Deformation behavior and resistance to fracture of glass-fabric pipes subjected to complex loading with torque and internal hydrostatic pressure

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Abstract. The results of fracture resistance and deformation behavior of thin-walled glass-plastics pipes subjected to internal hydrostatic pressure and torque at the conditions of complex and separate loading are considered.

As a result of the obtained data comparative analysis, the practical guidelines are stated pointing to the optimal design of tubular constructional products made of reinforced plastics operating at the conditions of internal pressure and torque.

1. Introduction
The widespread use of engineering methods for calculating structures made of composites based on the theories of elasticity of anisotropic body [1] and anisotropic plates and shells [2–4], and taking into account the peculiarities of material properties, brings to the fore a clear understanding of the specificity of the mechanical behavior of the composite at various loading effects taking into account the operating conditions of products [5]. For example, experimentally confirmed regularities of the deformation process under specific conditions can be very useful from the standpoint of the possible control of this process, as well as the correct approach to the choice of material for structures made of reinforced composites, taking into account operating conditions.

For actual operating conditions, tubular structural elements manufactured from reinforced composites, which are among the widely used products made from such materials, are subjected to combined static as well as cyclic loads, namely tension, compression, bending and torsion. In this case, the mode of deformation arising in the material can be reconstructed by using an adequate scheme of static as well as cyclic tensile or compressive forces and torques [6].

The results of the study of fracture resistance subjected to complex tensile loading and torsion of tubular elements from organic plastics, as well as from fiberglass, obtained by the method of cross-reel at axisymmetric angles of $\varphi = \pm 45^\circ$, are known from [7].

According to the data of this work, regardless of the sequence of axial tensile force or torque application and the level of the force factor remaining constant during the test applied at the first stage, there is a decrease in the resistance to fracture of organic plastics pipes compared to the limit of their respective strengths.
Practically similar to the above-mentioned phenomenon was recorded in the overwhelming majority of cases of identical tests carried out on fiberglass pipes. The only exception is the case of a slight increase to fracture resistance for the torsion (approximately 8% compared to the ultimate torsional strength) of pipes loaded at the first test stage with a tensile force corresponding to 0.4 part of their tensile strength subjected to axial tension.

According to the data of papers [8, 9], with sequential application of torque and axial tensile force, if the tension that is left constant during the test is applied permanently, in some cases (depending on the magnitude of the tensile force), there is a significant increase to fracture resistance for torsion (more than 30%) compared with the strength for a simple torsion of fiberglass fabric tubular elements with the base, directed along their axis ($\phi = 0^\circ$). For the case of the changing of the application sequence of the mentioned loading factors, there is a weak tendency to increase the resistance to destruction of these pipes subjected to tension, depending on the value of the constant torque previously applied to them.

This paper is considered the issue of deformation behavior and resistance to fracture of tubular elements manufactured from the laminated glass-fabric subjected to complex loading conditions, for the separate and combined effects of internal hydrostatic pressure (tension in the circumferential direction) and torque, taking into account the sequence of their application.

2. Experimental part

Glass-fabric pipes with an internal diameter of 38 mm, a wall thickness of 2.25 mm and a length of 285 mm were used as the initial elements, test pieces were obtained from ones by grinding (figure 1). The external diameter and length of the working part of the experimental tubular pieces are 39.7 mm and 60 mm, respectively.

The original glass-fabric pipes were manufactured by the method of warping glass fabric pre-impregnated with modified epoxy resin on a metal mandrel and followed by hot pressing on the side surface in special forms [10]. The linen plaiting glass fabric was used with the main overlap [11] of the type T-23 (TU 6-11-231-76) with a density (number of threads per 1 cm$^2$ of fabric) 36 : 20 (base : weft) produced by Sevan plant “Electroglass insulation” (Republic of Armenia). The magnitude of the glass fabric reinforcement $\mu$ is equal to 0.45 ($\mu_{\text{base}} = 0.29$, $\mu_{\text{weft}} = 0.16$). The direction of the glass fabric base is coincided with the direction of the longitudinal axis of the tubular test pieces ($\phi = 0^\circ$).

