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CREEP OF POLYMER COMPOSITE SHEET PILES WITH A POLYURETHANE MATRIX

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Abstract

Introduction. A progressive method for manufacturing building products from polymer composite materials based on reactive oligomers is the pultrusion method, which allows the production of thin-walled products with an arbitrary profile shape, including sheet piles. The scientific and technical literature contains insufficient information on the creep of glass-filled sheet piles with a polyurethane matrix under different levels and durations of bending loads, which complicates the prediction of the durability of these products. Objective is to establish the dependence of the creep modulus of domestic glass-filled sheet piles with a polyurethane matrix on the magnitude and duration of bending load along and across the pultrusion direction. **Methods:** the creep of glass-filled polyurethane sheet piles was studied using a lever-type test bench developed by the authors. **Results:** the influence of stress level (0.2–0.95 $σ_{bend}$) and duration of bending load on the deflection magnitude and creep modulus (GOST 57714–2017) of glass-filled polymer sheet piles with a polyurethane matrix along and across the pultrusion direction was studied. It was shown that no failure of the polyurethane composite sheet pile of grade ShK-200UM occurs within 10,000 hours at stress levels of 0.2 and 0.5 σbend. Failure of 50 % of the composite sheet pile samples with a polyurethane matrix at a stress level of 0.7 σbend occurs after 2,638 and 9,434 hours when tested across and along the pultrusion direction, respectively. By extrapolating the experimental “stress-strain” dependencies, the creep of polyurethane composite sheet piles for a period of up to 50 years was predicted.

Keywords: polyurethane sheet pile; pultrusion; deformation; deflection; creep modulus; stress level.

Introduction

One of the progressive methods for manufacturing building products from polymer composite materials (PCM) is the pultrusion method, based on producing composite profile products by pulling reinforcing glass, basalt, or carbon fibers impregnated with a binder based on reactive oligomers (polyester and epoxy oligomers or polyurethanes) through a heated forming die. This method allows the production of building products with stable strength properties both along the length of the product and across their cross-section. The pultrusion method is used to produce thin-walled products with arbitrary profile shapes (rods, pipes, angles, plates, channels, boxes, etc.). The pultrusion method is widely used for the production of both composite reinforcement (Stelanova et al., 2013; Seleznev et al., 2020; Seleznev et al., 2022) and composite sheet piles (Gritsenko and Nesterov 2015; Kokareva et al., 2015; Nemolochnov, 2019; Donetsky et al., 2017).

In the production of polymer composite sheet piles (PCSP), polyurethanes are preferred as the polymer matrix due to their high strength characteristics, wear resistance, chemical resistance, and good adhesion to fillers, while glass fiber is most often used as the fibrous filler. Compared to metal sheet piles, they have high strength and load-bearing capacity, resistance to various aggressive environments and bacteria, low weight, relatively low cost, and are environmentally friendly (Shanmugam, 2004; Levachev et al., 2019; Nemolochnov et al., 2019; Kornev et al., 2025). Some of the first domestic building products made from polymer composites using the pultrusion method were glass-filled polyurethane sheet piles of grades ShK-150UM and ShK-200UM, which have high performance characteristics (Nemolochnov, 2019; Donetsky et al., 2017; Nemolochnov et al., 2019; Kornev et al., 2025). A wide range of sheet pile profiles allows selecting sheet piles for any soil and structural requirements. Sheet pile walls are most often used (Gritsenko and Nesterov, 2015; Kokareva et al., 2015; Nemolochnov, 2019; Nemolochnov and Levachev, 2016; Levachev et al., 2018):

– for strengthening coastlines, canals, and protecting water bodies;

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– in the construction of port (berths, breakwaters, docks) and hydraulic engineering (dams, locks) structures, collectors, tunnels, and other underground structures;

– for constructing anti-filtration curtains on construction sites and protecting building foundations and bases, strengthening and enclosing excavation pits, trenches, slopes, and inclines;

– in the construction of water collectors and treatment facilities, urban improvement, and the creation of artificial reservoirs;

– for organizing sludge storage and storage facilities for chemically active substances.

Significant disadvantages of polymer composite sheet piles include:

– anisotropic properties of the sheet pile material depending on the direction of the applied load (longitudinal or transverse) and the type of load (tension or compression). This applies to both the strength and deformation characteristics of PCSP;

– brittle nature;

– low creep modulus and, consequently, low sheet pile stiffness leading to high deformability of structures;

– a more complex process of driving the sheet pile into the ground compared to metal sheet piles.

The main physical and mechanical characteristics of polymer sheet piles have been examined in considerable detail by domestic (Kokareva et al., 2015; Donetsky et al., 2017; Nemolochnov et al., 2019; Kornev et al., 2025) and foreign (Shanmugam, 2004; Levachev et al., 2019; Giroux and Shayo, 2003; Shao and Shanmugam, 2004; Ferdous et al., 2018) researchers. However, these publications contain practically no data on the actual load-bearing capacity of domestically produced PCMs and data on the creep of composite sheet piles under different levels and durations of bending loads. This limits the use of composite sheet piles in the construction industry and, in particular, in hydraulic engineering construction. Therefore, the aim of this work was to establish the dependence of the creep modulus of polyurethane glass-filled sheet piles on the magnitude and duration of bending load along and across the pultrusion direction.

Subject, Tasks and Methods

The objects of study were glass-filled PCSPs with a polyurethane matrix of grades ShK-150UM and ShK-200UM, the layout of individual elements of which is shown in Figs. 1 and 2. Samples of glass-filled polyurethane sheet piles obtained by pultrusion were provided by the company "Umatex". The main dimensions and operational characteristics of a single element of the studied sheet piles with a polyurethane matrix are given below:

ShK-150UM / ShK-200UM:
Section width, mm — 600 / 400;
Section height, mm — 145 / 200;
Section thickness, mm — 6 / 8;
Cross-sectional area of the pile, cm² — 61.6 / 58.6;
Permissible bending moment, kNm/m — 98 / 225;
Section modulus, cm³/m — 429 / 937;
Tensile breaking stress, MPa:
along the pultrusion direction — 770 / 770;
across the pultrusion direction — 150 / 150;
Tensile modulus of elasticity, GPa:
along the pultrusion direction — 33.4 / 33.4;
across the pultrusion direction — 14.1 / 14.1.

