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Potential Applications of Pultruded Polymer Composite Materials in Oilfield Infrastructure Development

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Abstract: The research aimed to investigate the applicability of pultruded glass fiber–reinforced polymer composites for structural elements in oilfield infrastructure, specifically examining the relationship between aggressive environmental exposure, degradation mechanisms, and mechanical performance. Physical experiments were carried out to assess the composites under simulated oilfield conditions, including chemical immersion, freeze–thaw cycling, and climatic aging. Tests included measurements of density, water absorption, tensile strength, modulus of elasticity, and elongation at break. Hydrolytic and chemical resistance evaluations (1 wt% NaOH, 10 wt% HCl), frost-resistance testing in 5 wt% NaCl, and cyclic temperature–humidity exposure were performed to evaluate the impact of degradation pathways on material integrity. Through statistical modeling of property retention, serviceability thresholds were identified, defined by specific environmental parameters: immersion times of 240 h, temperature cycling between –50 °C and +20 °C, and UV-humidity exposure. Within this framework, the production of composite profiles with target retention of ≥ 90 % tensile strength, ≥ 85 % flexural modulus, and water absorption ≤ 0.5 % over equivalent service periods was predicted.

Keywords: pultrusion, glass fiber composite, polymer composite, oilfield infrastructure, environmental degradation, mechanical property, chemical immersion, freeze–thaw cycling, climatic aging, water absorption, tensile strength, flexural modulus, hydrolytic resistance, frost resistance, statistical modeling.

1 Introduction

The operation of oil and gas facilities is characterized by significant operational challenges arising from the aggressive impact of environmental factors and the produced media [1-3]. Petroleum and gas fields are predominantly located in climatic zones subject to extreme temperature fluctuations throughout the year [4]. In addition to these conditions, adverse effects are exerted by atmospheric precipitation, contact with aggressive fluids containing salts, acids, and alkalis, and the presence of corrosion-active gases such as hydrogen sulfide and carbon dioxide.

Traditionally, steel has been the principal structural material for equipment and infrastructure in the oil and gas sector [5]. However, the primary drawback of steel structures is their high susceptibility to corrosion, which leads to premature failure of production equipment. Pipelines, pumping units, valves, and shut-off fittings are particularly prone to corrosive damage [6,7,8]. Beyond process equipment, auxiliary installations - such as cable racks, walkways, and service platforms - also succumb to corrosion processes [9]. All of these factors substantially increase the operating costs associated with the repair and maintenance of facilities.

In addition to corrosion-related issues, logistics operations significantly influence the efficiency of oil and gas facility operations. The transportation of heavy metal structures and equipment to remote, hard-to-access regions markedly increases the capital costs of field development and operation [10].

In view of the problems outlined above, the search for and implementation of alternative structural materials that can provide comparable or superior operational performance while reducing logistical and operating expenditures has become imperative. Polymer composite materials present an alternative to steel, offering comparable mechanical properties but with substantially lower mass and high resistance to aggressive environmental exposures [11,12]. The adoption of polymer composites can significantly reduce costs associated with transport, installation, and operation of oil and gas facilities [13,14].

This study examined polymer composite products used to manufacture auxiliary structures on oilfields. The specimens, in the form of profiles, sheets, and angles, were produced by the pultrusion method. This technique enables the mass production of fiberglass-reinforced plastic components with relatively stable physical and mechanical characteristics. However, the limited experience with pultruded products in the oil and gas sector, coupled with scarce laboratory data on their resistance in aggressive environments, hinders their widespread adoption [15]. The objective of this work was to obtain data on the resistance of pultruded components to the aggressive conditions characteristic of oil and gas fields.

2 Materials and Methods

2.1 Materials

The study's objects were glass fiber–reinforced polymer products manufactured using the pultrusion process. The tested components included flat sheets, rectangular profiles, and L-shaped angles. Figures 1-3 show the specimens' external appearance.

Fig. 1. – Sheet

Fig. 2. – Rectangular profile

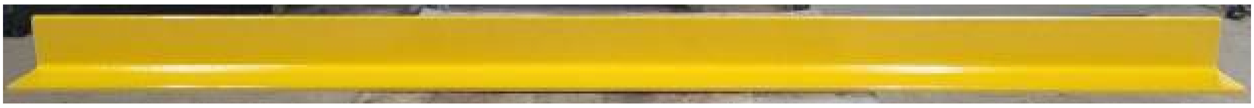

Fig. 3. – Angle

The examined products represent commercial items produced on the manufacturing lines of industrial-scale composite manufacturers.

