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Technologies of Production of Components of Electric Transmission Line Supports from Epoxy Binders by the Winding Method

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Abstract—Methods of production of large-scale articles from polymer composite materials (PCMs) are considered. It is shown that the technology of "wet" winding with the use of VSE-21 as a binder epoxy binder is most preferable.

Keywords: polymer composite materials, polymer binder, reinforcement, molding, winding
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Currently, polymer composite materials (PCMs), such as fiberglass and basalt reinforced plastics, are widely used in building supports. Abroad, fiberglass reinforced plastics have recently found wider application in supports and carriers of electric transmission lines (ETLs).

The geometric shape of the supports is, as a rule, plane cone or a cylindrical shell with an extension of up to 12 m. The carriers are made as formed bulks, with open and closed loops of section with a length of up to 9 m. The total scheme of the technology of manufacture of components from PCM is shown in Fig. 1. It is a quite complicated and multivariant process, since the properties of each of the components (filler and binder) can fundamentally differ. The technology of formation depends not only on the properties of the

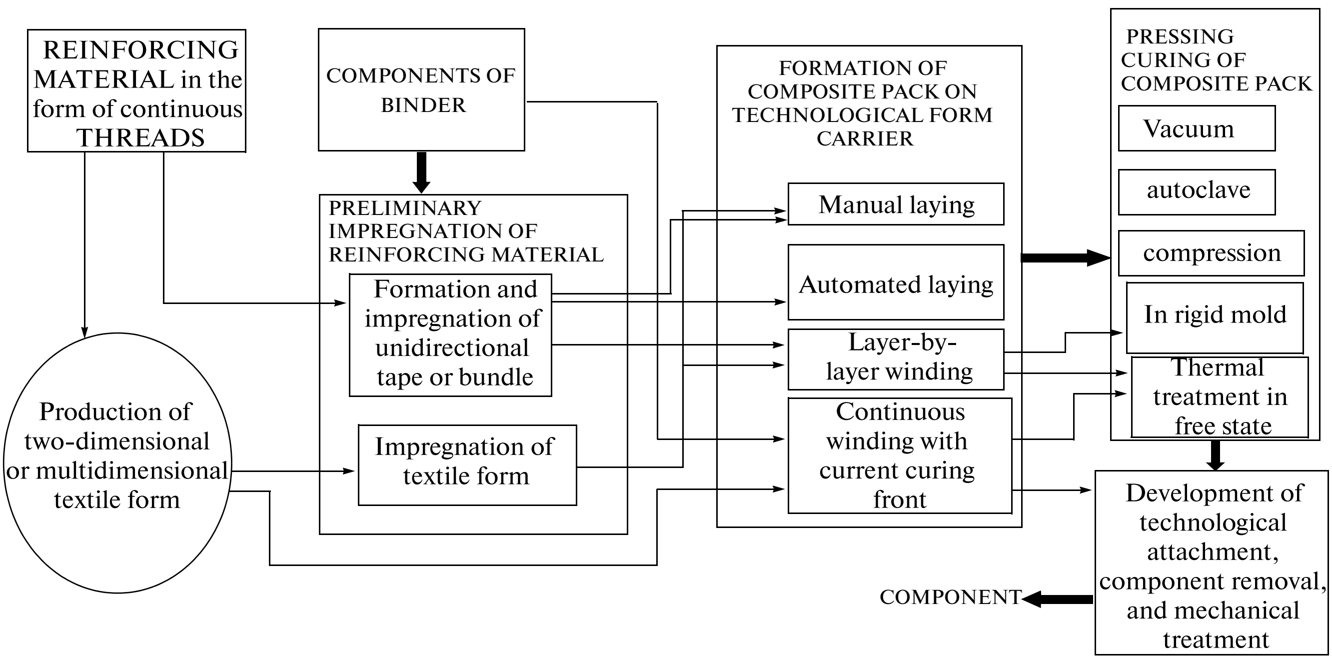

Fig. 1. Principle scheme of process of component production from PCM with the use of prepregs.