The creep of the polyurethane composite sheet pile of grade ShK-150UM was studied at stress levels from 0.21 to 0.95 σ_{bend} and a bending load duration of up to 3000 hours, and for the sheet pile of grade ShK-200UM — at stress levels of 0.2, 0.5, and 0.7 σ_{bend} and a load duration of up to 10,000 hours. The creep of glass-filled polyurethane sheet piles was determined using a lever-type test bench under three-point bending (Fig. 3) in accordance with the requirements of GOST R 57714–2017. Samples for creep testing of glass-filled polyurethane sheet piles along and across the pultrusion direction were obtained in accordance with the requirements of GOST R 56810–2015. For each given stress level, 12 PCM samples were tested.

The method for determining the creep of composite sheet piles is based on studying the deflections of PCSP samples measuring 120×12×7 mm as a function of the duration of a constant bending load at a given temperature and ambient humidity. The distance between supports was 100 mm. To measure

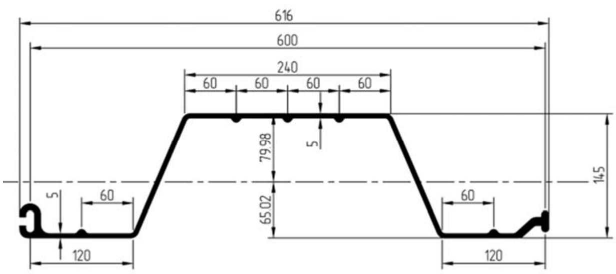

Fig. 1. Cross-section of an individual element of a composite sheet pile of channel profile, grade ShK-150UM

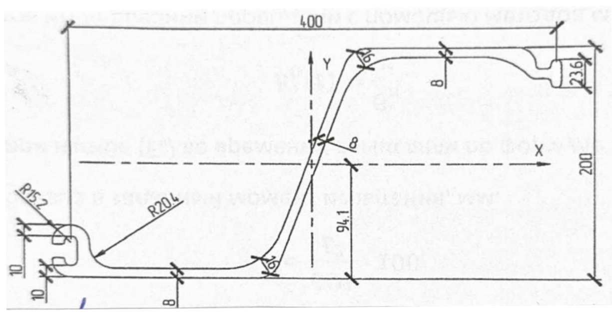

Fig. 2. Layout of an individual element of a composite glass-filled sheet pile with a polyurethane matrix, grade ShK-200UM

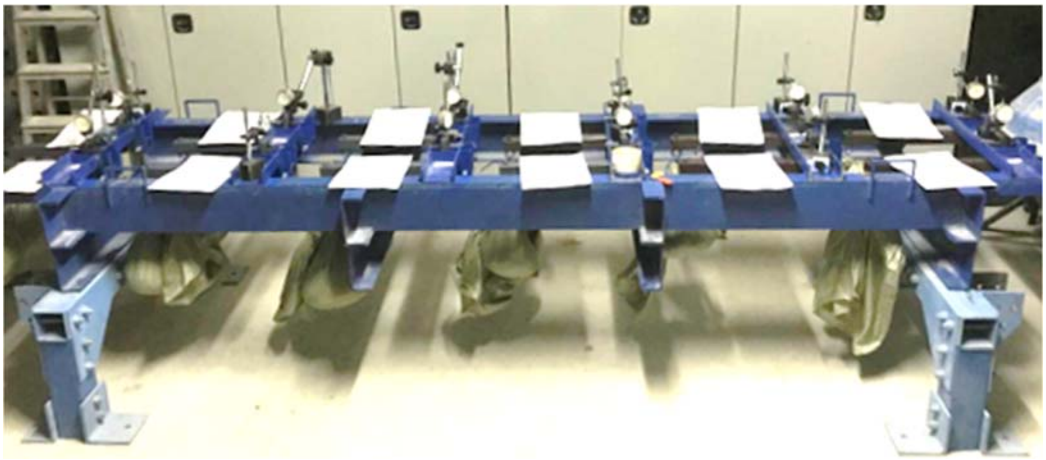

Fig. 3. Lever-type test bench for studying the creep of composite sheet piles

the deflections of the composite sheet pile, IC-50 dial indicators with a division value of 0.01 mm were used. Tests of glass-filled composite sheet piles with a polyurethane matrix were conducted on samples cut along and across the pultrusion direction of the sheet pile. Deflections of the composite sheet piles were measured at 1, 6, 12, and 30 minutes, and 1, 2, 5, 20, 50, 100, 200, 500, 700, 1000, 2000, 3000, 5000, and 10,000 hours after load application. The bending stress (σ_{bend}, MPa) was calculated using Formula 1:

$$\sigma_{\text{bend}} = \frac{3FL}{2bd^2}, \quad (1)$$

where:

L — distance between support centers, mm;

b — sample width, mm;

d — sample thickness, mm.

The relative strain of the extreme fibers of the composite sheet pile sample during bending (*r*, %) as a function of load duration (*t*) was calculated using Formula 2:

$$r = \frac{6Db}{L^2}100, \quad (2)$$

where *D* — sample deflection at a given test time, mm.

The bending creep modulus of the composite sheet pile (E_n, MPa) for a bending load duration of *t* hours was calculated using Formula 3:

$$E_n\left(t\right) = \frac{\sigma_{\text{bend}}}{r}. \quad (3)$$

The experimental results were processed using statistical methods in accordance with the recommendations of GOST R 50779.22–2005 (ISO 2602:1980).

Research Results and Discussion

The results of determining the relative strains of the extreme fibers and the creep modulus of the glass-filled polyurethane sheet pile of grade ShK-150UM along and across the pultrusion direction at bending stress levels from 0.21 to 0.95 σ_{bend} are given in Tables 1 and 2, and the isochronous graphical dependencies are shown in Figs. 4 and 5. Using interpolation methods, the bending stresses in the sheet pile along and across the pultrusion direction were calculated as a function of a relative strain of the extreme fibers equal to 1 % under

Table 1. **Bending creep of polyurethane sheet pile grade ShK-150UM along the pultrusion direction**

Relative stress level at bending, %	Time (hours)											
	0.1		1		10		100		1000		3000	
	***r*, %**	***E*, MPa**	***r*, %**	***E*, MPa**	***r*, %**	***E*, MPa**	***r*, %**	***E*, MPa**	***r*, %**	***E*, MPa**	***r*, %**	***E*, MPa**
0.21	0.68	26881	0.69	26270	0.71	25687	0.73	24857	0.77	23832	0.79	23334
0.28	0.91	27468	0.93	27006	0.95	26344	0.98	25506	1.02	24439	1.04	24161
0.41	1.22	29717	1.27	28554	1.30	28049	1.34	27163	1.41	25901	1.44	25218
0.57	1.64	30732	1.69	29894	1.72	28884	1.81	27867	1.91	26465	1.98	25516
0.65	1.63	34958	1.64	34710	1.65	34307	1.69	33601	1.76	32346	1.80	31588
0.76	2.41	27876	2.48	27131	2.53	26571	2.62	25640	2.74	24511	2.77	24251
0.85	3.21	23187	3.29	22640	–	–	–	–	–	–	–	–
0.95	2.97	28130	–	–	–	–	–	–	–	–	–	–

Note: Maximum bending stress along the pultrusion direction is taken as 880 MPa; *r* is relative strain of extreme fibers during bending; *E(t)* is bending creep modulus at time *t*.

