Principles of construction of the technological system for the manufacture of construction polymer reinforcement

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Abstract. The features of the technological operation of thermosetting the rod of composite reinforcement, which is performed in the polymerization chamber, are considered. Conditions are created to ensure the guaranteed quality of the thermosetting process, which consists in maintaining the stability of the main process parameters for a given speed of rod pulling. These parameters are identical to the set of influence factors recorded during definitive tests of rod samples at the certification of production. The factors influencing the quality of the product, which include 35 parameters of the curing process, are identified. A system for maintaining the stability of the parameters of the curing process, based on creating a forced, adjustable gas-air mixture flow rate and assessing the quality of the curing process by the heat flux, is proposed. This heat flux is carried by the rod and applicable to industrial conditions on real production lines.

1. Relevance

The construction of buildings and structures of the aerospace infrastructure using generally accepted classical solutions and projects does not always allow the plans of designers to use conceptually new engineering networks, types of components and models of defence equipment to be realized. In many cases it becomes necessary to place special engineering networks and communications inside buildings and structures. The best option for the placement of engineering utilities and communications is their laying in the underground space under the raised floor, made of slabs [1-3], reinforced with composite polymer reinforcement (CPR). The use of such fittings fully protects cable lines laid under raised floors from the action of electric and electromagnetic fields, because the CPR is a dielectric.

In modern realities, the use of radio transparent components is a prerequisite for the design and construction of special-purpose facilities, which include buildings and structures of the aerospace infrastructure. In them, the CPR should have not only high strength, but also have guaranteed design physical and mechanical properties [9-11], which determine its radio transparency for the means of detection (density, section shape, surface roughness, colour, etc.). Ensuring of these requirements can be achieved while maintaining stable parameters of the technological production process.
2. Features of the process
The process of manufacturing the CPR consists in the impregnation of the linear with a thermosetting resin (figure 1), the moulding of the rod in the die and the subsequent curing in the polymerization chamber.

**Figure 1.** Diagram of the process of creating the CPR rod on the production line.

In this process, we single out the multifactorial technological system for creating the rod of the CPR (figure 2). The first element of the system is a rod, which is characterized by the following geometrical parameters: the nominal radius of the power section of the rod is $R$; the deviation of the actual diameter from the nominal value, mm - $\Delta D$; the rod surface area receiving heat flux - $S$; single piece of reinforcement rod - $\Delta L$; the mass of a unit of linear size of the rod - $m_l$; the mass of "raw" rod - $m_{raw}$; the roving mass in a single segment of the rod - $m_r$; the rod specific mass - $\rho$; the value of the heat flux of a rod falling on a single segment is $\Delta L \cdot W_{\Delta L}$; heat transfer rate in the rod body $V$; the specific heat of the material of the rod - $c$.

**Figure 2.** Technological system of manufacturing the CPR rod.
The second element of the system is the curing chamber (figure 3). In the technological system, it is determined by such parameters as: the length of the active zone of the curing chamber - $L_{cc}$; the area of the flow area of the air channels at the entrance to the curing chamber - $S_a$ (section 0-0, figure 3); the area of the flow section of the channel for the expiration of the gas-air mixture from the curing chamber - $S_{g-am}$ (section 5-5, figure 3); the density of air entering to the curing chamber - $\gamma_a$; the density of the gas-air mixture flowing from the curing chamber - $\gamma_{g-am}$.

![Figure 3](image)

**Figure 3.** Typical sections of the gas-dynamic path of the polymerization chamber with forced ventilation of the working cavity.

The third element of the technological system is a thermosetting resin, which is characterized by the following parameters: the temperature of the thermosetting resin in the “raw” rod at the entrance to the curing chamber - $T_{tr}$; molecular mass - $Mr$; melting point - $T_{mp}$; density - $\rho$; breaking stress - $\sigma$; elastic modulus - $E$; heat resistance according to Martens - $H$; viscosity coefficient - $\mu$ and others.

The most important element in the system is the technological process occurring in the polymerization chamber. It consists of three successive stages (figure 4): preliminary heat treatment of rods; polymerisation of the resin on the surface of the rods and resin curing as the completion of heat treatment.

