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Fiberglass Coating of Railway Culvert Pipes

L. Trykoz[1], O. Pustovoitova[2], S. Kamchatnaya[3], V. Semenova-Kulish[4]

[1]*Ukrainian State University of Railway Transport, Feuerbach Sq., 7, 61050, Kharkiv, Ukraine,*
E-mail: lvtrikoz@ukr.net
[2]*O.M.Beketov National University of Urban Economy, Marshal Bazhanov Str., 17, 61002, Kharkiv, Ukraine,*
E-mail: pustovoitova999@gmail.com
[3]*Ukrainian State University of Railway Transport, Feuerbach Sq., 7, 61050, Kharkiv, Ukraine,*
E-mail: kamchatnayasn@gmail.com
[4]*Ukrainian State University of Railway Transport, Feuerbach Sq., 7, 61050, Kharkiv, Ukraine,*
E-mail: semenova.vita.v@gmail.com

Abstract

The culvert pipes in the railway roadbeds are an important element of the infrastructure. The pipes are subjected to chemical and electrochemical attack, the influence of frost and groundwater. Aggressive medium causes a negative change in a concrete structure and metal and results in pipe destruction. A glass-reinforced plastic band is proposed for internal and external protection of the pipes. The pipe construction, known as "pipe-in-pipe", has been obtained by the winding of the outer fiberglass layers at an angle of 45° to the longitudinal direction of the pipe. Then the pipe samples have been placed on a test stand to determine the presence of deformations. The experimental results showed that the glass-reinforced plastic band possesses the necessary physical and mechanical properties. It can be used for spiral reinforcement of the pressure concrete pipes instead of metal reinforcement. Replacement of steel reinforcement with fiberglass allows creating a pipe design for laying in the places with increased corrosive effects of groundwater, as well as in soils with a significant value of leakage currents and stray currents.
KEY WORDS: *culvert pipe, fiberglass coating, strength, deformation*

1. Introduction

Protection of railway infrastructure objects against destruction is one of the main problems in the railway industry. Such objects are culvert pipes in the railway embankments. The pipes are subjected to the effects of various loads and aggressive mediums. Due to corrosion, the pipe operational life is far less than the calculated one. There are many studies are devoted to the enhancement of the metal and concrete constructions by an external layer [1-4]. To manufacture composite pipes in [1], glass fibre is dipped into a resin solution and wound around a core pipe. Hybrid nanoparticles, modified by epoxy resin and applicable for the filament winding process, were studied in [2]. However, toxic vapours and low productivity under high temperature conditions are serious problems connected with the usage of the epoxy resin. A new non-toxic composition material has been proposed in [3]. This waterproof composition contains an acrylic polymer and a filler. More effective protection has been offered in [4]. It consists of the fibreglass plastic that is wrapped around pipes and gives them bigger strength and corrosion resistance.

The multilayered filament wrapped composites are widely distributed for strengthening and protection of the different constructions [5-7]. The Optimization of filament winding parameters for the design of a composite pipe is performed in [5]. This paper presents the design stages for the selection of the optimal fiber, matrix, volume fraction, and winding angle θ. Based on analytical estimations, the authors [5] found the optimal technological parameters with volume fraction 40% ÷ 60% and winding angle $\pm 44.5° < \theta < \pm 52.5°$. From these considerations, they suggest a customization in the pipe production, based on the estimated axial loads in exercise. The paper [6] presents the design optimization of filament winding composite cylindrical shell under hydrostatic pressure to maximize the critical buckling pressure. The design variables are fiber orientation and the corresponding number of layers. Results show that filament winding angles have a more significant effect on the critical buckling pressure than the number of layers. In paper [7], an analytical model is proposed to calculate the winding process-induced residual stresses for the multilayered filament wound composite parts. In the modeling the winding process, the contribution of the highest winding tension to the residual stresses of previously wound composite layers is calculated. Then, the value of complete residual stresses is obtained based on the principle of elastic superposition. The proposed analytical model is of high accuracy and can be used to calculate the residual stresses due to winding tensions for the multilayered filament wound composite parts.