Table 2. **Bending creep of polyurethane sheet pile grade ShK-150UM across the pultrusion direction**

Relative stress level at bending, %	Time (hours)											
	0.1		1		10		100		1000		3000	
	r, %	*E*, MPa	*r*, %	*E*, MPa	*r*, %	*E*, MPa	*r*, %	*E*, MPa	*r*, %	*E*, MPa	*r*, %	*E*, MPa
0.22	0.35	24060	0.37	23275	0.37	22097	0.42	20201	0.46	18620	0.47	17998
0.35	0.64	21777	0.66	20864	0.70	19916	0.73	18936	0.77	17868	0.79	17455
0.46	0.84	21461	0.87	20775	0.92	19746	0.98	18495	1.06	17072	1.09	16615
0.59	1.05	22012	1.07	21603	1.09	20869	1.15	20038	1.21	19115	1.23	18806
0.65	1.28	19864	1.34	18977	1.37	18222	1.46	17422	1.54	16519	1.57	16207
0.82	2.45	13034	–	–	–	–	–	–	–	–	–	–
0.93	2.59	13996	–	–	–	–	–	–	–	–	–	–

Note: Maximum bending stress across the pultrusion direction is taken as 390 MPa; *r* is relative strain of extreme fibers during bending; *E*(*t*) is bending creep modulus at time *t*.

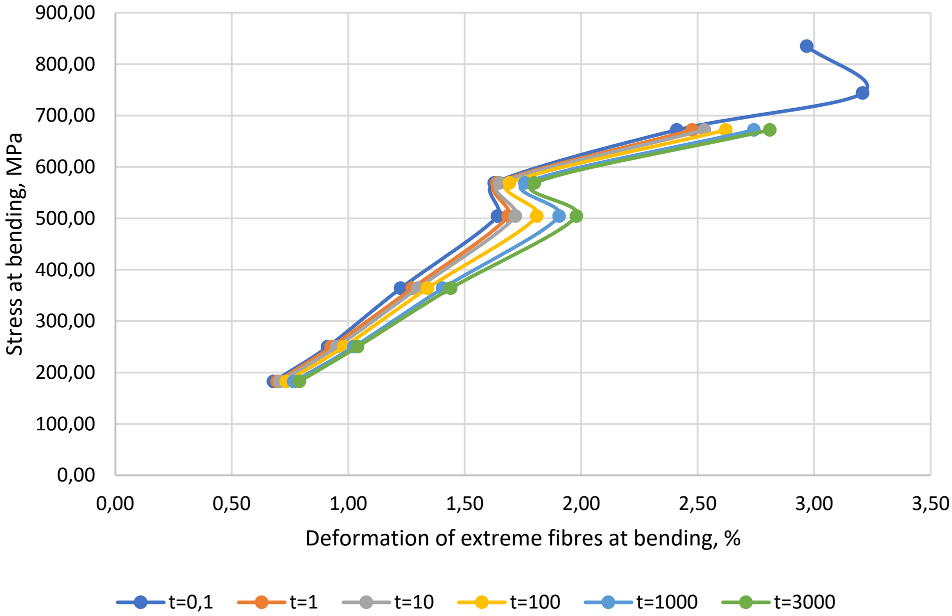

Fig. 4. Isochronous “stress-strain” curves of composite sheet pile ShK-150UM along the pultrusion direction under different durations of bending load

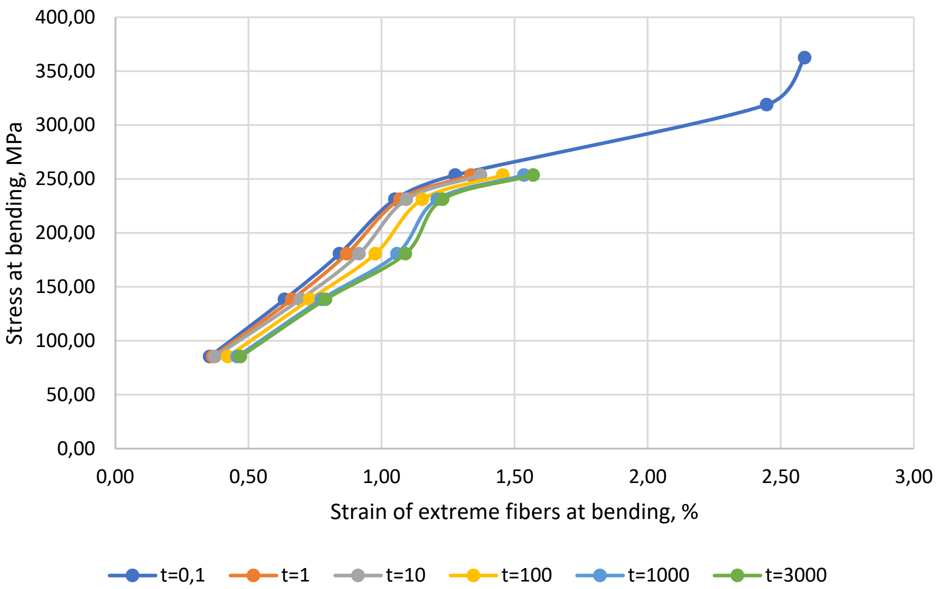

Fig. 5. Isochronous “stress-strain” curves of composite sheet pile ShK-150UM across the pultrusion direction under different durations of bending load

a bending load for 1000 hours. These stresses along and across the pultrusion direction of the glass-filled polyurethane sheet pile of grade ShK-150UM are 244 and 172 MPa, respectively.

The creep of glass-filled polyurethane sheet piles was studied in more detail using the example of the grade ShK-200UM sheet pile. The deflections, limiting strains of the extreme fibers, and creep modulus of the glass-filled composite sheet pile with a polyurethane matrix of grade ShK-200UM along and across the pultrusion direction as a function of bending load duration at stress levels of 0.2, 0.5, and 0.7 σ_{bend} are given in Tables 3 and 4 and Figs. 6–8. The stress levels during PCSP testing corresponded to bending stresses of 176, 440, and 616 MPa along, and 78, 195, and 273 MPa across the pultrusion direction of the sheet pile.

