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Features of production technologies of composite parts for the railway industry

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Abstract. The present article presents a comparative analysis of the technologies of manufacturing parts made of polymer fibrous composites. For each technology the advantages and disadvantages of its application are given, as well as the types of manufactured products are indicated. Based on these features, conclusions were made about the possibility and effectiveness of the described technologies for the production of composite parts for the railway industry. In addition to the standard, widely used technologies, 3D printing, which refers to the rapidly developing additive technologies, was considered. The comparison of technologies according to the key parameters is given in tabular form. **Key words:** composite materials manufacturing technologies, application efficiency, elements of railway structures.

1 Introduction

From the anisotropy of properties of fibrous composite materials (CM) follows not only their unique mechanical characteristics, but also certain technological features of manufacturing of certain assemblies and parts, which varies for different types of transport. For railway transport the most effective application of CM is provided not only by weight reduction, but also by solution of some engineering problem, for example increase of durability or quality wearing, increase of running smoothness, maintainability, simplicity of manufacturing and etc [1-7]. The chapters of the article are structured as follows: description of composite parts production technology, elements of railway constructions produced by the specified technology, effects achieved.

2 Winding

One of the oldest composite manufacturing technologies is the winding technology, which is used for continuous fibers, unidirectional ribbons, yarns or bundles. Winding is a relatively simple technology, the concept being that the continuous filler is fed from the bobbin onto a rotating mandrel, while being impregnated with a binder (figure 1) [8].

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Depending on how the filler is impregnated, there are two types of winding: wet and dry (figure 1) [9-10]. Wet winding involves impregnating the yarns immediately before winding on the mandrel. For this purpose the fibers go from the bobbin holder to the impregnating bath, are impregnated by the binder by pulling through the bath itself or by contacting with the roller, then through thread tensioner and spreader they come to the arbor and then are hardened. It is convenient to mold large-sized bodies of rotation using the wet winding method.

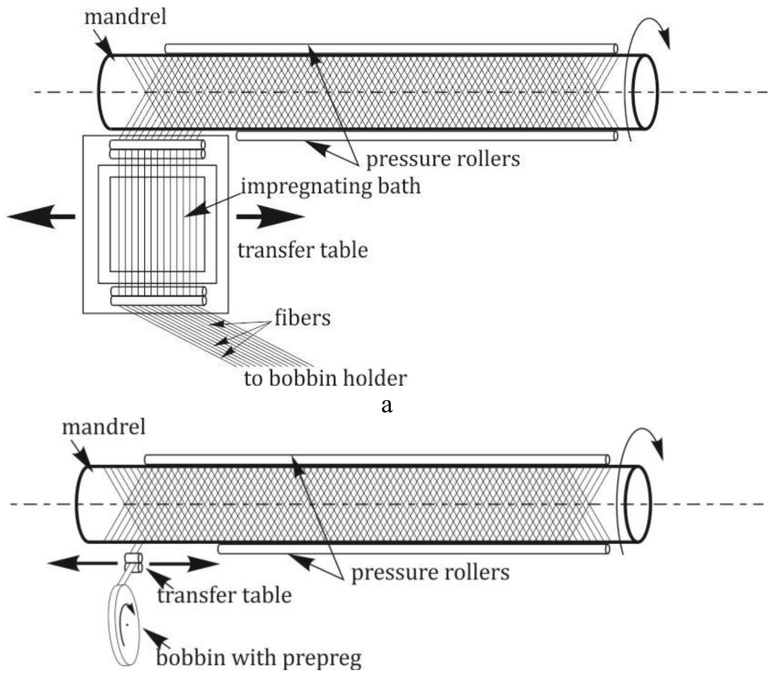

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Fig. 1. Winding process: a) wet; b) dry.

The impregnation of the fibers with a resin binder in dry winding technology takes place long before the direct winding onto the arbor. The fibers and yarns are impregnated with the matrix in a separate process step in which any excess binder is removed, and the composition itself is partially polymerized and wound into rolls. The resulting half-finished products are called prepregs, which are subsequently wound on an arbor similar to wet winding fibers, followed by final polymerization. Notably, under certain conditions, prepreg can be stored for up to several months, which simplifies the management of the production process. The dry winding method also allows the use of thermoplastic binders, which is not possible with wet winding. This winding technology is considered more productive, but it is also more expensive due to a separate prepreg manufacturing operation as well as the need for special storage conditions [10].

The winding technology is used to form bodies of rotation, for example, railway tanks (generally speaking, the cross-section of the body of rotation does not have to be round) which are used to transport liquid chemically active substances. The trains consisting of dozens of tanks are spread out over hundreds of meters. The advantages of fiber-reinforced plastics are obvious here - weight reduction: the use of fiber-reinforced plastic will reduce the weight of the tank by about 3 times, in addition it allows to get corrosion and chemical resistance and non-fragility.

