Strength analysis of aged polymer composites subjected to tensile loads

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Strength analysis of aged polymer composites subjected to tensile loads

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Abstract. It follows from the obtained data that the change of durability of the getinacks in stretching significantly depends on the pressing pressure value both at the age of 1 year and at the age of 4 years.

According to the data, in the case of samples of the first series, the ageing has not practically affected the durability of getinacks in stretching. In the case of samples of other series, the increase of age from 1 year to 4 years results in an increase of the getinacks durability, in particular, the increase is about 9% for the third series.

Comparing the values of failure tensile stresses given in the handbook of electrotechnics materials [1] with the data obtained by experimental investigation of aged glass textolite (GFRP composite-laminate) with the woven fiber orientation 0° and 90°, one can see a corresponding increase by approximately 25% and 35%.

The test results are approximated and compared with the experimental data. The corresponding figures are plotted on the basis of these data.

1. Introduction
The layered plastics, such as getinacks or textolites, have become more and more applicable in the electrotechnics as technologically convenient materials for the electro-isolation [1]. Depending on the chemical nature of the binding solution, filling, and a manufacturing technology, the layered plastics are suitable for long-term work at temperatures up to 180°C and for short-term work at higher temperatures [1].

The glass textolite (Glass Fibre Reinforced Polimer composite-laminate (GFRP composite-laminate)) is characterized by excellent thermal conductivity, moisture and biological resistance, and high strength, as well as it is lightweight, has good insulating properties, and is non-toxic. Because of its mechanical properties, heat resistance, and resistance to external environments, the glass textolite (GFRP composite–laminate) exceeds the PCB, and the maintenance of products manufactured from the glass textolite in the open air for 20 years is an important factor of production.

The polymer composites such as getinacks and glass textolite (GFRP composite–laminate) are easily liable to machine treatment such as cutting, drilling, turning and grinding, and for this reason, they are widely applied in aviation, metallurgy, oil and gas processing industry, shipbuilding, and in production of hardware and technical equipment of trolley buses and trams. In particular, the getinacks and glass textolite (GFRP composite-laminate) are used for production of items applicable in electrical engineering as structural and insulation materials.
A wide range of papers and books deal with investigation of mechanical properties of composites.

The influence of long-term storage on the mechanical properties of reinforced polymeric plastics was studied in [2]. The strength properties and ageing of sheet fiber glasses under various climatic conditions were studied in [3].

The influence of outer space conditions on parts of constructions subjected to tension, compression, and shear were investigated in [4]. The conditions of ageing both under the laboratory conditions and in the open space are compared.

The dissipative properties of plate reinforced composites cut out of composite at the angles $\varphi = 0^\circ, 5^\circ, 15^\circ, 30^\circ, 45^\circ, 60^\circ,$ and $90^\circ$ to the reinforcement direction were investigated in [5].

The deformation behavior, strength and mechanical properties of unidirectional carbon fiber laminates are considered in [6]. The dissipative properties of the polymeric composites determined as a result of their repeated–static loading with regard to the technological factors and the environment temperature–moisture conditions are known from [7].

The first part of the book [8] reviews the processes and modeling of composite ageing including the physical and chemical ageing of polymeric composites, ageing of glass–ceramic matrix composites, chemical ageing mechanisms, stress corrosion cracking, thermo-oxidative ageing, spectroscopy of ageing composites, modeling physical and accelerated ageing, and ageing of silicon carbide composites. The second part examines the ageing of composites in transport applications including aircraft, vehicles and ships. The third part reviews the ageing of composites in nontransport applications such as implants in medical devices, oil and gas refining, construction, chemical processing, and underwater applications.

In the paper [9], the author analyzes the mechanical properties of plain-weave composites by employing different micromechanical models, and their in-plane and flexural properties are estimated by analytical approaches including the rule of mixtures and one-dimensional composite beam and two-dimensional mosaic models. Expressions for effective material properties are obtained in [9] for one-, two-, and three-ply woven composites.

It is of great interest to study the influence of “age” (ageing) on the mechanical properties of getinacks and glass textolite (GFRP composite-laminate), which are widely used in various branches of engineering.

2. Experimental part

Experimental samples of getinacks (figure 1) as double-sided blades whose sizes satisfy the requirements of GOST (State Standard Specification) 1199-78 were cut out from a sheet of getinacks of thickness 5 mm received by regulated thermo-pressing technology [10] for three different pressure values (1.9, 2.4, and 5.1 MPa).

In all three parties, the sheet getinacks cut out from the sulfate–cellulose paper saturated by the phenol–formaldehyde binding solution were cooled down after polymerization in the switched off furnace to avoid the temperature pressure.

The experimental samples of glass textolite (GFRP composite-laminate) (figure 2) as double-sided blades whose sizes satisfy the requirements of GOST (State Standard Specification) 1199-78 were cut out from a sheet of glass textolite (GFRP composite–laminate) of thickness $\approx 9$ mm at the angles of the woven fiber orientation $0^\circ$ and $90^\circ$.