Based on the experimental data presented in Tables 3 and 4, dependencies of the relative strains of the extreme fibers (Fig. 7) and the bending creep modulus (Fig. 8) of the glass-filled polyurethane sheet pile along and across the pultrusion direction at stress levels of 0.2, 0.5, and 0.7 σ_{bend} were plotted in logarithmic coordinates. The dependencies of the relative strains of the extreme fibers during bending of the polyurethane sheet pile on the duration of the bending load can be represented as third-degree polynomials:

− along the pultrusion direction:

- at stress level 0.2 σ_{bend}:

$y = 0.0007x^3 + 0.0004x^2 + 0.0088x - 0.1427$;

- at stress level 0.5 σ_{bend}:

$y = 0.0007x^3 + 0.0004x^2 + 0.0058x + 0.2077$;

- at stress level 0.7 σ_{bend}:

$y = 0.0011x^3 + 0.0012x^2 + 0.0027x + 0.3257$;

– across the pultrusion direction:

- at stress level 0.2 σ_{bend}:

$y = 0.0004x^3 + 0.0015x^2 + 0.0183x - 0.38$;

- at stress level 0.5 σ_{bend}:

$y = 0.0008x^3 + 0.0007x^2 + 0.0093x + 0.0354$;

- at stress level 0.7 σ_{bend}:

$y = 0.0004x^3 + 0.0031x^2 + 0.0146x + 0.1844$,

where y is the logarithm of the strains of the extreme fibers of the polyurethane sheet pile;

x is the logarithm of the duration of the bending load.

The dependence of the creep modulus of the glass-filled composite sheet pile with a polyurethane

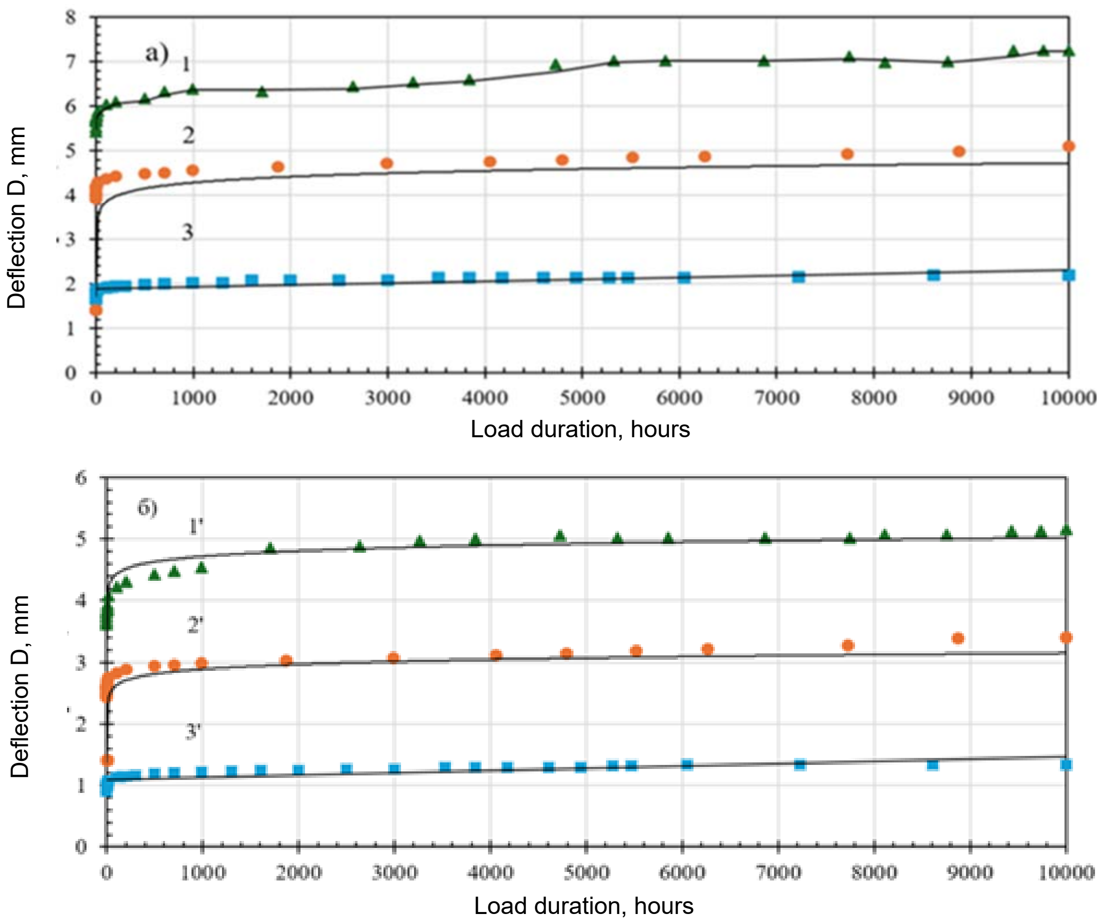

Fig. 6. Dependencies of the deflection magnitude of composite sheet pile grade ShK-200UM along (a) and across (b) the pultrusion direction on the duration of bending load: 1, 1' — at stress level 0.2 σ_{bend}; 2, 2' — at stress level 0.5 σ_{bend}; 3, 3' — at stress level 0.7 σ_{bend}.

Table 3. **Deflection magnitudes, strains, and creep modulus of glass-filled sheet pile with polyurethane matrix at stress levels of 0.2 and 0.5 σ_{bend}**

Load duration *t*, hours	Along the pultrusion direction			Across the pultrusion direction		
	Deflection, mm	Strain, %	Creep modulus, MPa	Deflection, mm	Strain, %	Creep modulus, MPa
0.02	1.73/3.99	0.69/1.55	25555/28629	0.96/2.49	0.39/1.03	19829/19035
0.1	1.76/4.06	0.71/1.58	25036/28158	0.97/2.56	0.40/1.06	19494/18556
0.2	1.77/4.13	0.71/1.61	24902/27549	0.98/2.59	0.41/1.07	19325/18352
0.5	1.79/4.15	0.72/1.62	24680/27415	1.00/2.61	0.41/1.08	19012/18190
1.0	1.80/4.17	0.72/1.62	24518/27302	1.01/2.64	0.42/1.09	18827/17977
2	1.82/4.19	0.73/1.63	24302/27151	1.02/2.66	0.42/1.10	18581/17844
5	1.83/4.23	0.73/1.65	24113/26921	1.04/2.71	0.43/1.12	18245/17507
20	1.86/4.28	0.75/1.67	23754/26619	1.08/2.75	0.45/1.14	17600/17268
100	1.91/4.36	0.77/1.70	23133/26105	1.13/2.83	0.47/1.17	16813/16818
200	1.94/4.42	0.78/1.72	22837/25791	1.16/2.88	0.48/1.19	16421/16545
500	1.96/4.49	0.79/1.75	22512/25396	1.19/2.94	0.49/1.21	16007/16187
700	1.98/4.51	0.80/1.76	22282/25276	1.20/2.96	0.50/1.22	15763/16068
1000	2.00/4.54	0.80/1.77	22099/25132	1.22/2.98	0.50/1.23	15544/15959
2000	2.08/4.64	0.83/1.81	21368/24566	1.25/3.03	0.52/1.25	15168/15684
5000	2.12/4.80	0.85/1.87	20926/23806	1.29/3.15	0.53/1.30	14667/15105
10000	2.20/5.08	0.88/1.98	20104/22543	1.34/3.40	0.55/1.40	14160/13992