2.2 Methods

The research methodology involved the evaluation of the initial properties of the polymer composite materials (PCMs) in their as-received condition and the assessment of the impact of aggressive environmental factors on their operational performance. The exposure to aggressive media included immersion of specimens in 1 wt% NaOH solution and 10 wt% HCl solution, as well as frost resistance tests (evaluating the effects of cyclic transitions through 0 °C), and the influence of elevated temperature, humidity, and ultraviolet radiation.

Changes in the physical and mechanical properties of the materials were monitored by measuring density, water absorption, ultimate tensile strength, and elongation at break. The test specimens had a paddle-shaped geometry, an example of which is shown in Figure 4.

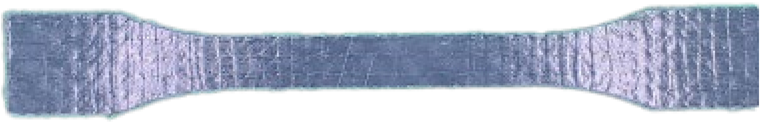

Fig. 4 – Example of a specimen for mechanical testing

Tensile tests were carried out using a Zwick//Roell Z050 universal testing machine (Figure 5) equipped with flat hydraulic grips

Fig. 5 – Zwick//Roell Z050 universal testing machine

The density of the materials was determined using the hydrostatic weighing method in accordance with the Russian standard GOST 15139 «*Plastics. Methods for the determination of density (mass density)*», by comparing the mass of equal volumes of the test material and a reference liquid of known density (distilled water).

Water absorption was evaluated in accordance with the requirements of ISO 62:2008 *«Plastics - Determination of water absorption»*. The method is based on measuring the mass change of the specimens before and after immersion in distilled water at room temperature.

Mechanical properties were assessed in accordance with ISO 527-5 *«Plastics – Determination of tensile properties. Part 5: Test conditions for unidirectional fibre-reinforced plastic composites»* through uniaxial tensile testing at ambient temperature. The parameters determined included ultimate tensile strength, modulus of elasticity, and elongation at break.

The impact of aggressive media was evaluated according to ISO 175 *«Plastics – Methods of test for the determination of the effects of immersion in liquid chemicals»* by completely immersing the specimens in chemical solutions at room temperature for 240 hours in laboratory glass containers. After exposure, the samples were conditioned to remove absorbed liquid, followed by measurement of their physical and mechanical properties.

Frost resistance tests were carried out based on the Russian standard GOST 10060 «*Concretes. Methods for determination of frost-resistance*» . The procedure included cycles of freezing and thawing in a 5% aqueous solution of sodium chloride. The specimen surfaces were left unsealed during testing. The test program is summarized in Table 1.

Table No. 1

Conditions for frost resistance testing

Test Conditions			
Saturation medium	Freezing medium, temperature, and duration		Thawing medium, temperature, and duration
5% NaCl solution	5% NaCl solution, (–50 ± 2) °C, 2.5 h	5% NaCl solution, (–10 ± 2) °C, 1.5 h	5% NaCl solution, (+20 ± 2) °C, 3 h

Three test cycles were conducted, each consisting of ten freeze–thaw transitions at 0 °C.

3 Results and Discussion

Table 2 presents the density measurement results of the tested specimens.

Table No. 2

Density evaluation results of the specimens

Specimen type	Density, kg/m³
Sheet	1848
Rectangular profile	1981
Angle	2048

The density evaluation results indicate similar values among the tested products. As expected, the density of the examined polymer composite materials is significantly lower than that of steel (≈7800 kg/m³), which will influence the overall weight of the final product.

Table 3 presents the water absorption evaluation results.