![Figure 4](image)

a - the beginning of heat treatment    b - dynamic stage    c - completion of heat treatment

**Figure 4.** Stages of curing of the rod in the polymerization chamber.
The following parameters influence the operation of this element in the technological system: the temperature of the rod at the outlet of the curing chamber - $T_r$; the normalized value of thermal energy - $[W]$; heat transfer coefficient - $\lambda$; the heat flux of air entering the solidification chamber is $W_a$; heat flow carried away with the gas-air mixture - $W_{g-a m}$; specific heat of air entering the curing chamber - $C_a$; the specific heat of the gas-air mixture from the curing chamber is $C_{g-a m}$; mass of thermosetting resin in the liquid phase - $m_{tr}$; the normalized duration of thermal exposure - $[t_f]$; the duration of stay in the chamber of a single segment of the rod $\Delta L - t_{cc}$; the coefficient of stability of the process of curing - $k_s$; rod pulling speed - $V_{pr}$; the speed of the incoming air flow - $V_a$; flow rate of the gas-air mixture - $V_{g-a m}$; temperature inside the curing chamber - $T_{cc}$; air temperature at the entrance to the curing chamber - $T_a$; the temperature of the gas-air mixture at the outlet of the curing chamber - $T_{g-a m}$.

The technological process in the polymerization chamber has the following features [4-6]:
- the material is cured directly in the created product;
- the finished product is created in the course of the production cycle for efficiently constant pulling at working speed $V_{pr}$; as it is known [9], the change of this speed when receiving a product with a certified specific size is unacceptable;
- there is a strong dependence of the design strength characteristics of the product on the duration of the curing operation $\Delta t_{cur}$ and the parameters of the curing chamber mode.

The experience of creating the CPR rod shows that its guaranteed quality is achieved in the case of maximum stability of the parameters of the polymerization process mode in the curing chamber.

On this basis, the analysis of the functioning of the technological system in order to obtain a quality CPR is proposed to be built on the principle of identifying criticalities [6, 7] with the help of a certain set of indicators. One of these indicators has the following content.

Curing in the polymerization chamber takes place on a “raw” CPR billet, which has the shape of a cylindrical rod in the form of a linear filler with a temperature $T_{lin}$ bonded with a liquid thermosetting resin at a temperature of - $T_{tsr}$.

When entering to the heat-affected zone of the polymerization chamber, the surface of the rod is exposed to heat flow - $W$, the value of which is proportional to the square of the radius of the power rod - $R$ and the temperature inside the curing chamber - $T_{cc}$. The length of stay of a single length of rod - $L_1$ in the polymerization chamber will be.

$$t_{cp} = \frac{L_1}{V_{pr}}$$

During this period of time, heat energy passes through the surface of the rod $W_{s1}$.

The duration of such heat exposure has a regulatory limit - $[t_f]$. This is a regulatory limit

$$[t_f] = f(\lambda, R, T)$$

depends on the heat transfer coefficient - $\lambda$, the rod radius - $R$ and the temperature in the curing chamber - $T_{cc}$.

The actual duration of the rod under the influence of heat flow is determined by the pulling speed of the rod $V_{pr}$, and the length of the curing chamber $L_{cc}$.
\[ t_{so} = \frac{L_{so}}{V_{ap}} \]  

(2)

The criticality in this case will be determined by the ratio between these two durations (1) and (2). When they coincide \( t_{cc} = [t_r] \), a criticality arises, which is associated with non-observance of the technological procedure in the course of the polymerization for a given diameter of the reinforcing bar.

Of course, to ensure compliance with the process regulations, it is necessary to monitor and maintain the relevant parameters stable in time and at a given level for the duration of the certification tests.

Ensuring the stability of the parameters of the curing process occurs at a decrease in the dynamism of heat exchange processes between the cold air entering the chamber, the heating rod and the gas-air mixture leaving the chamber.

This can be achieved: a) by creating in a typical polymerization chamber [4] an adjustable in size and stable heat removal by pumping air and a gas-air mixture; b) the organization in the polymerization chamber of an adjustable exhaust gas-air mixture.

The parameters controlling the process are the readings of the air flow rate sensor in the exhaust duct (figure 3) and the temperature of the gas-air mixture flow.

To do this, according to the indications of the flow rate of the gas-air mixture - \( V_{g-a,m} \) and its temperature - \( T_{g-a,m} \), a special control system turns on the PID-regulation of heating in the polymerization chamber, as a result of which the process in the polymerization chamber will occur within the limits specified by the specified technological regulations, thereby ensuring design strength properties product characteristics.

**Conclusions**

A system has been proposed for maintaining the stability of the parameters of the curing process, based on creating a compulsory variable-value gas-air mixture and assessing the quality of the curing process by the amount of heat flow carried by the rod. With the help of this system, the stability of technological parameters within the pre-established technical regulations was ensured by identifying and overcoming criticalities.

The features of the technological process of thermosetting the rod of composite reinforcement, which is performed in the polymerization chamber, are identified and formulated. The conditions for ensuring the guaranteed quality of the heat-curing process are formed, which consists in maintaining the stability of the main process parameters for a given rod pulling speed. These parameters are identical to a set of influence factors recorded during definitive tests of rod samples during production certification.

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