Based on the winding and curing process, an analytical model of residual stresses was established in [8]. This model can be used to analyse the stress state of a composite cylinder before and after removal of a mandrel. The degree of shrinkage deformation and the coefficient of thermal expansion are introduced as controlled variables to develop a model of residual stresses. The numerical simulation and slitting experiment for composite wrapped cylinder after mandrel removal are investigated. The analysis shows that the maximum difference of radial stress between the model and the experiment is 0.14 MPa around the neutral axis. In this case, the maximum difference of hoop stresses is 2.6 MPa which occurs along the outer radius. In addition, the corresponding errors hoop and radial stress are 9.0% and 7.7%, respectively. The result indicates that this model can be used to predict residual stresses and the winding tension to guarantee that the hoop wound cylinder with an inner liner has a uniform residual hoop stress. The new high-strength composite fibrous materials, such as fiberglass, basalt fiber reinforced polymers, carbon-filled plastics, proved to be quite perspective in the manufacturing of multilayer products and constructions. In this study, a pipe construction is offered which consists of an internal pipe (metal or concrete), a glass-reinforced plastic band, a heat-insulation layer (if necessary), and a second glass-reinforced plastic band (Fig. 1). The acrylic powder-liquid type plastic is applied as the binder to provide the adhesion strength between the pipe and the band. Powdered component (polymer) is a high-molecular methyl methacrylate-based substance. Liquid component (hardener) of acrylic plastic is methacrylic methyl ester (methyl methacrylate monomer). The pipe construction, known as "pipe in pipe", has been obtained during winding of the outer fiberglass band at an angle of 45° to the longitudinal direction of the pipe. After curing, the pipe samples have been placed on the test stand to determine stress and deformations (Fig. 2).

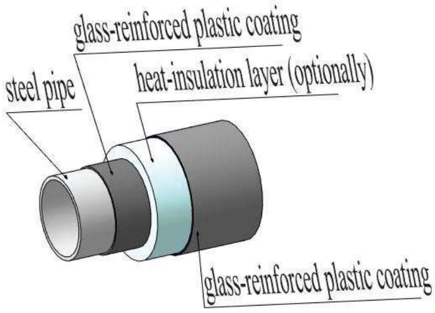

Fig. 1 The pipe construction

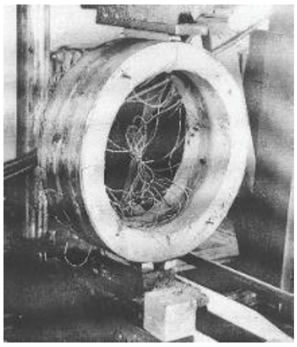

Fig. 2 The pipe testing

The aim of the test is to find out the maximum value of critical stress for the band during its pre-tensioning and winding process. The complexity of this challenge is the definition of the stress value which depends on the loading speed of the band. It necessitates a lot of test samples, a special test stand, stability of the test conditions, and long testing time. We applied the rapid test method which is as follow.

2. Theoretical Study

As has been shown in [4], the increase of a pipe diameter does not lead to the corresponding increase of its strength. The reason is the insignificant participation of external layers of concrete or steel in taking up loads. A needed effect can be reached by multilayer winding of prestressed steel wire or strip on a cylinder. The idea to form compound cylinder constructions is used extensively in civil engineering for manufacturing of the high-strength constructions. In this case, a brittle construction material obtains additional strength and plastic properties in the conditions of compressive three-dimensional stress. Using this effect, known "a hoop effect", a number of ways to reinforce concrete were developed: concrete in a steel wire coil, concrete in a pipe, concrete with tubular steel reinforcement, etc. High strength properties of such constructions made it possible to decrease the proper weight of constructions and save the construction materials (steel, cement, etc.). The developed new high-strength composite fibrous materials, such as fiberglass, basalt fiber reinforced polymers, and carbon-filled plastics, proved to be quite promising in the manufacturing of multilayer high-strength items and constructions.

There is an increase of deformations observed under a constant load. This increase stops when the load is below a certain limit. In this case, elastic deformations disappear immediately after load is removed. The plastic deformations remain. If the load is over a certain limit, the deformations grow until sample is destroyed. The maximum stress, which does not cause sample destruction regardless of load application time, is referred to as limit of long-term resistance. There are following principles that are applied to define the long-term resistance.

1. There is a linear dependence between a rate of the plastic deformation growing and the critical stress, which causes plastic deformations to appear.
2. The critical rate of growth the deformation corresponds to the critical stress.