It should be noted that the experimental part of the considered studies was carried out 30 years after the manufacture of initial glass tubular elements.
Below is a summary of the research methodology.

Initially, the strength limits (ultimate strength) in the circumferential direction ($\sigma_{\theta\theta}^{\text{ult}} = 458.2 \text{ MPa}$) and for the simple torsion ($\tau_{\theta z}^{\text{ult}} = 36.2 \text{ MPa}$) were determined on one part of total number of tubular test pieces by the random sampling.

Another part of experimental twin test pieces was loaded by internal hydrostatic pressure to a certain level (corresponding to $0.4, 0.6, 0.8\sigma_{\theta\theta}^{\text{ult}}$), and then, keeping this load constant, was brought to destruction by means of a stepwise increase of torque $M_T$.

In addition, tests were carried out on other tubular twin test pieces by the reverse order of application of the indicated loading factors: at the first test stage, the test pieces were loaded with a torque of a certain level (corresponding to $0.4, 0.6, 0.8\tau_{\theta z}^{\text{ult}}$), and then, keeping load constant, they were brought to destruction subjected to the action of stepwise increasing internal hydrostatic pressure.

In order to obtain relatively complete information on the deformation behavior of fiberglass pipes, each load stage increasing during the test corresponded to $0.03–0.08$ and $0.05–0.07$ parts of the fracture resistance of test pieces subjected to torsion and internal hydrostatic pressure, respectively. In view of that it is possible to obtain data on deformations to a stress level corresponding to $0.88–0.90$ parts from its fracture value.

The exposure of test pieces at each step of the load increasing during the test is corresponded only to the time required for recording the deformation. Measurements of deformations were carried out applying a mechanical device designed for simultaneous reading of circumferential, axial and angular deformations (figure 1).

According to the above-mentioned programs, the test duration of each piece carried out was approximately 6–10 minutes depending on the magnitude of the failure stress. In each case, the tests applied data 4, . . . , 6 twin test pieces, the fracture of ones took place at the working area.

3. Results and discussions

Before proceeding to the consideration of obtained experimental results, we note that the data on the resistance to fracture of glass-fabric tubular test pieces subjected to combined complex loading with internal hydrostatic pressure and torque were fully discussed in the paper [12]. Consideration of the deformation behavior of these pipes subjected to internal hydrostatic pressure, taking into account that ones were initially loaded by torque, was carried out in the paper [13]. Aiming to formulate some general conclusions and practical recommendations, the selected data from these papers are brought here.

4. Torsion of glass-plastics pipes

According to the obtained experimental data, the resistance to fracture during torsion (shear) $\tau_{\theta z}^{\text{ult}}$ of glass-fabric pipes subjected to a constant internal hydrostatic pressure corresponding to $0.4\sigma_{\theta\theta}^{\text{ult}}$ is approximately 40% more relative to their ultimate strength at the simple torsion $\tau_{\theta z}^{\text{ult}}$ (at the pure shear, that is $\sigma_{\theta\theta} = 0$).

During torsion, the fracture resistance of pipes pre-loaded with an internal hydrostatic pressure, corresponding to 0.6 and 0.8 parts of $\sigma_{\theta\theta}^{\text{ult}}$, is 22% and 47% less, respectively, compared with the limit of their strength at the simple torsion.

The above-mentioned significant increase of the fracture resistance at shear $\tau_{\theta z}^{\text{ult}}$ of tubular elements manufactured from glass-fabric plastics with reinforcement angle $\varphi = 0^\circ$, preloaded by internal hydrostatic pressure, corresponding to $0.4\sigma_{\theta\theta}^{\text{ult}}$ with respect to their strength at the pure shear $\tau_{\theta z}^{\text{ult}}$, is mainly due to the relatively uniform distribution of stresses in the reinforcing component of the composite material-glass-fabric. And the decrease of the magnitude $\tau_{\theta z}^{\text{ult}}$ that occurred at the above-mentioned high levels of previously applied internal hydrostatic pressure can be explained by the fact that, even before the beginning of the torsion process, the pipes already acquire a certain barrel shape (the convexity of side surface of the pipes), leading to a
decrease in the initial density of the glass fabric (the number of threads per 1 cm² of fabric), and, consequently, to an increase of possible formation of the stress concentration areas at relatively low levels of torque, i.e. $\tau_{\theta z}$.

