
Dissipation energy, A_D, J	5.35	3.71	1.71	1.14
Coefficient of dissipation, β	0.42	0.4	0.24	0.18

Fig. 6 shows the dependence of change in the dissipative properties of the material of an outer reinforcing fabric frame of the «T» type PFH with an inner diameter of 77 mm during the consecutive deformation cycles on the load mode.

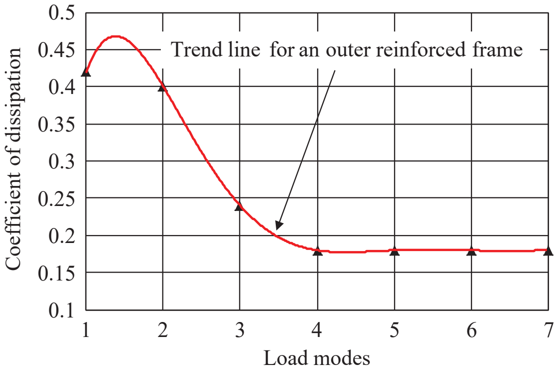

Fig. 6. Dependence of the dissipative properties of the material of an outer reinforcing fabric frame of the «T» type PFH with an inner diameter of 77 mm on a load mode

The resulting dependence was approximated with a polynomial trend line by using the Microsoft Excel 2007 tabular processor. The type of trend line was selected on the basis of the calculated value of the determination coefficient, which characterizes the degree of proximity of the specified line to the source data. The resulting trend line is described by the corresponding equation (3):

$$Y_i = -0.0002X_i^6 + 0.0074X_i^5 - 0.0879X_i^4 + \\ + 0.5246X_i^3 - 1.6118X_i^2 + 2.248X_i - 0.66, \qquad (3)$$

where Y_i is the forecast value of the pressure fire hose dissipation coefficient of the i-th sample; X_i is the load modes of the i-th sample.

The possible types of trend lines considered were exponential, linear, logarithmic, and power. Thus, for the exponential line, the determination coefficient was 0.7739; for linear – 0.749; for logarithmic – 0.8619; for power – the determination coefficient was 0.867. Accordingly, the highest value of 1 was obtained for the polynomial trend line.

5. 2. Results from the experimental study of the dissipative properties of an inner waterproofing rubber layer of fire hoses

A similar procedure, described above, was used to study the dissipative properties of an inner waterproofing rubber layer of the «T» type fire hose with an inner diameter of 77 mm.

The results from the experimental study of the material of an inner waterproofing rubber layer are given in Table 4.

Table 4

Results from the experimental tests of the material of an inner waterproofing rubber layer

Deformation, mm	Load, *N*									
	Cycle 1		Cycle 2		Cycle 3		Cycle 4		Cycles 5–7	
	L	*U*	*L*	*U*	*L*	*U*	*L*	*U*	*L*	*U*
0	0	–	–	–	–	–	–	–	–	–
1.0	24	–	–	–	–	–	–	–	–	–
2.0	48	0	0	–	–	–	–	–	–	–
3.0	96	12	36	0	0	–	–	–	–	–
4.0	108	24	048	24	24	0	0	–	–	–
5.0	120	36	096	36	60	12	36	0	0	0
6.0	132	60	120	72	108	24	72	12	24	12
7.0	168	84	180	84	132	60	84	36	36	24
8.0	192	120	204	132	192	96	132	48	60	36
9.0	204	168	216	168	216	156	168	96	84	48
10.0	252	252	240	240	228	204	204	144	144	72
11.0	–	–	–	–	264	264	228	180	192	108
12.0	–	–	–	–	–	–	240	216	216	156
13.0	–	–	–	–	–	–	272	272	252	204
14.0	–	–	–	–	–	–	–	–	288	288

For the next study, the experimental results from testing a fragment of the material of an inner waterproofing rubber layer are approximated by Microsoft Excel 2007 software (Fig. 7–11) with appropriate polynomials by determining the equations of their trends for the subsequent mathematical treatment.