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3 Pultrusion

One more technology for molding composite parts with continuous fibers is pultrusion (figure 2) (from English - pull through). The idea of the technology is to pull the fibers or ribbons impregnated with the binder through the heated die [11]. Pultrusion is used for forming composite profiles while the cross-section of the die determines the shape and size of the cross-section of the profile.

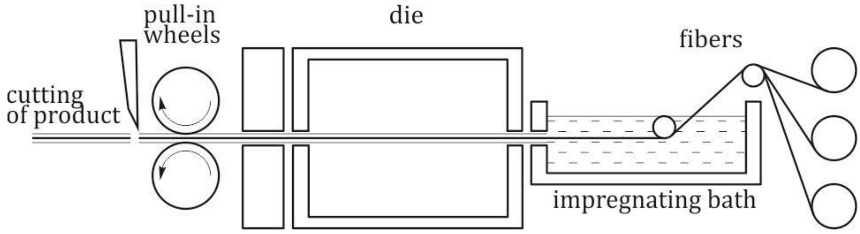

Fig. 2. Schematic diagram of the pultrusion process.

The pultrusion process is carried out in two ways: the filler is impregnated in a special container in front of the die or the dry fibers laid in the profile are impregnated directly in the die [12].

Die temperature and speed of pulling are very important for initial curing of the material, so that the profile does not lose its shape as it leaves the die. Further curing is done in the furnace. Molding pressure is also created by the die by means of a gradual decrease in cross-sectional dimensions.

The advantages of pultrusion are high precision, simplicity and universality of production: to change the shape of the profile it is necessary to change the preforming hole. The disadvantages are the need for precise control of the viscosity and temperature of the binder, as well as the pulling speed [12].

If it is required to produce the skeleton of the structure, pultrusion is irreplaceable. In the rolling stock it is possible to use pultrusion pipes and profiles as strength elements of composite panels for the sidewalls and roofs of the cars. While the sidewalls are made of steel profiles and sheet metal, however Ural Carriage Works has produced the hopper car and roof for it of composites. Laying of the fibers along the profile considerably increases its stiffness as the elastic modulus of the unidirectional package of layers is maximal, that is why the profiles made of fiber composite materials are not inferior to steel ones in strength and stiffness and besides they gain much in corrosion resistance and weight.

Profiles made of composite material are used in the construction of bridge spans [13-14].

4 Contact molding

The most accessible technology of composite products manufacturing is contact molding (figure 3). The basic principle of the method is layer-by-layer laying of fabrics or mats on a special mold and their further impregnation with a curing binder [14]. There are two more important steps in this technology: processing of the mold with the special anti-adhesion composition before laying in order to remove the product without any problems after impregnation and compaction of the composite by the special rollers after laying of every layer. Roller compaction not only creates molding pressure but also removes some air from the liquid binder to reduce the porosity of the material [15].

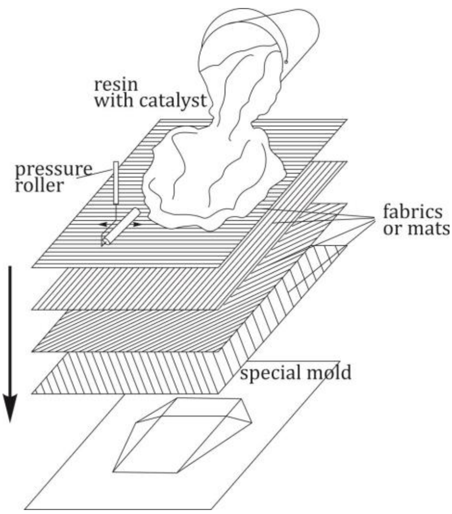

Fig. 3. Schematic diagram of the contact molding process.

According to the type of filler, as well as the technological equipment used, contact molding is divided into three technologies: manual lay-up, automated lay-up and sputtering [14, 16].

Manual lay-up (Figure 3) is the simplest and cheapest technology, involving manual labor of molders. Hence the obvious disadvantages of the method: high requirements for molder qualification, since the quality of the part directly depends on him, as well as the need to work in protective gear, since the technology is considered to be "dirty".

Automated lay-up is similar to manual molding, except that the material is stacked on the mold by a special machine that moves along complex trajectories. It should be noted that automated lay-up may result in wrinkles that cannot be eliminated by the machine, so prepregs and tapes of smaller widths are used for this process.