The glass textolite (GFRP composite–laminate) is a laminate made of glass–cloth saturated by the thermosetting tar. The glass textolite (GFRP composite–laminate) is intended for manufacturing sheets and products for constructional purposes.

According to GOST (State Standard Specification) 25500-82, the getinacks and glass textolite (GFRP composite–laminate) test pieces were stored in horizontal position at a distance of at least 50 mm from the floor. The storage room was closed and the dry indoor air temperature was 20–25°C (the temperature interval stated by State Standard Specification from $-10^\circ$C to $+40^\circ$C).
Figure 1. Experimental double-sided spattle-shaped getinacks sample.

Figure 2. Experimental double-sided spattle-shaped GFRP composite–laminate sample.
The tests were performed by the testing machine ZD 10/90 at the loading speed 5 mm/min.

Experimental researches were carried out in 1 year and 4 years after the manufacturing of getinacks experimental samples, and in approximately 35 years after the manufacturing of glass textolite (GFRP composite–laminate) experimental samples.

During the unidirectional tensile loading, the samples were tested with the loading step $0.1\sigma_u$ ($\sigma_u$ is ultimate strength of samples). The maximal value of the applied loading was $0.9\sigma_u$ and $0.8\sigma_u$ for getinacks and glass textolite (GFRP composite–laminate) experimental samples, respectively. The experimental data were recorded by a clock-type meter. The experimental data are evaluated and curves are plotted (figures 3 and 4).

The experimental data ($\sigma$ and $\varepsilon$) are approximated by the equation

$$\sigma = \alpha \varepsilon + \beta \varepsilon^n,$$
where $\varepsilon$ is the strain value determined from the permanent set value, and $\alpha$, $\beta$, and $n$ are approximation parameters.

3. Results and discussion

The results of testing are given in tables 1 and 2 and in figures 3 and 4. In figure 3 ($a$, $b$, and $c$) and figure 4 ($a$ and $b$), the experimental data are plotted by dotted curves, and the theoretical values are plotted by solid lines.

It follows from the data given in table 1 that the change of durability of getinacks in stretching significantly depends on pressing pressure value both at the age of 1 year and at the age of 4 years. So, for $\tau = 1$ year, the durability of samples of the second series is by 16% greater than the durability of samples of the first series. The durability of samples of the third series is approximately by 20% greater than the durability of samples of the first series (see the table 1).

For $\tau=4$ years, the durability of samples of the second and third series is approximately by 22% and 29% greater than the durability of samples of the first series, respectively.

According to the data given in table 1, in the case of samples of the first series, the ageing has not practically affected the durability of getinacks in stretching. In the case of samples of other series, the increase of the age from 1 year to 4 years results in an increase in the durability.
Table 1. Durability of samples in stretching.

| Series No. | Pressure of pressing, MPa | Age of samples at the time of experiment, year | Durability of samples during the stretching, MPa |
|------------|---------------------------|----------------------------------------------|-----------------------------------------------|
| I          | 1.9                       | 1                                            | 117.3 ± 1.322                                 |
|            |                           | 4                                            | 118.4 ± 1.334                                 |
| II         | 2.4                       | 1                                            | 136.1 ± 14.997                                |
|            |                           | 4                                            | 144.3 ± 15.903                                |
| III        | 5.1                       | 1                                            | 140.4 ± 5.64                                  |
|            |                           | 4                                            | 152.8 ± 5.176                                  |

Table 2. Failure tensile stress.

| Woven fiber orientation | Failure tensile stress, MPa |
|-------------------------|-----------------------------|
|                         | 0°                          | 90°                          |
| GFRP handbook values    | 300                         | 200                          |
| GFRP aged values        | 402                         | 307                          |

of getinacks; in particular, the increase is about 9% for the third series.

It follows from the diagrams in figure 3 that, under the influence of short-term forces, the ageing leads to an increase in the deformability of getinacks. The higher the level of the pressing pressure on the material, the less the deformability of getinacks.

Comparing the failure tensile stress values given in the handbook of electrotechnics materials [1] and obtained by the experimental investigation of aged glass textolite (GFRP composite–laminate) with the woven fiber orientation 0° and 90°, one can see an increase of approximately 25% and 35%, respectively (table 2).

It follows from the diagrams in figure 4 that, under the influence of short-term forces, the ageing leads to an increase in the deformability of getinacks. For glass textolite (GFRP composite–laminate) with the angles of the woven fiber orientation 0° and 90°, the experimental and theoretical curves coincide by 97% (the error is 3%) and 95.55% (the error is 4.45%), respectively.

Conclusions

The constructional elements from getinacks on the basis of sulfate–cellulose paper saturated by a phenol–formaldehyde binding solution should be manufactured by pressing under the pressure at least equal to 5.1 MPa, which ensures smaller deformation changes and the practical independence of the mechanical properties of the age.

The influence of ageing on the mechanical properties of glass textolite (GFRP composite–laminate) subjected to unidirectional tensile loads should be insignificant.

The applied equation allows plotting the theoretical curves close to the curves plotted on the basis of experimental data.

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