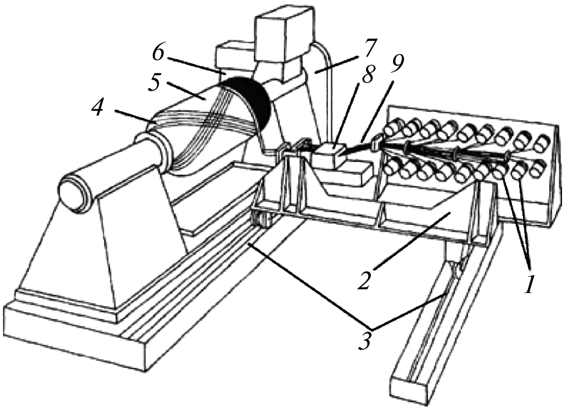

Fig. 2. Scheme of "wet" winding of component: (*1*) bobbin with threads, (*2*) bobbin holder, (*3*) laying–impregnating section, (*4*) helical layers, (*5*) mount, (*6*) circumferential layers, (*7*) rotary drive, (*8*) bath with binder, and (*9*) formed unidirectional tape.

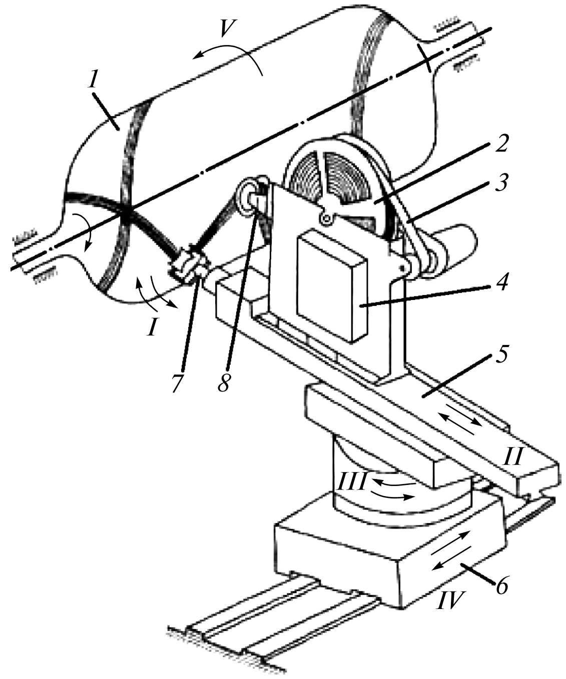

Fig. 3. Scheme of "dry" winding of article: (*1*) mounting, (*2*) bobbin with prepreg, (*3*) dividing 1
film, (*4*) heater, (*5*) support, (*6*) carriage, (*7*) head, and (*8*) tension device.

materials used, but also on the sizes of the articles obtained and their form and function.

The purpose of the present work is selection of an optimal technology for manufacturing ETL supports and carriers from PCM.

One of the most productive methods of forming the articles of various geometric shapes from PCM is layer-by-layer winding, which is used in production of [1]

—bodies of rotation (balloons, vessels, tubes, ties, sections);

—details of a nonround section with a rectilinear axis (spars, braces, stabilizers, stiffening members);

—details of a round section with curvilinear axis (air ducts, air intakes); and

—network structures (mesh frames, filters, trussed modules, stiffening members).

The principle of the winding technology is that the thread or tape of a reinforcing filler impregnated by polymer binder is placed under tension by a particular track on the technological mounting, the configuration of which corresponds to the inner surface of the detail prepared [2, 3]. The material packing occurs at the expense of the normal to the surface mounting of the constituent of the tension force. The material layers are formed at the expense of sequential shifting of each turn relative to the previous one by the width of this turn; moreover, the turns laid must be mounted in the state of statistical equilibrium, i.e., retained in a given position without slipping.

The following methods of winding are distinguished by the conditions of impregnation:

—"wet"—impregnation is performed during winding (Fig. 2);

—"dry"—winding is performed by preliminary
1 impregnated and dried tape (prepreg); and

—winding by an unimpregnated filler with ensuing impregnation.