Table No. 3

Water absorption evaluation results

Specimen type	Water absorption, %
Sheet	0.21
Rectangular profile	0.18
Angle	0.63

The water absorption evaluation results showed an elevated value (0.63%) for the angle-shaped specimen, which is attributed to the structural and geometric features facilitating moisture ingress. Despite the absence of regulatory requirements for water absorption in the Russian standard GOST 33344 «*Constructive pultruded profiles from polymer composites. General specifications*», elevated water absorption under operational conditions, can adversely affect material durability. Specifically, moisture penetration followed by freezing at low service temperatures induces internal stresses and may lead to microcrack formation, accelerated material degradation, and reduced mechanical properties and operational reliability.

Table 4 presents the results of mechanical tensile tests for the sheet-type specimen.

Table No. 4

Water absorption evaluation results

Product type		Sample No.	Ultimate tensile strength, MPa				
Material name	**Fiber orientation angle, °**		**Control sample**	**1% NaOH**	**10% HCl**	**Climatic exposure**	**Frost resistance**
Sheet	0	1	512	564	576	560	556
		2	532	526	534	536	535
		3	539	557	542	545	530
		4	513	556	559	550	536
		5	545	540	544	548	542
		Average	528	549	551	548	540
	90	1	75	71	73	70	59
		2	61	78	68	60	62
		3	71	70	71	62	65
		4	67	74	65	64	63
		5	69	60	64	68	67
		Average	69	71	68	65	63

The obtained results demonstrate that the tensile strength values of the polymer composite materials (PCMs) in the reinforcement direction exceed those of structural steels commonly used in oilfield infrastructure (e.g., the tensile strength of steel 09G2S is approximately 470 MPa). At the same time, the strength of PCMs perpendicular to the reinforcement direction is considerably lower, which is attributable to the specifics of the manufacturing process and is not a critical factor for profile- or angle-type components. The Russian standard GOST 33344 specifies a minimum tensile strength of 240 MPa in the reinforcement direction and 50 MPa perpendicular to it. The test results comply with the standard requirements, and no adverse effects of aggressive exposures on mechanical performance were observed.

Table 5 presents the tensile test results of the pultruded rectangular profile.

Table No. 5

Mechanical test results of the pultruded rectangular profile

Product type		**Sample No.**	**Ultimate tensile strength, MPa**				
Material name	**Fiber orientation angle, °**		**Control sample**	**1% NaOH**	**10% HCl**	**Climatic exposure**	**Frost resistance**
Rectangular profile	0	1	402	447	431	425	449
		2	415	444	444	415	420
		3	418	415	415	422	421
		4	403	425	435	419	422
		5	413	418	427	426	425
		Average	410	429	430	421	427

The tensile strength values of the rectangular profile were lower than those of the sheet-type specimens under similar test conditions. The variation may result from differences in the manufacturing process. Nevertheless, the values conform to the requirements of GOST 33344 and correspond to the tensile strength levels of steel components. Due to the shape of the specimen, tensile tests perpendicular to the reinforcement direction could not be performed. No degradation of mechanical properties after exposure to aggressive environments was observed.

Table 6 presents the tensile test results of the pultruded angle.

Table No. 6

Mechanical test results of the pultruded angle

Product type		**Sample No.**	**Ultimate tensile strength, MPa**				
Material name	**Fiber orientation angle, °**		**Control sample**	**1% NaOH**	**10% HCl**	**Climatic exposure**	**Frost resistance**
Angle profile / L-profile	0	1	594	650	693	585	590
		2	588	694	592	610	584
		3	573	631	612	601	595
		4	580	651	625	612	598
		5	579	656	599	624	590
		Average	582	656	624	606	591

The tensile strength of the angle-type specimens exceeded that of other products tested in this study. This difference may be due to the use of a different binder or manufacturing process for this specific product. Details of the materials used are considered proprietary and, therefore, are not disclosed in this study.

The obtained tensile strength values meet the requirements of the Russian standard GOST 33344 and are comparable to those of structural steel. Due to the specimen's geometry, testing in the direction perpendicular to the reinforcement was not possible. No mechanical degradation was observed following exposure to aggressive environments.

Figure 6 shows the average tensile strength values in the reinforcement direction for all tested specimens, including both control and exposed samples.