The sputtering technology is used to mold products using a mixture of binder with chopped fiber. The polymer in the liquid state is fed into the forming zone through the spraying heads, on the other side the chopped fiber is fed there as well. In order to remove the air and create forming pressure the composite is rolled. The spraying process can be manual or automated.

The main disadvantages of the technology are relatively low productivity and low material usage factor, but contact molding allows relatively inexpensive creation of large structures of complex shapes with minimum molding costs.

Contact molding is used for single-unit production of large items such as small ships and boats, car hulls and various panels. For the railway industry, molding makes it possible to produce passenger car bodies, as well as various internal elements with complex surface curvature.

5 Resin transfer molding

The RTM technology (figure 4) is based on the injection of a resin under pressure into a special mold with a pre-packed filler and subsequent curing [16]. The tooling is similar to the press mold - the mold consists of a punch and a die. The die is heated to the desired temperature for fast curing of the binder.

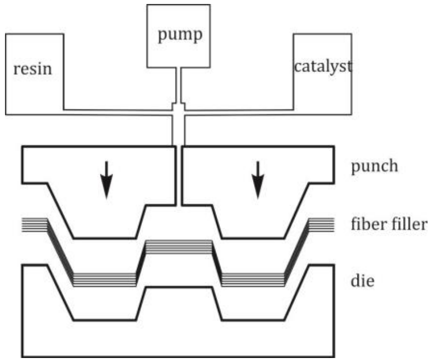

Fig. 4. Schematic diagram of the RTM process.

Since the binder channels have a small diameter, the liquid matrix must not be viscous. This makes it impossible to use thermoplastic polymers in RTM [16, 3].

There are two types of technology - direct pressure impregnation (RTM) and vacuum impregnation (RTM-light). In RTM the solid punch is pressed against the die by additional pressure, while impregnation in vacuum involves the pressing of the die and punch by atmospheric pressure due to the vacuum inside [9]. The light punch is mirrored to the die.

The advantages include the possibility of full automation of the production process, high material usage rate and low porosity of products. The disadvantages are the high cost of tooling production and its narrow specialization (the die is used for one particular product), and high energy intensity of production.

High accuracy and repeatability of obtained parts allow using pressure impregnation for mass production.

Application of this technology makes it possible to produce such products as railway sleepers made of composite materials. Such track structure elements are not affected by weather conditions and have higher operational characteristics, such as cold resistance.

6 Vacuum infusion

The vacuum infusion technology (figure 5) involves impregnating the lined reinforcing fabric in a vacuum bag using atmospheric pressure and further curing of the bag [17, 18]. The vacuum package, in addition to the fabric and vacuum bag, can include a molding surface, distribution fabric, impregnation fabric and a gating system for oversized parts. An important feature of the technology is that the polymer binder must be degassed before impregnation to reduce the porosity of the material.

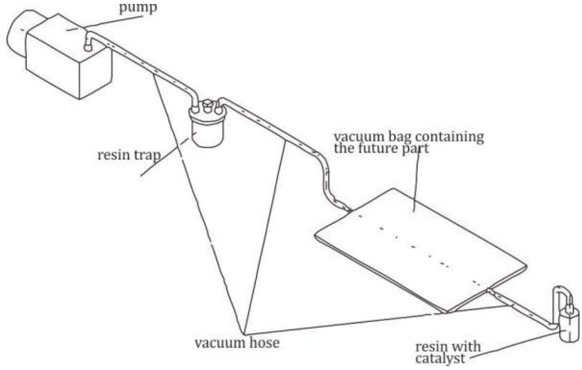

Fig. 5. Schematic diagram of the vacuum infusion process.

A vacuum pump creates a vacuum inside the bag, after which the degassed binder impregnates the fabric and the excess of it goes into the resin trap.

Vacuum molding can be done in an autoclave, which reduces the viscosity of the binder and improves the impregnation of the filler [1, 18-21].

The main advantages of vacuum infusion are simplicity and manufacturability, low cost of equipment and tooling, as well as versatility - the technology allows molding products of any shape and size. The disadvantages are high requirements for molder skills, labor-intensive manufacturing of a sealed vacuum bag, as well as high consumption of equipment materials - hoses, impregnating and distribution fabric, as well as the vacuum film itself are disposed after each impregnation.

Thermosetting liquid polymers and polymer films, which are partially cured matrixes, are used as binders for vacuum infusion. The film is placed on the fabric in a vacuum bag and impregnates the fibers under pressure. The advantage of such a matrix is the equal thickness over the entire surface of the part [22].

The vacuum infusion method is quite simple. It is used to manufacture the frames of wheeled carts for city trains, as well as individual load-bearing elements. By laying the fibers at specified angles, it is possible to obtain the desired characteristics of the structure, and they can vary greatly in different areas of the same element.