The "wet" winding provides better moldability of 2
articles at high leaktightness; therefore it is mainly 3
used for production of large-size mountings of complicated configuration and high-pressure vessels. The productivity of the "wet" winding is not as high as that of the "dry" one, because of a limitation of the impregnation rate of the reinforcing material, and does not exceed 2–3 kg of the prepreg obtained per 1
minute.

The "dry" winding provides uniform content of the binder given during the prepreg production and, as a 1
result, stability of the article's strength properties by (Fig. 3). Using the "dry" method, the production standard rises and productivity increases. However, with this method, it is necessary to provide significant tension of the fittings. The supply rate of the preliminary impregnated reinforcing material in such technology can achieve 10 kg/min.

Sand–adhesive mixtures, joining cement, plaster–sand mixtures, Wood alloy, wax–paraffin mixtures, etc., are used as materials for single-use (destructible) mountings.

There are various methods of winding, which differ from each other in the conditions of impregnation of the reinforcing fillers—in the scheme of reinforcing or type of winding track.

The schemes of reinforcing can be divided into

—circumferential (transverse) winding;

—longitudinal winding;

—orbital winding, a winding in the longitudinal direction by plane windings at a sharp angle to the axis;

—helical winding; and

—direct winding, a winding of fabric on the rotating mount on the whole width of the roll.

When complex schemes of reinforcing are used, a combination of two methods of winding—helical–circumferential, orbital–circumferential, longitudinal–helical, etc.—is used.

During winding, a given scheme of the elementary layers with normalized preliminary tension is realized, which is almost impossible during laying. However, during winding, the reinforcing scheme is limited by the condition of "not sliding" of thread from the track of laying on the mounting determined by the friction coefficient of threads by the mounting and between each other, as well as by the geometric form of the part that is being wound. In practice, winding by geodesic (or nearly so) lines of this rotation shell is used, which imposes particular restrictions on the selection of the reinforcing scheme in designing parts.

In contrast to "dry" winding, the reinforcing track is impregnated during its being delivered into a carriage with a roller–layer. The reinforcing tape during "wet" winding is formed from individual complex or woven roving threads immediately before being delivered to the laying–impregnating section. However, a very important advantage of the "wet" winding pro-
1 cess, in contrast to winding by prepreg, is the possibility of controlling the level of the preliminary tension of each elementary thread, which allows one to not only equalize the tension of each thread, but also form a composite pack with the level given of the preliminary tension of the reinforcing fibers. Achieving the level of preliminary tension of the fiber in practice compared with the level of working stress in the structure is possible only with the use of the "wet" winding method.

The advantages of "wet" winding include the possibility of using cold-curing binders. In this case, during production of a large-size part, the winding process is carried out with the current front of the binder curing.

The leading companies manufacturing equipment for "dry" and "wet" winding areas are McClean Anderson (United States), EHA Composite Machinery GmbH (Germany), and Mikrosam (Macedonia). They produce a variety of equipment, which have software allowing one to model winding processes and a highly automated system of control, allowing one to minimize the influence of the human factor on the process of part manufacture, which allows one to fabricate parts (almost in an automated mode) at rates of up to 100 m/m.

Among Russian companies, OJSC Savelov Machine-Building Factory, which produces a variety of special winding equipment, is a leader.

The process of composite pack pressing and binder
1 curing with the use of prepreg technologies is performed by well-known traditional methods: in autoclaves and vacuum bags, the compression method in a rigid mold, or direct pressing or in free state. Curing and pressing in autoclaves or only with the use of vacuum, as well as direct pressing in a rigid mold, are used for technological processes with the use of laying and winding and the formation of composite packs. Compression molding is used, as a rule, only after prepreg 1
laying, and the curing in the free state is used only after "wet" winding with a guaranteed level of the preliminary tension of the reinforcing threads.

For a component for general engineering, a sufficient level of quality is achieved with the use of the vacuum method of molding; for this purpose, only an industrial oven with a corresponding volume of the working zone is needed.