From the data brought in figure 2, where the graphs of dependence $\gamma_{\theta z}$ on $\tau_{\theta z}$ are presented, it can be noted that for all the cases of the tests considered here, an increase of the tangential stress $\tau_{\theta z}$ magnitude leads to an increase with a significant rate of shear strains $\gamma_{\theta z}$. The most probably, the shear creep of glass-fabric pipes developing at the process of their loading by stepwise increasing torque (last 6–10 minutes as was noted above), can have a significant role in such deformation behavior.

The resistance to deformation for the shear of glass-fabric pipes subjected to torsion under conditions $\sigma_{\theta \theta} = 0.4\sigma_{\theta \theta}^{ult}$ = const at low stress magnitudes is significantly greater than one of pipes subjected to simple torsion (figure 2). However, the noted difference is gradually obliterated in the process of $\tau_{\theta z}$ further increase.

For cases of the previously applied internal hydrostatic pressure high levels (corresponding to 0.6 and 0.8$\sigma_{\theta \theta}^{ult}$), there is a significant decrease in the resistance to deformation of glass-fabric pipes subjected to torsion, as well as the straightening of the dependency curves between $\tau_{\theta z}$ and $\gamma_{\theta z}$ (figure 2). At the same time, these phenomena turn out to be more expressive, the higher the stress $\sigma_{\theta \theta}$ magnitude in the circumferential direction.

The observed significant decrease in the resistance to shear deformation of glass-fabric pipes preloaded with internal hydrostatic pressure of high levels and then subjected to step-by-step torsion is mainly due to the fact that, as already noted, before the beginning of the torsion process there is a decrease in the initial density of the reinforcing composite glass-fabric leading to an increase of the pipes deformability at torsion. The most probably, the above-mentioned straightening of dependency curves between $\tau_{\theta z}$ and $\gamma_{\theta z}$ is a consequence of the creep resistance increase at shear observed at the high levels of constant internal hydrostatic pressure previously applied to the pipes [14].

The idea relating to the deformation behavior in the circumferential direction of glass-fabric pipes subjected to torsion under the conditions of constantly acting internal hydrostatic pressure (dependence graphs $\varepsilon_{\theta \theta}$ on $\tau_{\theta z}$) can be obtained from the data brought in figure 3.

According to these data, at the simple torsion ($\sigma_{\theta \theta} = 0$) during the process of a torque stepwise increase (last 6–10 minutes already noted), there is a monotonous decrease of deformations in the
Figure 3. Curves of deformation in the circumferential direction of glass-plastics pipes subjected to torsion under the conditions of constantly acting internal hydrostatic pressure $\sigma_\theta$ or its absence

circumferential direction (narrowing) of pipes with a variable changing speed. This phenomenon turns out to be more intense when a torque acts on a tubular test piece that exceeds 0.5 part of its limiting value that is likely due to the intensification of the shear creep process of pipes.

The above-described deformation behavior in the circumferential direction, detected by simple torsion of tubular elements made of glass-fabric reinforced plastics with an angle of reinforcement $\varphi = 0^\circ$, will be called the effect of physical non-linearity of the composite material in the following presentation. It is assumed that a similar effect can be observed for the cases of other angles of the reinforcement of the fabric plastics thin-walled tubular elements at their simple torsion.