Note — The numerator shows the values of deflection, strain, and creep modulus of the PCS (polymer composite sheet) at a stress level of 0.2 σ_{bend}, and the denominator shows the values at a stress level of 0.5 $\sigma_{bend.}$

Table 4. **Deflection magnitudes, strains, and creep modulus of glass-filled sheet pile with polyurethane matrix at stress level 0.7 σ_{bend}**

Load duration *t*, hours	Along the pultrusion direction			Across the pultrusion direction		
	Deflection, mm	Strain, %	Creep modulus, MPa	Deflection, mm	Strain, %	Creep modulus, MPa
0.02	5.43	2.03	30567	3.62	1.45	18992
0.1	5.53	2.06	30025	3.67	1.47	18727
0.2	5.63	2.10	29484	3.75	1.50	18333
0.5	5.68	2.12	29228	3.83	1.53	17979
1.0	5.72	2.13	29029	3.85	1.54	17861
2	5.74	214	28924	3.88	1.56	17718
5	5.77	2.15	28776	3.94	1.58	17411
20	5.87	2.19	28294	4.08	1.63	16818
100	6.02	2.24	27629	4.22	1.69	16214
200	6.10	2.27	27262	4.31	1.73	15920
500	6.17	2.30	26935	4.42	1.77	15519
700	6.33	2.36	26314	4.49	1.80	15285
1000	6.40	2.38	26074	4.55	1.82	15053
2000	6.34	2.36	26196	4.86	1.95	14087
5000	6.95	2.59	23821	5.06	2.02	13528
10000	7.25	2.71	22895	5.14	2.07	13213

matrix on the duration of the bending load can be represented by the following equations:

− along the pultrusion direction:

- at stress level 0.2 σ_{bend}:

$$z = 4.3881 - 0.0007x^3 - 0.0004x^2 - 0.0088x; \quad R^2 = 0.9951;$$

- at stress level 0.5 σ_{bend}:

$$z = 4.4358 - 0.0007x^3 - 0.0004x^2 - 0.0058x; \quad R^2 = 0.9915;$$

- at stress level 0.7 σ_{bend}:

$$z = 4.4639 - 0.0011x^3 - 0.0012x^2 - 0.0027x; \quad R^2 = 0.975;$$

− across the pultrusion direction:

- at stress level 0.2 σ_{bend}:

$$z = 4.272 - 0.0004x^3 - 0.0015x^2 - 0.0183x; \quad R^2 = 0.9977;$$

- at stress level 0.5 σ_{bend}:

$$z = 4.2546 - 0.0008x^3 - 0.0007x^2 - 0.0093x; \quad R^2 = 0.9864;$$

- at stress level 0.7 σ_{bend}:

$$z = 4.2518 - 0.0004x^3 - 0.0031x^2 - 0.0146x; \quad R^2 = 0.9929,$$

where *z* is the logarithm of the creep modulus of the composite sheet pile;

x is the logarithm of the duration of the bending load.

The dependence of the bending stresses of the polyurethane sheet pile grade ShK-200UM along and across the pultrusion direction on the relative strains of the extreme fibers is shown in Fig. 9. From Fig. 9, it follows that at stress levels of 0.2 and 0.5 σ_{bend}, failure of the glass-filled polyurethane sheet pile along and across the pultrusion direction does not occur during testing for 10,000 hours. At the same time, at a stress level of 0.7 σ_{bend}, failure of 50 % of the studied sheet pile samples occurs after 2,638 and 9,434 hours when tested across and along the pultrusion direction, respectively, and failure of the first