7 Additive technologies

Today a perspective and dynamically developing direction is the creation of composite structures with the help of additive technologies. First of all, we are talking about three-dimensional (3D) printing. By analogy with the well-known plastic printing, a control program is created with the help of software and the construction is created layer by layer according to the specified trajectories. The only difference is that the polymer is fed into the die along with the reinforcing components (Figure 6). The fibers can be continuous (printing is continuous and the construction is created from a single fiber) or cut (finely dispersed fibers are distributed throughout the volume of the plastic) [23].

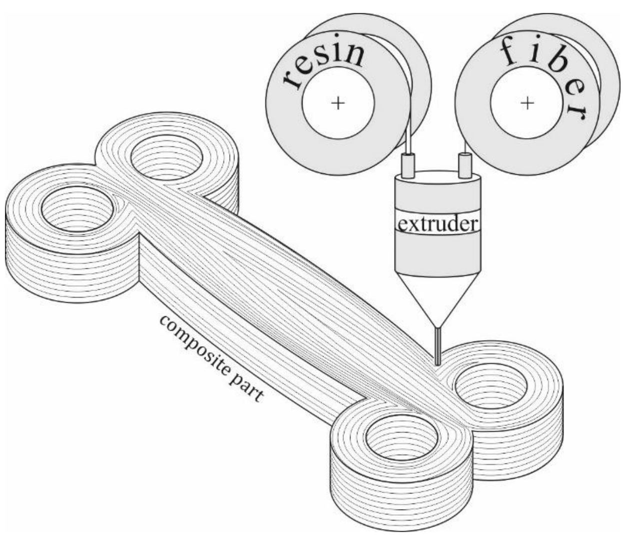

Fig. 6. Schematic diagram of fiber 3D printing.

To create polymer composites by 3D printing, a more heat-resistant matrix can also be used, which increases the requirements to the working temperatures of the die and makes adjustments to the cooling of the construction. This and many other features of the application of additive technologies for the production of PCM are now being actively studied by scientists at the international level. The huge potential and possibilities of 3D printing of composites are of high interest both for science and for production [24-25].

For railway transport with the help of 3D printing technologies it is possible to produce elements of fasteners, brackets, corners, supports. The most valuable thing in this method is very high flexibility of production - it is possible to produce a construction element of almost any shape with quite good mechanical characteristics.

8 Comparison of technologies

As each technology has the strongly stated advantages and disadvantages the choice of technology at production of composite parts for railway industry should be based on comparison of technologies on the certain parameters that is convenient to do by means of special tables. The example of a qualitative estimation (in terms: "low - high") of methods of manufacture on key parameters is resulted in table 1. In this case, the parameter "product characteristics" includes not only mechanical characteristics, but also technological ones - porosity, accuracy of dimensions and geometry, etc.

Table 1. Comparison of key parameters of composite technologies.

Technology	Relative cost per kilogram of product	Manufactured products	Product characteristics	Productivity	Degree of automation
Winding	Low-Medium	Pipes, shafts, cylinders	High	Medium	High
Pultrusion	Medium	Rods, profiles	High-Very high	Medium-High	Very high
Contact molding	Very low	Panels of any profile, covers	Low	Low-Medium	Low
RTM	High-Very high	Complex profile load-bearing panels and parts	Very high	Medium-High	High
Vacuum infusion	Medium	Complex shaped multi-sized parts	Medium-High	Medium-High	Very low
3D prining	High	Multi-sized load-bearing elements	High	Very low	Very high

Of course, a comparative analysis based only on qualitative estimates of parameters cannot give a satisfactory result, so if necessary, each parameter can be specified and quantified depending on the problem to be solved. For example, to compare specific values of the strength, elastic modulus, and porosity in the section "product characteristics" or the number of finished parts for a certain time interval in the section "productivity".

9 Conclusion

The above-mentioned technologies of production of structures from polymer fiber composites, today, are practically a complete list of the methods applied in practice. Certainly, there is a large number of all possible variations of the presented technologies, however the basic techniques in them remain, only the tooling changes. Moreover, it is important to underline once again, that the considered techniques are applicable only for PCM production. For creation of structures from metal or ceramic composites (for example, inserts for brake pads, contact rails, grinding wheels) other much more labor-consuming and complex technologies are used.

In order to ensure high technological and operational characteristics of the finished products it is necessary to consider the units and assemblies as a whole, taking into account their connection with the overall system. Only in this way it is possible to qualitatively use composite materials for production of constructions. Of course, it will require enormous efforts, but the technologies and methods of design and calculation are known, the only thing left is to apply them!

Think composites! - The famous composites scientist S. Tsai has once said, this phrase suits to the full extent for the railway!

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