For the case of complex loading, a stepwise increase of torque leads to an increase of deformations in the circumferential direction (expansion) of glass-fabric pipes with a substantially increasing speed, and even more significant, the higher the level of internal hydrostatic pressure $\sigma_\theta$ previously applied to the pipes (figure 3). This phenomenon seems to be related to the fact that in addition to the initial decrease of the density of the glass fabric mating due to loading by the internal pressure at the first stage, at the torsion stage takes place the distortion of the initial direction of the glass-fiber reinforcing glass-fabric composite, thereby intensifying the process of pipe compliance with respect to expansion. It is assumed that the more significant is the level of indicated intensification, the higher the level of internal hydrostatic pressure previously applied to the pipes.

Let us discuss the deformation behavior in the direction of the axis of the glass-fabric pipes tested according to the program considered here (graphs of dependence $\varepsilon_{zz}$ on $\tau_{\theta z}$, figure 4).

At the simple torsion ($\sigma_\theta = 0$), during the process of tangential stress $\tau_{\theta z}$ stepwise increase, the shortening of tubular elements manufactured from the glass-fabric plastics with reinforcement angle $\varphi = 0^\circ$ is observed. That is mainly a consequence of the above-mentioned effect of physical non-linearity of the composite material (see figure 3).

The nature of the behavior of axial (longitudinal) deformations of glass-fabric pipes subjected to torsion under the conditions of constantly acting internal hydrostatic pressure of various levels turns out to be different. Here, in the process of step-by-step increase of the torque, at the beginning of this process pipes have experienced elongation and then shortening (figure 4). Meanwhile, the tangential stress $\tau_{\theta z}$ magnitude, at which a change in the direction of deformation occurs in the longitudinal direction, depends significantly on the value of the constant internal...
Figure 4. Curves of deformation in the longitudinal direction of glass-plastics pipes subjected to torsion under the conditions of permanent internal hydrostatic pressure $\sigma_{\theta\theta}$ or its absence

hydrostatic pressure $\sigma_{\theta\theta}$ previously applied to the pipes.

For the case of torsion, the maximum value of elongation strain obtained by pipes for $\sigma_{\theta\theta} = 0.4\sigma_{\theta\theta}^{\text{ult}} = \text{const}$ is approximately acquired $\varepsilon_{zz} = 0.2 \times 10^{-3}$ and observed at the value of tangential stress $\tau_{\theta z} = 11.4\text{ MPa}$ (for this case $\tau_{\theta z}/\tau_{\theta z}^{\text{ult}} \approx 0.23$). With a further increase of stress until the value of 44.7 MPa, the shortening of pipes occurs, the value of one reaches up to $\varepsilon_{zz} \approx 1.72 \times 10^{-3}$.

For cases of torsion, the maximum value of elongation strain obtained by pipes for $\sigma_{\theta\theta} = 0.6\sigma_{\theta\theta}^{\text{ult}} = \text{const}$ and $\sigma_{\theta\theta} = 0.8\sigma_{\theta\theta}^{\text{ult}} = \text{const}$ is approximately acquired $\varepsilon_{zz} = 0.11 \times 10^{-3}$ and $\varepsilon_{zz} = 0.04 \times 10^{-3}$, correspondingly, and observed at the value of tangential stress $\tau_{\theta z} = 6.4\text{ MPa}$ ($\tau_{\theta z}/\tau_{\theta z}^{\text{ult}} \approx 0.23$) and $\tau_{\theta z} = 3.2\text{ MPa}$ ($\tau_{\theta z}/\tau_{\theta z}^{\text{ult}} \approx 0.17$). With a further increase of stress $\tau_{\theta z}$ until the value of 25.6 MPa (for the underlined first case) and 17.6 MPa (for the second one), the monotonous shortening of pipes occurs, the value of ones reaches up to $\varepsilon_{zz} \approx 0.7 \times 10^{-3}$ and $\varepsilon_{zz} \approx 0.42 \times 10^{-3}$, correspondingly.

The deformation behavior of glass-fabric pipes subjected to torsion in the axial direction, preloaded with internal hydrostatic pressure, can be given the following interpretation.

The deformations in the indicated direction are mainly composed of the following components developing simultaneously during the process of pipes torsion:

- elongation is mainly the result of a straightening process with a decaying rate of technologically regularly curved fibers of the base of glass fabric due to pre-loading of pipes with constant internal hydrostatic pressure;
- shortening is mainly due to the process of distortion the initial direction of the fibers of the glass fabric in view of increasing torque.

