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## REINFORCEMENT OF POLYMER PIPES WITH LONGITUDINAL FIBERS

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**Abstract.** The aim of the study is to evaluate the influence of the spatial arrangement and volumetric content of continuous longitudinal fibers in the wall of polymer composite pipes on their strength characteristics compared to a 6061-T6 aluminum pipe. It is shown that the central arrangement of the reinforced layer with a fiber content of 70–80 % (vol.), primarily when using carbon fibers, provides an optimal safety factor and displacement, and the use of a reinforced polymer pipe allows increasing the safety margin up to 230 % compared to the base aluminum pipe. The obtained dependencies allow for a justified choice of the composite layer configuration when designing reinforced pipes for a given operating pressure.

**Keywords:** composite material, polymer, fibers, reinforcement, pipe.

The use of polymer pipes [1], and especially composite ones, is one of the main directions for replacing metal pipelines due to their low weight, corrosion resistance, and high performance characteristics [2–3]. Numerous studies show that their strength and durability significantly depend on the wall structure, type of reinforcement, volume fraction, and location of fibers, while rational partial reinforcement with controlled placement of the reinforced layer along the pipe thickness has been insufficiently studied [2].

The authors have patented a method for forming reinforced polymer pipes using an improved angular extrusion head, the design of which allows for reinforcing pipes with continuous longitudinal fibers and providing different volumetric content and options for their arrangement in the pipe cross-section (Pat. No. UA153089U).

The aim of the study is a quantitative assessment of the influence of the arrangement and volumetric content of continuous longitudinal reinforcing fibers in the wall of polymer pipes using numerical simulation in ANSYS Static Structural for pipes formed according to the method proposed by the authors. Separately, a comparison of the ultimate load-bearing capacity and stress-strain state of such composite pipes with a base aluminum pipe was performed.

Numerical analysis was carried out for pipes with a matrix made of polypropylene PP-R R200P, reinforced with glass and carbon fiber, with an outer diameter of 90 mm and a wall thickness of 5 mm, as well as with the arrangement of fibers in the inner and central layers and a volume content of 30, 50, 70, and 80 %, loaded with an internal pressure of 28.89 MPa (the burst pressure of an aluminum pipe) under the condition of its cantilever fastening with a hinged-movable support. The properties of the fibers without taking into account the matrix were taken as average values for the corresponding materials according to known experimental data [4–5], and the strength limit of the reinforced layer and the main characteristics of the composite were determined by the rule of mixtures for the longitudinal direction and the Halpin–Tsai model for the transverse direction.

Based on the numerical simulation results, the influence of the composite layer arrangement along the wall thickness and the volumetric fiber content on the stress-strain state and the ultimate load-bearing capacity of composite polymer pipes was analyzed. It was obtained that for the central layer of the composite reinforced with glass fiber – with an increase in the composite content from 30 to 80 %, the safety factor of the structure  $n$  increases from 1.51 to 2.30 and the displacements  $\delta$  in

the transverse direction decrease from 8,11 to 6,29 mm; for the inner layer of the composite reinforced with glass fiber – a corresponding increase in  $n$  from 1 to 1.24 and a decrease in  $\delta$  from 10.98 to 10.18 mm; for the central layer of the composite reinforced with glass fiber – an increase in  $n$  from 2.07 to 3.33 and a decrease in  $\delta$  from 8.05 to 6.20 mm; for the inner layer of the composite reinforced with glass fiber – an increase in  $n$  from 1.04 to 1.74 and a decrease in  $\delta$  from 21.90 to 14.42 mm; for the aluminum pipe –  $n = 1$  and  $\delta \approx 0.14$  mm.

The results obtained allow us to highlight the following patterns: 1) with the same volume content and fiber arrangement, composites with carbon fiber provide a greater safety margin compared to glass fiber; 2) for both types of fibers in all variants of fiber content, the central layer gives a higher safety factor and smaller displacements than the inner one; 3) the internal arrangement of the composite layer relative to the central one causes a significant increase in transverse displacements and a decrease in the safety margin, which reflects a decrease in stiffness under internal pressure; 4) increasing the concentration of reinforcing fibers in the wall thickness increases the safety factor (especially with a central arrangement) and stiffness, which is expressed in a decrease in displacements.

Comparison with the simulation results of a 6061-T6 aluminum pipe shows that reinforced pipes with central reinforcement outperform the aluminum analog by 1.5–3.3 times, which confirms the potential for increasing operational reliability when switching to composite structures. At the same time, composite pipes are characterized by increased deformability: minimum displacements of 6.2–6.3 mm are two orders of magnitude higher than the value for an aluminum pipe of 0.14 mm due to the lower elastic modulus of polymer composites in the transverse direction, which should be taken into account when designing systems with tight deformation tolerances.

The obtained dependencies allow for a justified choice of the composite layer configuration (type of fiber, its volumetric content, and arrangement along the wall thickness) when designing composite pipes for a given range of operating pressures.

## CONCLUSIONS

The obtained simulation results of the ultimate load-bearing capacity and stress-strain state of reinforced polymer pipes under burst pressure loading show that the best ratio of safety factor and displacement is achieved for pipes with a central arrangement of the reinforcing layer and a high fiber content, especially in the case of carbon fiber reinforcement. The use of a reinforced polymer pipe allows increasing the strength by 230 % compared to the base aluminum pipe, but it is accompanied by an increase in elastic displacements, which determines the expediency of its use in conditions where the load-bearing capacity is a critical parameter, rather than stiffness.

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