The critical stress is considered to be a constant of the material under static loading. In dynamic tests the critical stress depends on the strain rate, the method of load application, and is not constant. The problem lies in the following question: what can be considered to be the dynamic strength of the material, and how to predict the ultimate strength characteristics under dynamic effects. The second problem is a stress relaxation in the glass-reinforced plastic band. The winding of every next layer of the band leads to decrease of the stress in the layer beneath. In Fig. 3 it is shown how the stress changes under winding of the band made of an isotropic material (nickel) and an anisotropic material (fiberglass plastic).

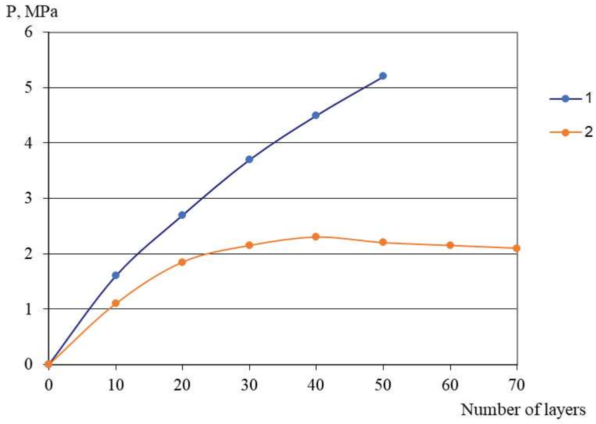

Fig. 3 The stress change under winding of the band made of an isotropic material *1* and an anisotropic material *2*

As can be seen in Fig. 3, the decrease of the prestressing force does not occur under the winding of the isotropic material. It means that the pressure grows in proportion to the number of layers. In opposite, this dependency becomes nonlinear for the anisotropic material even under a small number of wraps (Fig. 3, curve *2*). The fiberglass layers must work evenly in the thickness of the band. For this, the needed prestressing force must be provided in every band layer.

3. Experimental Study

To solve this problem the following approach has been applied. Based on the experimental results with samples that have different rates of deformation, dependence can be found between the critical stress and the rate of increase of the elastic deformation, which is simultaneously the growth rate of the plastic deformations. Three groups of the fiberglass band have been tested under the following deformation rates: $0.75{\cdot}10^{-5}$ s^{-1}, $1.25{\cdot}10^{-5}$ s^{-1}, $1.75 \cdot 10^{-5}$ s^{-1}. The band was stretched until broken. The experimental results are shown in Fig. 4. The stress increases linearly until a certain value. Then, increase slows down a bit while the destruction process develops in the sample. According to Fig. 4, the critical stress σ_s have been determined which corresponds to the transfer from elastic deformation to the plastic one for each of the three deformation rates. After that, the diagram has been plotted to show the dependency between the critical stress and the rate of its growth (Fig. 5). The critical deformation value ε_s is represented by dark dots. Tangents to respective curves are drawn for each dot. These dots correspond to the critical stress σ_s. These tangents cross an axis of abscissas at angles α_1, α_2, α_3, respectively. The slope of each tangent is equal to the rate of the growth of the critical elastic strain that corresponds to the found critical stress.

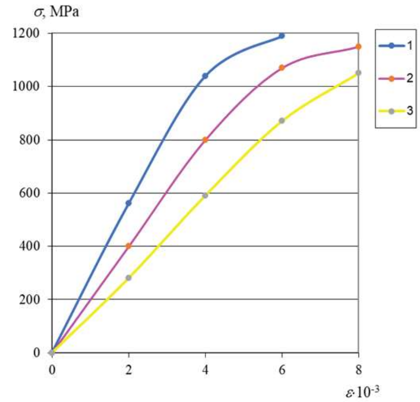

Fig. 4 Stress - deformation variation curve for deformation rates: *1* – $0.75{\cdot}10^{-5}$ s^{-1}; *2* – $1.25{\cdot}10^{-5}$ s^{-1}; *3* – $1.75 \cdot 10^{-5}$ s^{-1}