The algebraic ratio of the noted items may be due to the deformation behavior in the axial direction of thin-walled tubular elements of fabric glass-plastics with reinforcement angle $\varphi = 0^\circ$, subjected to complex loading according to the program considered here. It is assumed that the greater the magnitude of the above-mentioned elongation taking place, as already noted by straightening the regularly curved fibers of the glass fabric, will be, the less the preliminary bulge of the side surface of the pipes will be at the moment of their loading by the step-by-step torque (i.e. the lower the level of internal hydrostatic pressure applied to the pipes at the first loading stage).
5. Internal hydrostatic pressure of glass-plastic pipes

The main results of the study of the deformation behavior and fracture resistance of fabric glass-plastics pipes with reinforcement angle \( \varphi = 0^\circ \) subjected to internal hydrostatic pressure and torque of various levels, are brought and discussed here.

Experiments have shown that the effect of a pre-applied torque corresponding to \( 0.4\sigma_{\theta z}^{\text{ult}} \) on the fracture resistance of tubular test pieces subjected to internal pressure (the limit of the ultimate strength of pipes in the circumferential direction \( \sigma_{\theta \theta}^{\text{ult}} \)) is insignificant. It was also found that during the loading of the test piece, at the first stage of the test, with a torque corresponding to 0.6 and 0.8\( \sigma_{\theta z}^{\text{ult}} \), there is a decrease of value \( \sigma_{\theta \theta}^{\text{ult}} \) about 24% and 28%, respectively.

The marked drop of the resistance to fracture \( \sigma_{\theta \theta}^{\text{ult}} \) of glass-plastics pipes is mainly due to the uneven development of stresses into the reinforcing component of the composite lasting during the increase of the internal hydrostatic pressure, thereby leading to the formation of stress concentration areas at low stress \( \sigma_{\theta \theta} \) magnitudes. Here it is assumed that, due to the pre-loading of pipes by a torque, the initial interposition of the fibers of the glass-fabric knitting — reinforcing component of the composite is distorted and this phenomenon is continued during the process of step-by-step increasing of the internal hydrostatic pressure into the pipes.

It was defined by carried measurements that for the test cases considered here, the relationship between the stresses \( \sigma_{\theta \theta} \) in the circumferential direction and the strains \( \varepsilon_{\theta \theta} \) of the glass-fabric pipes in the same direction has rectilinear behavior explained by the structural feature of the weft fibers of the plain weave type glass-fabric [11].

It was also found that at the same stress \( \sigma_{\theta \theta} \) value, the magnitudes of the strains \( \varepsilon_{\theta \theta} \) of the pipes tested for \( \tau_{\theta z} = 0 \) and \( \tau_{\theta z} = 0.4\sigma_{\theta z}^{\text{ult}} = \text{const} \) differ little from each other. A similar picture is observed for the cases of testing pipes at the conditions \( \tau_{\theta z} = 0.6\sigma_{\theta z}^{\text{ult}} = \text{const} \) and \( \tau_{\theta z} = 0.8\sigma_{\theta z}^{\text{ult}} = \text{const} \). Meanwhile, in the latter cases of tests with the same value of stress \( \sigma_{\theta \theta} \), the magnitudes of \( \varepsilon_{\theta \theta} \) turn out to be 30–35% higher compared to the magnitudes of the similar strain obtained in the above-mentioned two cases of glass-plastic pipes testing.

Let’s consider the nature of the glass-fabric pipes deformation for the shear subjected to the step-by-step loading by the internal hydrostatic pressure, initially loaded by the torque \( M_T \) of various levels.

Based on research, for the case when \( M_T = 0 \), the shear strains \( \gamma_{\theta z} \) do not appear into experimental tubular test pieces loaded by the internal hydrostatic pressure.