Fig. 8 shows the polynomial trends of cycle 2 when loading-unloading the PFH material fragments.

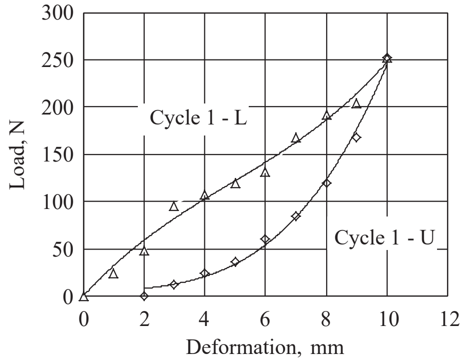

Fig. 7. Deformation curve of the waterproofing layer sample. Cycle 1: *L* — loading; *U* — unloading

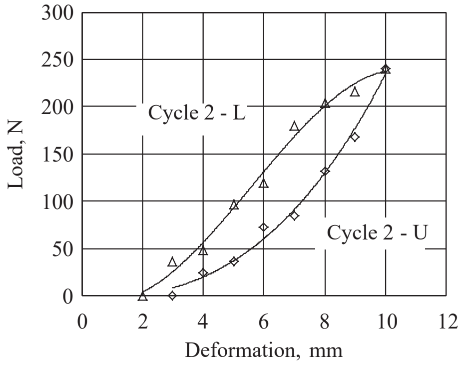

Fig. 8. Deformation curve of the waterproofing layer sample. Cycle 2: *L* — loading; *U* — unloading

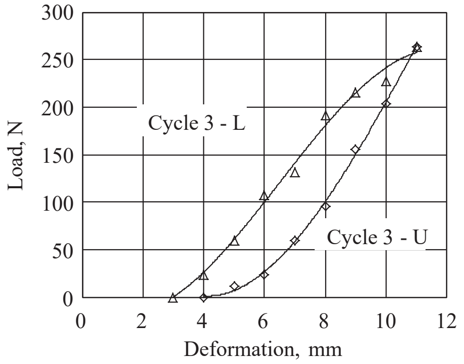

Fig. 9. Deformation curve of the waterproofing layer sample. Cycle 3: *L* — loading; *U* — unloading

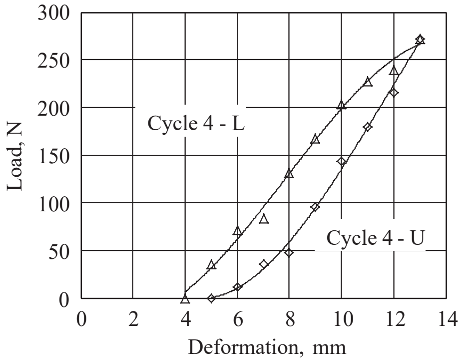

Fig. 10. Deformation curve of the waterproofing layer sample. Cycle 4: *L* — loading; *U* — unloading

Fig. 10 shows the polynomial trends of cycle 4 when loading-unloading the PFH material fragments.

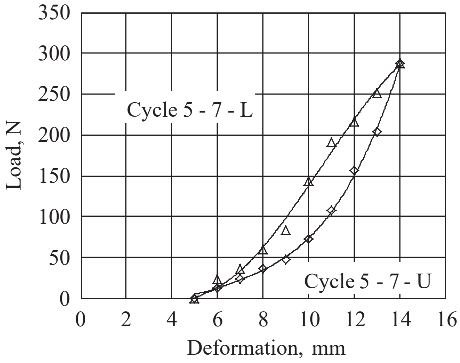

Fig. 11. Deformation curve of the waterproofing layer sample. Cycles 1–5: *L* – loading; *U* – unloading

The resulting trend lines (Fig. 7–11) describe the corresponding equations that are given in Table 5.

According to equations (1) and (2), we determine the energy of loading, unloading, dissipation, as well as the dimensionless dissipation coefficient. The calculation results are given in Table 6.