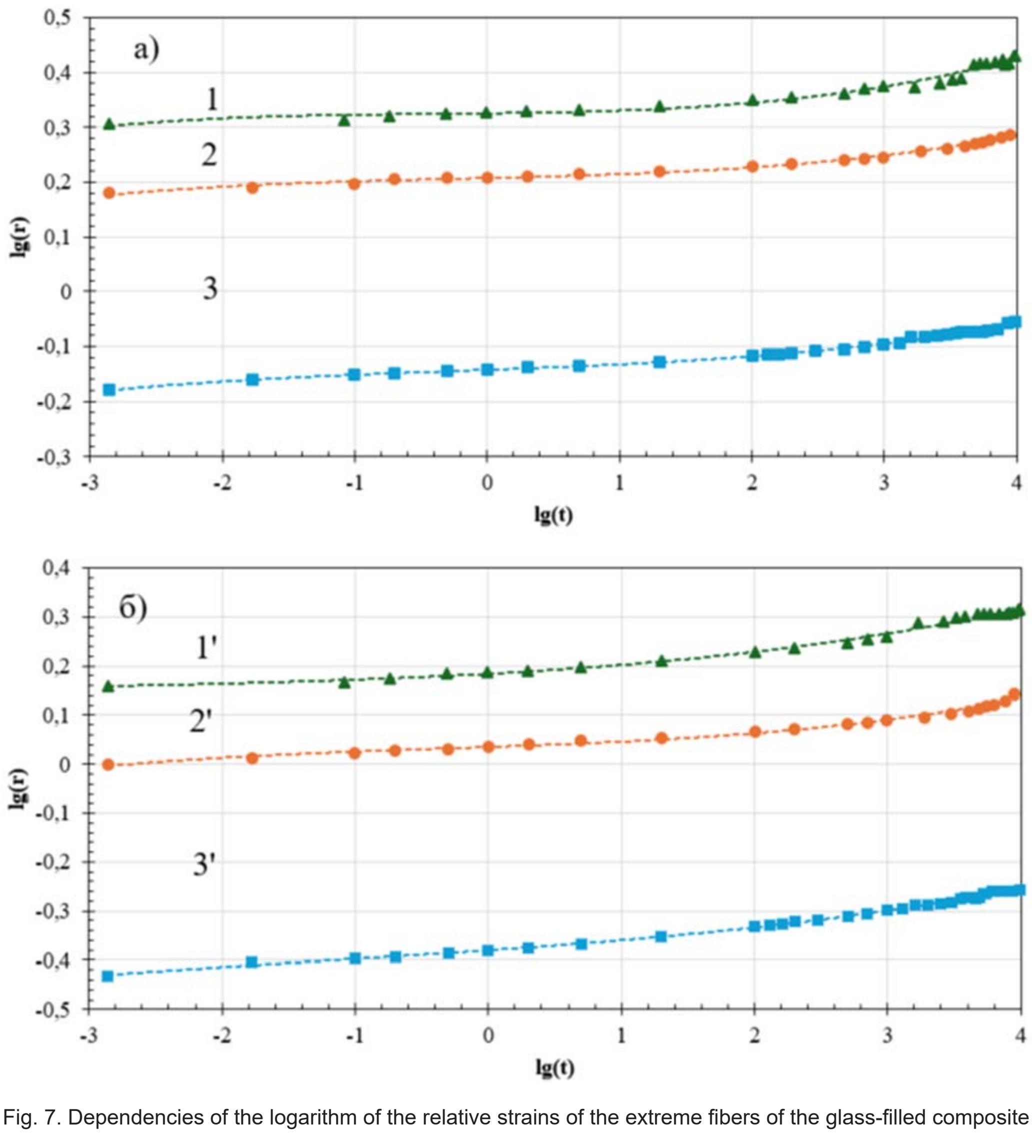

Fig. 7. Dependencies of the logarithm of the relative strains of the extreme fibers of the glass-filled composite sheet pile with polyurethane matrix during bending along (a) and across (b) the pultrusion direction on the logarithm of the bending load duration: 1, 1' — at stress level 0.7 σ_{bend}; 2, 2' — at stress level 0.5 σ_{bend}; 3, 3' — at stress level 0.2 σ_{bend}

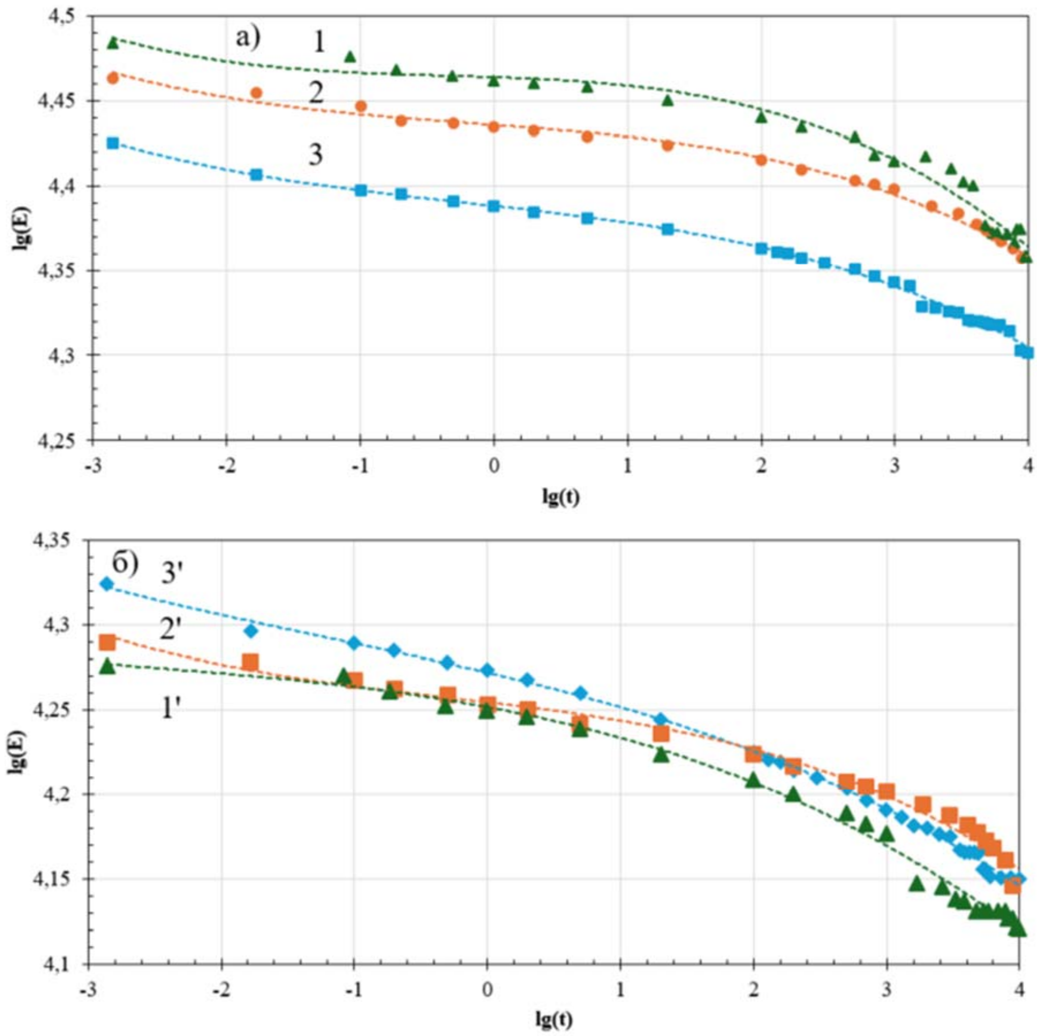

Fig. 8. Dependencies of the logarithm of the creep modulus of the glass-filled composite sheet pile with polyurethane matrix along (a) and across (b) the pultrusion direction on the logarithm of the bending load duration: 1, 1' — at stress level 0.7 σ_{bend}; 2, 2' — at stress level 0.5 σ_{bend}; 3, 3' — at stress level 0.2 σ_{bend}

sheet pile samples occurs after 1,702 and 200 hours, respectively. In accordance with the requirements of GOST R 57714–2017, the stresses at a relative strain of the extreme fibers during bending equal to 1 % under a bending load for 1,000 hours were calculated. The calculated stress values along and across the pultrusion direction are 253 and 153 MPa, respectively, which corresponds to 30 % and 40 % of the bending strength of the composite sheet pile. It should be noted that for the polyurethane sheet pile of grade ShK-200UM, the stress under bending loads along the pultrusion direction is 3.7 % higher, and the stress across the pultrusion direction is 12.4 % lower than for the PCSP of grade ShK-150UM.