Research also showed that for tubular test pieces preloaded by the torque \( M_T \) of various levels with increasing internal hydrostatic pressure, the appearance and development of shear strains \( \gamma_{\theta z} \) with a significantly increasing rate is observed. In this case, the more intense is this phenomenon, the larger is the value of \( M_T \). The experimentally established last pattern can serve as a justification for the statement that the appearance and development of the shear strains of glass-fabric pipes subjected to constant torque during the process of internal pressure step-by-step increase is caused mainly by shear strains of creep that appear and develop during this process. [15]. At the same time, the comparison of the mentioned and corresponding data brought in the paper [15] indicates that the step-by-step increase of the internal hydrostatic pressure can significantly increase the pipe compliance with respect to shear creep deformations.

Tested on the program considered here, the graphical illustration of the deformation behavior in the direction of the glass-fabric pipes axis can be obtained from the curves brought in figure 5.

It can be noted from the data of this figure 5, the process of deformation in the axial (longitudinal) direction of glass-fabric pipes loaded only with internal hydrostatic pressure (i.e. for \( \tau_{\theta z} = 0 \)) has the following character: as the load increases step-by-step (stress \( \sigma_{\theta \theta} \) in the circumferential direction), the first pipes are subjected to shortening and then — elongation. Almost the same type of deformation in the longitudinal direction is also observed in tubular test pieces subjected to internal pressure at the condition of a constantly acting torque, corresponding
Figure 5. Curves of deformation in the longitudinal direction of glass-fabric pipes subjected to internal hydrostatic pressure at the conditions of constant acting torque or its absence

to $\tau_{\theta z} = 0.6\tau_{\theta z}^{\text{ult}}$ and $\tau_{\theta z} = 0.8\tau_{\theta z}^{\text{ult}}$ (figure 5). The boundary of stresses $\sigma_{\theta\theta}$, at ones the transition from the initial shortening to a further elongation occurs, of the glass-fabric pipes turns out to be greatest, for the case, they are only loaded by the internal hydrostatic pressure. For tubular test pieces in the case of complex loading (for $\tau_{\theta z} = 0.6\tau_{\theta z}^{\text{ult}}$ and $\tau_{\theta z} = 0.8\tau_{\theta z}^{\text{ult}}$), the lower is the indicated stress boundary, the greater the torque value that the tubular test pieces are preloaded.

The monotonic elongation of glass-plastic pipes is observed at the step-by-step loading by the internal hydrostatic pressure subjected to the torque, corresponding to $0.8\tau_{\theta z}^{\text{ult}}$ (figure 5).

The above-mentioned behavior of the longitudinal deformations of fabric glass-plastic pipes with the base, directed along the axis, can be given the following explanation.

Deformations in the longitudinal direction of glass-fabric pipes, subjected to the internal hydrostatic pressure only, mainly consist of the components arising from the phenomena simultaneously developing as internal pressure increases: an increase in the convexity measure of the side surface of the pipes (getting of a barrel-shaped pipe) and the straightening technologically regularly curved base fibers of glass-fabric knitting — reinforcing component of the glass-plastics. Meanwhile, at the beginning of the process of the internal hydrostatic pressure increasing, the getting of barrel-shaped pipes takes a dominant role in the deformation behavior in the longitudinal direction leading to their shortening. The further increasing of the hydrostatic pressure, the straightening factor of technologically regularly curved base fibers of the glass-fabric knitting begin to increasingly prevail over the factor of barrel-shaped pipes, as a result of one, the pipes elongation process appear and develop with increasing speed.

In the case of considered here, the effect of complex loading is on the behavior of deformations in the longitudinal direction of glass-plastic pipes, besides the above-mentioned factors, the shear creep arising in the process of step-by-step increase of the internal hydrostatic pressure, lasting 6–10 min, as it was already noted, can take place significantly. The nature of deformation in the longitudinal direction (implying a preliminary shortening and subsequent elongation or only elongation) of glass-fabric pipes with the reinforcement angle $\varphi = 0^\circ$, subjected to the complex loading with the torque and internal hydrostatic pressure, if torsion is applied initially is determines by the ratio of the above-mentioned summand deformations values.