To prepare components by direct or compression pressing, a technological attachment that not only provides the geometric form of the article, but also the given deviations of the geometry during the action on it of the internal pressure of pressing, is required. For large-size articles, such methods of creation of the molding pressure will lead to significant complications and an increase in weight and mold cost. It is worthwhile using direct pressing or compression molding and the corresponding attachment for elongated articles, the length of which significantly exceeds the cross-section area, for example, an ETL support.

Recently, a technological attachment made of PCM has been widely used in the production of articles from PCM. The advantages of such attachments are clear, since problems such as production of large-size articles are solved. One of them is the compatibility of the thermal deformations of an attachment and prepared large-size component: the difference of the coefficients of the thermal expansion of traditionally used materials as the material of attachment and a PCM component leads to residual stresses that causing a defect in shape in the components after molding (buckling).

Use of PCM for the technological attachment allows one to select the reinforcing material and scheme of its laying during production of the attachment itself in such way as to minimize the difference of the thermal deformations between the detail and attachment.

In addition, during production of the attachment from PCM, it is sufficient to introduce into its material heating elements providing uniform heating of the component by area; moreover, the power inputs for thermal treatment decrease in comparison with the use of a simple industrial oven.

Thus, the use of vacuum molding and heated attachment from PCM in the production of large-size articles is determined to be a resource-saving technological process.

The analysis performed of construction and tech- 4
noeconomic factors of various technologies (table)—in particular, relative volume of manual (not automated) work and equipment productivity, complexity,

Comparative characteristics of molding technologies of large-size articles from glass-reinforced plastic

Method of production	Method of curing	Method of molding	Brief characteristic of quality	Estimate of productivity	Relative labor content of manual work, %
“Wet” winding on rigid mounting	Hot	Vacuum or autoclave	High stability	Low	15–20
	Cold	Without use of special equipment	Average stability	Low	5–10
“Dry” winding on rigid mounting	Hot	Vacuum or autoclave	High stability	High	15–20
Laying of prepregs on rigid mounting	Hot	Vacuum or autoclave	Low stability (at manual laying)	Average	15–20
Pultrusion with impregnation in die	Hot		High stability	High	5–10
Pultrusion with use of prepregs	Hot				5–10

and cost—allowed one to select the following types of technology for production of standard constructions.

For the sections of the vertical column and structural beams, the most preferable is the technology of “wet” winding with ensuing vacuum molding, which allows one to obtain a glossy external surface. It is proposed to use woven roving thread of RVMPN trademark as the main reinforcing material, with local reinforcements being made from the woven roving fabric from a similar fiber (bast mat); it is proposed to use epoxy binder of VSE-21 trademark, the properties of which are given below, as the binder.

Characteristics of VSE-21 Binder

External view, color	Transparent homogeneous fluid resin from light-brown to dark-brown color
Glass transition point, °C:	
dry	170
wet*	155
Moisture absorption**, %	1.2
Density of cured binder, g/sm^3	1.2487
Time of gelatinization at 120 ± 2°C, min	20
Apparent viscosity at 60 ± 2°C, Pa s	0.20
Shelf life of binder components at 25°C, months	3
Shelf life of produced binder at 25°C, days	2
Shelf life of produced binder at – 5°C, days	15
Ultimate tensile strength, MPa	75
Elastic modulus in tension, GPa	3.4
Relative tensile elongation, %	3.2

* Boiling for 7 h in water.

** Exposure up to equilibrium saturation at 60°C and relative moisture 85%.

This binder has a high elastic modulus, quite good values of the relative elongation value, and good adhesion to fiber. To provide adhesion strength of the binder–fiber joint, as a rule, the following ratio of elastic modulus of binder E_b and fiber E_f is used: $E_b/E_f = 0.06–0.01$; i.e., the elongation of the binder must be slightly greater than that of the fiber. It is easy to meet this requirement for this type of binder with the use of woven roving thread. High mechanical strength, chemical stability, good electrical properties after curing, and small shrinkage are also advantages of this binder.

As a result of the analysis performed, materials and technological solutions that allow one to provide a required quality of ETL components that are least labor- intensive and have the highest productivity are chosen.

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SPELL: 1. prepreg, 2. moldability, 3. leaktightness, 4. technoeconomic