It should be noted that approximating the dependencies of the relative strains of the extreme fibers and the creep modulus of the glass-filled composite sheet pile with a polyurethane matrix by linear functions is only possible in the steady-state creep region:

- at a stress level of 0.2 σ_{bend} — up to 5,631 hours;
- at a stress level of 0.5 σ_{bend} — up to 2,615 hours;
- at a stress level of 0.7 σ_{bend} — up to 604 hours.

A sufficiently accurate approximation of these values is achieved using third-degree polynomials. Extrapolating the obtained values to a period of up to 50 years (438,000 hours), additional "stress-strain" isochrones were constructed for 100,000 hours and 438,000 hours (Fig. 9, curves 7 and 8). The limiting strain under long-term loading was taken as the strain values of the extreme fibers that do not lead to failure, determined as the lower bound of the one-sided confidence interval with a probability of 0.95 according to GOST 50779.22–2005. The stresses leading to failure of the studied glass-filled sheet pile material with a polyurethane matrix under a load duration of 50 years, calculated from the isochronous curves based on extrapolation data, are 465 and 189 MPa for the longitudinal and transverse pultrusion directions, respectively,

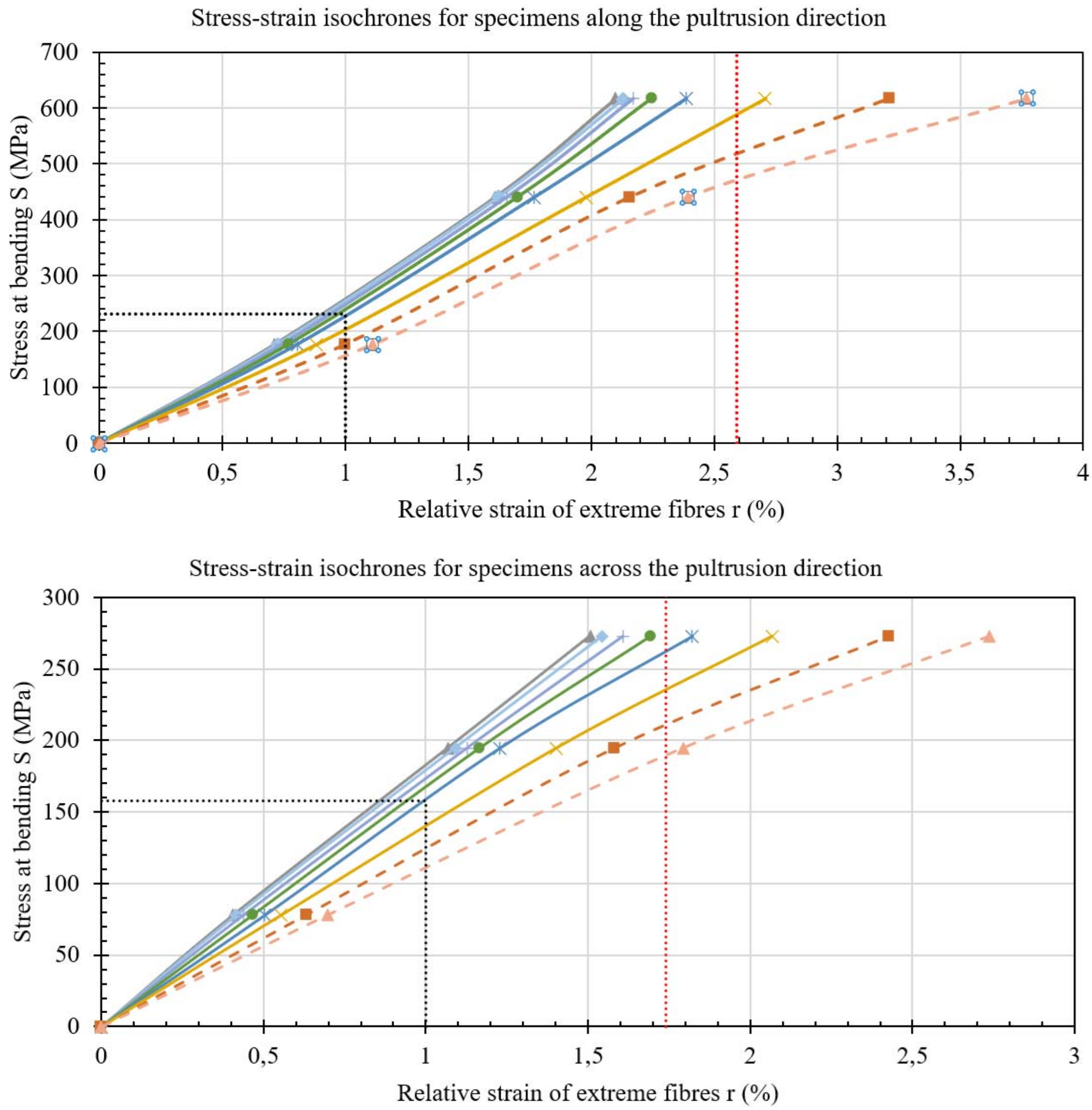

Fig. 9. Dependencies of the bending stress of the glass-filled composite sheet pile with polyurethane matrix along (a) and across (b) the pultrusion direction on the relative strain of the extreme fibers at: 1–10 min; 2–1 hour; 3–10 hours; 4–100 hours; 5–1,000 hours; 6–10,000 hours; 7–100,000 hours; 8–438,000 hours

which corresponds to 53 % and 49 % of the bending strength of the composite sheet pile.

Conclusions

As a result of the performed experimental studies, the influence of the stress level and duration of the bending load on the creep parameters of glass-filled composite sheet piles with a polyurethane matrix along and across the pultrusion direction was established. It was calculated that the stresses in the studied glass-filled PCSPs under a bending load for 1000 hours and a relative strain of the extreme fibers equal to 1 % are, along and across the pultrusion direction for sheet piles of grades ShK-150UM and ShK-200UM, 244 MPa, 172 MPa, and 253 MPa, respectively. These stresses in the glass-filled polyurethane sheet pile of grade ShK-200UM across and along the pultrusion direction occur at 30 % and 40 % of the bending strength of the PCSP, respectively. It was shown that failure of the polyurethane sheet pile of grade ShK-200UM does not occur within 10,000 hours at stress levels of 0.2 and 0.5 σ_{bend}. Failure of this sheet pile at a stress level of 0.7 σ_{bend} occurs after 2,538 and 9,434 hours when tested across and along the pultrusion direction, respectively, during PCSP production. By extrapolating the experimental “stress-strain” dependencies, the stress leading to failure of ShK-200UM under a bending load duration of 50 years was calculated: for the longitudinal and transverse pultrusion directions, the breaking stresses are 465 and 189 MPa, respectively, which corresponds to 53 % and 49 % of the bending strength of the composite sheet pile.