Table 5

Regression equations and the degree of reliability of waterproofing layer material's processes

Cycle No.	The equation of the applied load (y) dependent on deformation (x)	Degree of reliability
1-*L*	$y=0.2199x^3-3.2309x^2+35.072x$	$R^2=0.9988$
1-*U*	$y=0.3278x^3-1.3643x^2+5.4036x$	$R^2=0.9954$
2-*L*	$y=-0.571x^3+9.5979x^2-15.167x$	$R^2=0.9908$
2-*U*	$y=0.1308x^3+1.2572x^2-2.2097x$	$R^2=0.9914$
3-*L*	$y=-0.5285x^3+10.311x^2-26.099x$	$R^2=0.9928$
3-*U*	$y=-0.3636x^3+12.61x^2-85.857x+166.75$	$R^2=0.9986$
4-*L*	$y=-0.3148x^3+7.4309x^2-22.938x$	$R^2=0.9938$
4-*U*	$y=-0.2997x^3+10.58x^2-79.354x+170.61$	$R^2=0.9958$
5–7-*L*	$y=-0.4289x^3+13.587x^2-102.15x+230.26$	$R^2=0.9939$
5–7-*U*	$y=0.4406E^3-8.5105x^2+65.273x-168.32$	$R^2=0.999$

Table 6

Results from calculating the experimental tests of a waterproofing layer's material

Characteristic, designation, dimensionality	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycles 5–7
Energy at loading, A_L, J	1.23	1.02	1.082	1.302	1.225
Energy at unloading, A_U, J	0.7	0.632	0.678	0.884	0.837
Dissipation energy, A_D, J	0.6	0.388	0.404	0.436	0.388
Coefficient of dissipation, β	0.49	0.38	0.373	0.335	0.316

Fig. 12 shows the dependence of change in the dissipative properties of the material of an inner waterproofing rubber layer of the «T» type PFH with an inner diameter of 77 mm during the sequential deformation cycles on a load mode.

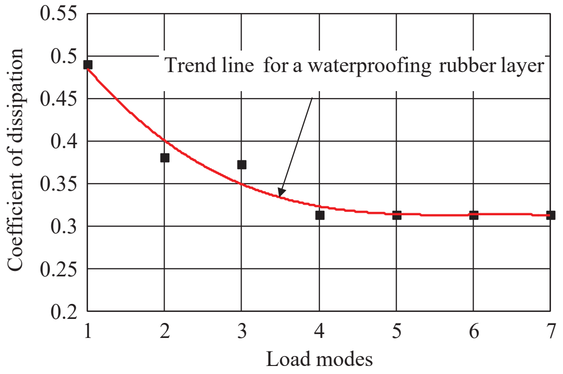

Fig. 12. Dependence of the dissipative properties of the material of an inner waterproofing rubber layer of the «T» type PFH with an inner diameter of 77 mm on a load mode

The resulting dependence was approximated with a polynomial trend line by using the Microsoft Excel 2007 tabular processor. The type of trend line was selected on the basis of the calculated value of the determination coefficient, which characterizes the degree of proximity of the specified line to the source data. The resulting trend line is described by the corresponding equation (4):

$$y=-0.0014X_i^3+0.0251X_i^2-0.15X_i+0.6107, \qquad (4)$$

where Y_i is the predictive value of the dissipation coefficient for an inner waterproofing rubber layer of the *i*-th sample; X_i is the load modes of the *i*-th sample.

The possible types of trend lines considered were exponential, linear, logarithmic, and power. Thus, for the exponential line, the determination coefficient was 0.7481; for linear – 0.7161; for logarithmic – 0.9015; for power, the coefficient of determination was 0.914. Accordingly, the highest value of 0.96 was obtained for the polynomial trend line.

The overall results of our experiment on stretching the material of a fire hose with an inner diameter of 77 mm in the transverse direction, taking into consideration its structural elements, are given in Table 7.