Special attention should be paid to the nature of deformation in the longitudinal direction of tubular elements appearing in the process of loading ones only by internal hydrostatic pressure. In this case, as it was already noted, during the increasing of the hydrostatic pressure, pipes
from the beginning experience shortening and then elongation. The change of the deformation direction is occurred at the level of the circumferential stress \( \sigma_{\theta\theta} \) of 0.45 part of the tensile strength \( \sigma_{\theta\theta}^{\text{ult}} \) of pipes in the circumferential direction. This indicates that the conducting longitudinal deformations with a cyclically varying direction of deformation, in addition to cyclic circumferential deformations, are appearing for the case of operation of the above-mentioned tubular elements at the conditions of re-cyclic (pulsating) internal hydrostatic pressure.

Probably, the observed effect of shortening-elongation of thin-walled pipes with a pulsating internal pressure is inherent to the analogous effects observed in natural thin-walled vessels experiencing an internal pulsating pressure.

**Conclusions**

1. The residual stresses formed in the manufacturing process and the uncovenanted shear stresses arising during operation cannot affect practically the carrying capacity of tubular elements made of fabric plastics with a base directed along the axis (reinforcement angle \( \varphi = 0^\circ \)) operating under internal hydrostatic pressure, if the sum of these stresses does not exceed 0.4 part of the ultimate strength of the pipes during the simple torsion.

A significant increase in the carrying capacity during the torsion of the same tubular elements made of fabric plastics with a reinforcement angle \( \varphi = 0^\circ \) can be achieved by preloading them with an internal hydrostatic pressure of 0.4 part of its limiting value at the uniaxial internal pressure.

2. The tubular elements of fabric plastics with a base directed along the axis operating in the corresponding assemblies of mechanisms and machines at the conditions of simple (only) torsion (for example, the shafts of cardan gears of motor vehicles and fast-rotating rotors) can be narrowed that one is leading to the shortening of pipes.

In addition to the circumferential deformations, the accompanying longitudinal deformations may also occur for the case of operation at the conditions of only internal hydrostatic pressure action in tubular products made of fabric plastics with \( \varphi = 0^\circ \) (for example, vessels made of composites or reinforced with fabric plastics).

The above-mentioned issue indicates that the occurrence of unforeseen operating conditions cyclically, with an intense frequency, repetitive torques for the first case of operation of tubular products and the pulsating internal hydrostatic pressure for the second case can significantly affect the durability of their reliable operation. This is justified by the fact that the material of the products, and in particular its matrix is the most vulnerable link of the reinforced composites, during operation will be exposed to a cyclically repetitive complex stress state, in some cases alternating. That is known, in most cases, it is the destruction of the matrix, and it is not the destruction of the reinforcing fibers, that is the cause of the premature failure of products made of composites [16].

In order to facilitate the operating conditions of tubular products made of reinforced composites, and thereby ensuring the service life of their reliable functioning, it is necessary to apply appropriate preventive measures.

In particular, for the above-mentioned products from fabric plastics with \( \varphi = 0^\circ \), operating under the influence of cyclically repetitive internal hydrostatic pressure \( p \), it is recommended to put a limit on the value of this pressure, namely, to comply with the condition \( p \leq 0.45p_f \) (\( p_f \) is failure pressure), i.e. to the level of \( p \), at which the products so far are only subject to shortening (see figure 5).

In the case of tubular products subjected to torsion during the operation, it is advisable to take measures aimed to minimizing unintended pulsating torques, in particular, to provide dampeners for damping the torsional vibrations in the corresponding machine units.

Minimizing the negative phenomena leading to the imminent failure of tubular products made of fabric plastics, such as those above-mentioned, can be achieved by a constructive method of
solving the problem. For example, the provision of oriented stiffeners:

- circumferential, providing maximum resistance with respect to the occurrence of deformations in the circumferential direction for products operating under the influence of internal hydrostatic pressure;
- mutually in crisscross manner under angles symmetric to the axis, providing resistance to shear of tubular products operating at the conditions of torsion.

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