References

Donetsky, K. I., Karavaev, R. Yu., Tsybin, A. I., Veshkin, E. A., and Mikhaldykin, E. S. (2017). Structural Fiberglass for Manufacturing Sheet Pile Enclosure Elements. *Aviation Materials and Technologies*, 3 (48), pp. 56–64. DOI: 10.18577/2071-9140-2017-0-3-56-64.

Ferdous, W., Bai, Y., Almutairi, A.D., Satasivam, S., and Jeske, J. (2018). Modular Assembly of Water-Retaining Walls Using GFRP Hollow Profiles: Components and Connection Performance. *Composite Structures*, 194, pp. 1–11. DOI: 10.1016/j.compstruct.2018.03.074.

Giroux, C. and Shao, Y. (2003). Flexural and Rigidity of Composite Sheet Piles. *Composites for Construction, ASCE*, 74, pp. 348–355. DOI: 10.1061/(ASCE)1090-0268(2003)7:4(348).

Gritsenko, V.A. and Nesterov, A.S. (2015). Application of plastic tongue-and-groove piles In construction. *Construction Technique and Technology*, 4, pp. 65–71.

Kokareva, K. A., Belyaev, N. D., and Yalyshchev, A. I. (2015). Sheet Pilings From Ultra Composite In Hydraulic Engineering. *Construction of Unique Buildings and Structures*, 4 (31), pp. 163–172.

Kornev, O. A., Mikhaldykin, E. S., Zhidkov, Yu. A., Silantyev, A. S., and Ushkov, V. A. (2025). Operational Properties Of Polymer Composite Sheet Piling With Polyurethane Matrix Of The CSHP-150UM Brand. *Technique and Technology of Silicates*, 32 (4), pp. 394–406. DOI: 10.62980/2076-0655-2025-394-406.

Levachev, S. N., Galimov, I. M., Filippov, V. V., Zubachev, N. A., and Nemolochnov, A. G. (2019). Mooring Structure with Rigid Anchorage. *Power Technology and Engineering*, 52 (6), pp. 652–656. DOI: 10.1007/s10749-019-01007-x.

Levachev, S. N., Galimov, I. M., Nemolochnov, A. G., Filippov, V. V., and Zubachev, N. A. (2018). Berthing Structure with Rigid Anchor Device. *Hydraulic Engineering*, 10, pp. 31–36.

Nemolochnov, A. G. (2019). Improvement of Designs of Bank Protection Structures Using Composite Sheet Piles. *PhD Thesis in Technical Sciences: 05.23.07*. Moscow.

Nemolochnov, A. G. and Levachev, S. N. (2016). Composite Sheet Piles: Nomenclature and Experience. *Transport Construction*, 7, pp. 8–11.

Nemolochnov, A. G., Levachev, S. N., Galimov, I. M., and Zubachev, N. A. (2019). The Results of the Test FRP Composite Sheet Piles SHK-150. *Hydraulic Engineering*, 8, pp. 18–21.

Seleznev, V. A., Kakusha, V. A., Gorbunov, I. A., Gukov, N. A., and Ushkov, V. A. (2022). Physical and Mechanical Characteristics of Glass Composite Reinforcement. *Vestnik of Volga State University of Technology. Series «Materials. Constructions. Technologies»*, 1 (21), pp. 15–26. DOI: 10.25686/2542-114X.2022.1.15.

Seleznev, V. A., Samchenko, S. V., Kakusha, V. A., Gukov, N. A., and Ushkov, V. A. (2020). Effect of Temperature and Aggressive Environmental Agents on Material Properties of Glass Fiber Polymers. *Technique and Technology of Silicates*, 27 (2), pp. 41–45.

Shanmugam, J. (2004). *Moment Capacity and Deflection Behavior of Pultruded FRP Composite Sheet Piles*. Master of Engineering Thesis. McGill University, Montreal, Canada.

Shao, Y. and Shanmugam, J. (2004). Moment Capacities and Deflection Limits of PFRP Sheet Piles. *Composites for Construction*, 106, pp. 520–528.

Stelanova, V. F., Stelanov, A. Yu., and Zhirkov, E.P. (2013). *Polymer Composite Reinforcement*. Moscow: Bumazhnik LLC.

ПОЛЗУЧЕСТЬ ПОЛИМЕРНЫХ КОМПОЗИТНЫХ ШПУНТОВ С ПОЛИУРЕТАНОВОЙ МАТРИЦЕЙ

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Аннотация
Введение. Прогрессивным методом производства строительных изделий из полимерных композитных материалов на основе реакционноспособных олигомеров является метод пултрузии, позволяющий производить тонкостенные изделия с профилем произвольной формы, в том числе шпунтовые сваи. В научно-технической литературе недостаточно сведений о ползучести стеклонаполненных шпунтов с полиуретановой матрицей при различном уровне и продолжительности воздействия изгибающих нагрузок, что затрудняет прогнозирование долговечности указанных изделий. **Цель исследования:** установление зависимости модуля ползучести отечественных стеклонаполненных шпунтов с полиуретановой матрицей от величины и продолжительный воздействия изгибающей нагрузки вдоль и поперек направления пултрузии. **Методы:** ползучесть стеклонаполненных полиуретановых шпунтов исследовали с помощью испытательного стенда рычажного типа, разработанного авторами. **Результаты:** изучено влияние уровня напряжений (0,2–0,95 $б_{изг}$) и продолжительность воздействия изгибающей нагрузки на величину прогиба и модуль ползучести (ГОСТ 57714–2017) стеклонаполненных полимерных шпунтов с полиуретановой матрицей вдоль и поперек направления пултрузии. Показано, что разрушения полиуретанового композитного шпунта марки ШК-200УМ в течение 10000 часов при уровне напряжений 0,2 и 0,5 $б_{изг}$ не наблюдается. Разрушение 50 % образцов композитного шпунта с полиуретановой матрицей при уровне напряжений 0,7 $б_{изг}$ происходит через 2638 и 9434 часа при испытании соответственно поперек и вдоль направления пултрузии изготовления шпунта. Экстраполяцией экспериментальных зависимостей «напряжение–деформация» спрогнозирована ползучесть полиуретановых композитных шпунтов на период до 50 лет.

Ключевые слова: полиуретановый шпунт; пултрузия; деформация; прогиб; модуль ползучести; уровень напряжений.