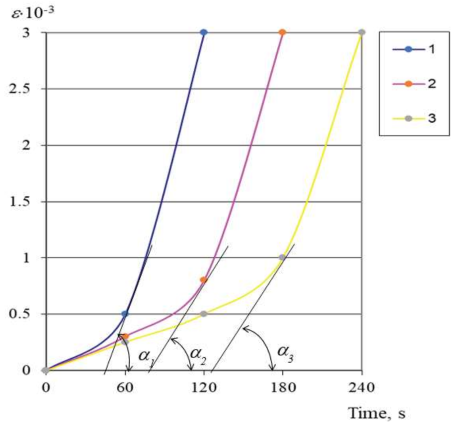

Fig. 5 Deformation - time variation curve for deformation rates: *1* – $0.75{\cdot}10^{-5}$ s^{-1}; *2* – $1.25{\cdot}10^{-5}$ s^{-1}; *3* – $1.75 \cdot 10^{-5}$ s^{-1}

The next step is to plot a graph which shows a dependence between the critical stress σ_s and the critical rate v_s (Fig. 6, line *1*). To find out the limit of long-term resistance, a straight line is drawn through the obtained points σ_s. This line is drawn until it intersects the y-axis. The point of intersection is the value of critical stress when the rate of growth of elastic strain is equal to zero (Fig. 6, line *2*). This point is the value of the limit of long-term resistance sought for the fiberglass band. These test curves (Fig. 4 and Fig. 5) are obtained in experiments with the strain rate that varies from experiment to experiment. So, they are reference curves for a mathematical model of the dynamic deformation of materials. Based on this method, software will be developed for calculation of the critical stress.

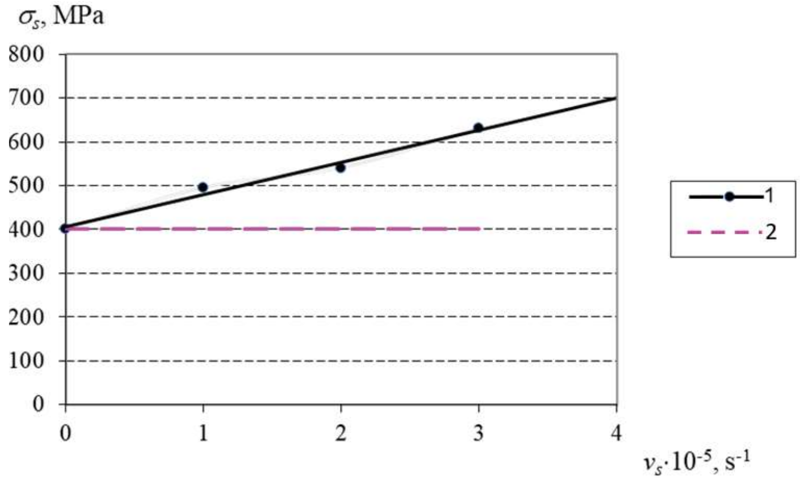

Fig. 6 Critical stress – critical rate dependency

At this critical stress of 400 MPa, the reinforcement band must be winded to provide the necessary compression stress in the pipe. Also, the plastic deformations will not appear under any winding rate at this critical stress. The critical stress is referred to as an important characteristic along with such parameters as the winding rate, a step and angle of an over-wrap, the tension force, etc. The change of the over-wrap direction, relative positions of the wrap, and the fiberglass tension has been made the management of the anisotropic properties for the building products and constructions possible.

4. Conclusions

Experimental data show that the stresses in the fiberglass coating depend on the winding rate. Also, it has been observed that the decrease of the prestressing tension happens due to stress relaxation and plastic strains. To prevent the appearance of plastic deformations, the critical stress value has been determined to be 400 MPa. This critical stress value is used to create prestressing tension of the glass-reinforced plastic band at any winding rate without the appearance of plastic deformations. It is a technological base for directed reinforcement of the products and constructions with the usage of the continuous filament winding method. This method allows:

- to create the effective type of the non-metal reinforcement;
- to execute biaxial and triaxial compression of the elements;
- to obtain the reinforcement that corresponds to an operational stress state;
- to develop a continuous reinforcement method for the constructions of any shape;
- to wrap a required number of layers for protection against corrosion.

According to physical and mechanical properties, the developed fiberglass plastic coating is a potential protective and strengthening material which allows creating the corrosion-resistant and durable materials.

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Contents

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