Table 7

Summary table of the results from an experimental study into some mechanical properties of a fire hose

Characteristic, designation, dimensionality	Cycle 1	Cycle 2	Cycle 3	Cycles 4–7
Outer fabric reinforced frame				
Maximal load, F_{max}, *N*	4,164	3,864	3,720	3,600
Maximal deformation, $\Delta\ell^{max}$, mm	6.0	4.5	4.0	3.5
Maximal relative deformation, ε^{max}, %	8.0	6.0	5.3	4.7
Residual deformation, $\Delta\ell^{res}$, mm	1.5	0.5	0.5	0
Coefficient of dissipation, β_f^Y	0.42	0.4	0.24	0.18
Inner waterproofing rubber layer				
Maximal load, F_{max}, *N*	252	240	264	288
Maximal deformation, $\Delta\ell^{max}$, mm	10	8	8	9
Maximal relative deformation, ε^{max}, %	13.0	10.7	10.7	12.0
Residual deformation, $\Delta\ell^{res}$, mm	2	1	1	0
Coefficient of dissipation, β_w^Y	0.49	0.38	0.373	0.316

Table 7 gives the maximum load, maximum deformation, maximum relative deformation, residual deformation, and a dissipation coefficient for the hose material.

5. Discussion of results of studying the elastic and dissipative properties of pressure fire hoses

The result of our series of experimental studies to determine dissipative properties when stretching the material of the «T» type PFH with an inner diameter of 77 mm has established that the significant initial hysteresis of the fragment of both the outer reinforcing fabric frame and the waterproofing rubber layer of the fire hose (Fig. 2–5, 7–11), during repeated tests (cycles 3÷7), is significantly reduced. That, together with the reduction of residual deformations and the stabilization of elastic properties (Table 7), brings the behavior of the hose material in the transverse direction closer to the elastic one. With a maximum deformation of the hose fragments within 3.5÷10 % during the first and second test cycles, the dissipative characteristics changed significantly and only then their stabilization took place under the final modes (Table 7).

Comparing the earlier reported results [16] with our findings allows us to argue that, first, the hoses are structurally the same. Second, with an increase in the diameter of the hose, the thickness of the PFH material increases, namely, both the thickness of the reinforced frame and the inner waterproofing rubber layer increases. Third, when analyzing the results from an experimental study in [16], we can draw a conclusion about the orthotropy of the hose material relative to the longitudinal (along the base) and transverse (along the weft) directions. Fourth, to determine the stable indicators, it is necessary to repeat the experiment.

Our experimental study was limited to one type of hose and did not take into consideration its wear. This limitation could be eliminated by investigating a pressure hose with an arbitrary period of use, and by conducting tests involving different types of fire hoses.

Further development of related studies might include experimental analysis of the impact of an artificial defect, the influence of high temperatures on the mechanical properties of the hose material. At the same time, one should consider the different types of hoses with an arbitrary period of their use.

6. Conclusions

1. Our experimental study to determine the dissipative properties of the fabric reinforced frame at stretching in the transverse direction has found that the dissipation coefficient stabilized at the level of 0.18. And the initial dissipation coefficients of the reinforced frame of a fire hose during the first and second test cycles are much greater than 0.4; during repeated tests, cycles 4–7, they decrease. A polynomial equation of the sixth degree (3) has been built, which describes the dependence of change in the dissipative properties of the material of an outer reinforced fabric frame of the «T» type PFH with an inner diameter of 77 mm during the successive deformation cycles on a load mode. The value of approximation reliability is $R^2=1$.

2. Our experimental study to determine the dissipative properties of an inner waterproofing rubber layer at stretching in the transverse direction has established that the dissipation coefficient stabilized at the level of 0.316. And during the first-fourth test cycles, the dissipation coefficients of the waterproofing rubber layer of a fire hose vary significantly from 0.49 to 0.335; during repeated tests (cycles 5–7), they decrease and stabilize. A polynomial equation of the third degree (4) has been built, which describes the dependence of change in the dissipative properties of the material of an inner waterproofing rubber layer of the «T» type PFH with an inner diameter of 77 mm during the successive deformation cycles on a load mode. The value of approximation reliability is $R^2=0.96$.

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