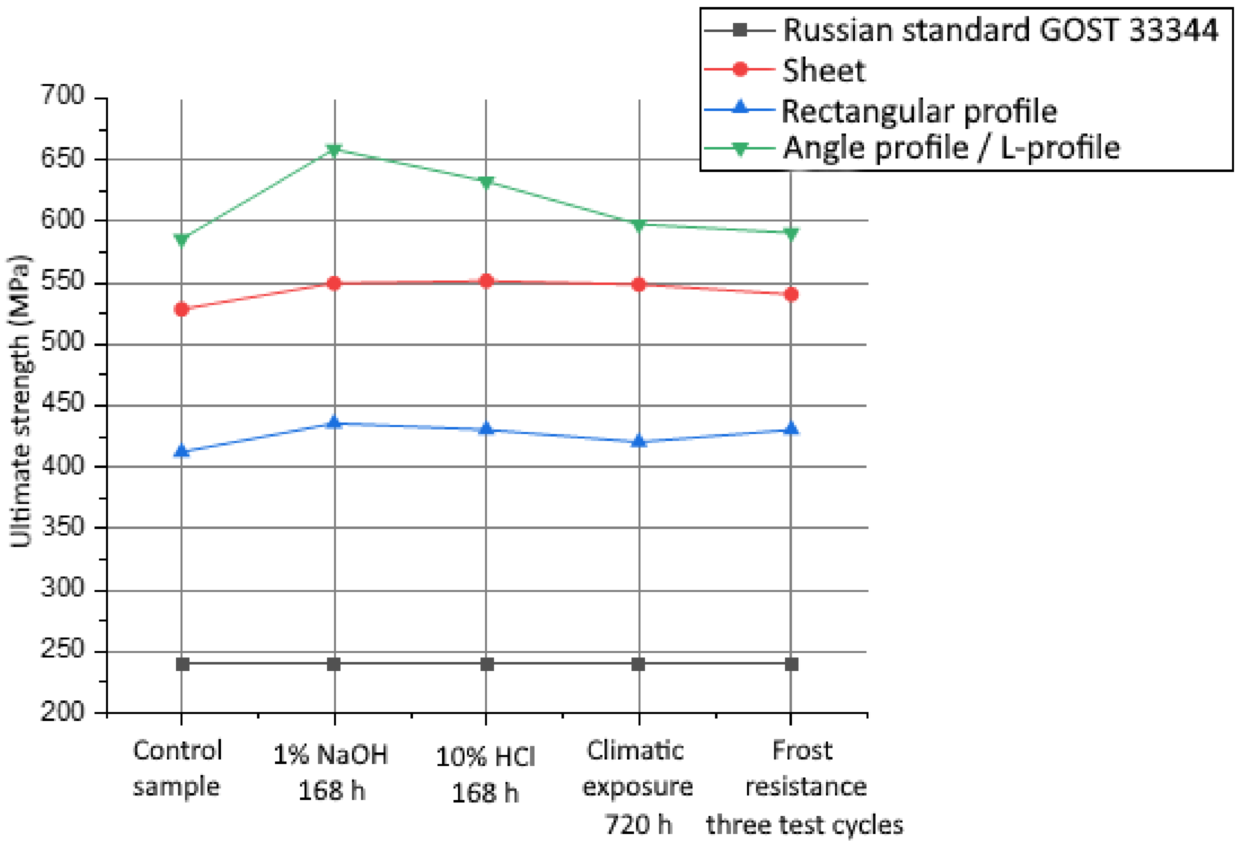

Fig. 6 – Average tensile strength in the reinforcement direction for the tested specimens

4 Conclusions

In this study, laboratory tests were conducted to assess the applicability of pultruded polymer composite products for use in the construction of oilfield infrastructure under aggressive environmental conditions. Based on the analysis of the obtained results, the following conclusions can be drawn:

1. The average tensile strength values of control specimens tested along the fiber reinforcement direction ranged from 410 to 582 MPa, meeting regulatory requirements and comparable to those of structural steels.
2. Exposure to a 1% NaOH aqueous solution did not significantly affect the tensile strength of the tested materials.
3. Immersion in a 1% HCl aqueous solution did not reduce tensile strength, indicating the materials' high chemical resistance.

4. The results of climatic testing, including cyclic temperature fluctuations and exposure to humidity, did not reveal notable degradation of the mechanical properties.
5. Thus, the experimental findings confirm the feasibility and potential of using pultruded polymer composite products as structural elements in the construction of oil and gas infrastructure.

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