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The “Engineer” publishes the most significant results of scientific and applied research carried out in universities of transport profile, as well as other higher educational institutions, research institutes, and centers of the Republic of Uzbekistan and foreign countries.

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Modeling of curing under IR lamp of multilayer fiberglass parts based on epoxy binder and determination of heating effect on the process kinetics

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Abstract: The results of modeling the kinetics of the heating process of a 20 mm thick GFRP part are presented. Exothermic effects related to the peculiarities of epoxy binder curing were taken into account during modeling. Using Siemens NX software, the temperature distribution along the thickness of the fiberglass sample was determined. It was found that the curing process of composite structures of large thickness is significantly influenced by self-heating of oligomer, as well as the changing value of volumetric heat capacity in the process of polymerization.

Keywords: fiberglass, glass fiber-reinforced polymer (GFRP), epoxy binder, curing, infrared heating

1. Introduction

Nowadays, such polymer composite materials as glass plastics, organoplastics and basalt plastics are becoming more and more widespread and are used in aircraft construction, mechanical engineering, in the manufacture of rocket and space technology products and in many other industries [1, 2]. If the reinforcing filler in such PCMs is a fabric, in conditions of single and small-scale production, the main technology of parts manufacturing is vacuum infusion, and in conditions of mass production - pressure impregnation (a variation of which is RTM technology) [3].

As a rule, epoxy materials are used as a binder in the production of composite structures, the curing of which can occur at elevated temperatures ranging from 100°C to 200°C. The process of curing (or formation of mesh polymers) is an irreversible transition of the binder from liquid to solid state, which leads to polymers with a spatial structure. The choice of curing temperature is determined by the composition of the binder used, however, the kinetics of the heating process and the total duration of the curing process is influenced by the heat transfer mechanism, which is completely determined by the technological equipment used. In addition, the effect of self-heating has a significant influence, which is greater the greater the height of the liquid column of the polymerizing oligomer.

Most fiber reinforcing materials have low thermophysical characteristics (heat capacity and thermal conductivity), which leads to the occurrence of large temperature differences across the thickness of the composite structure during curing. Such reinforcing fillers include glass, basalt and organic fabrics (tapes, fibers). In the scientific literature, much attention has been paid to the study of the kinetics of the heating process during the curing of PCM parts, including glass-reinforced plastics [4-8], however, the vast majority of researchers considered only heating under convection conditions, in which drying cabinets (or ovens) are used as the technological equipment for heating. Nowadays, infrared heating units (IR units), which provide fast heating of thin-walled composite structures to temperatures of +150°C and even more due to radiation, are becoming more and more widespread.

The aim of the work is to study the kinetics of the curing process of fiberglass parts under the influence of infrared heaters of different radiation power.

2. Objects and methods of research

Theoretical evaluation of temperature distribution in the process of heating the part depending on the power of the used heater is carried out in this work. The calculation model is a square part made of fiberglass (Table 1) with geometric dimensions of 200x200x20mm. The tooling is made of the same material as the part. Stochastic glass mat was used as filler, which allowed to consider this PCM as isotropic. As a binder the epoxy composition of VSK-14-1 grade was used, which is widely used in aircraft construction.

Table 1

Properties of GFRP

Density, kg/m^2	1800
Specific heat capacity, J/(kg·°C)	900
Thermal conductivity, W/(m·°C):):	
λ_1	0,55
λ_2	0,55
λ_3	0,51
Coefficient of thermal expansion, $°C^{-1}$	$5\cdot10^6$

The simulation process was performed in the CAD/CAM/CAE program Siemens NX in the Pre/postprocessor application with tools for finite element modeling and visualization of results, which includes reference multidisciplinary simulation workflows.

The modeling process consisted of several steps:

- creation of an electronic geometric model of the part and tooling;
- creation of a finite element model that takes into account material properties and thermophysical properties of the structure;
- setting of boundary conditions and loads on the modeling object.

In addition, convection is modeled on all surfaces of the part, except for the bottom surface, to take into account the

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characteristics of the environment - the air in the room. For this purpose, characteristics such as:

- convection coefficient, with a value of 15 $\frac{W}{m^2K}$;
- the initial ambient temperature is 25°C.

But at the same time, the settings were set to heat the ambient air at a rate of 0.5$\frac{°C}{min}$ max. to 36°C.

The next step was to set the radiation heating directed from the heaters from top to bottom on the part. The settings were:

- IR spectrum;
- value of heat loads at different lamp heating modes of 1600W and 2400W.

The thermo-optical properties of fiberglass with an emission coefficient equal to 0.8 were set for the parts.

The values of heat load, depending on the power of the used heating source, are given in Table 2.

Table 2

Heat load values as a function of time per grid element

Time, minutes	IR lamp power, W	Heat load
0-37	1600	0,05
37-40		0,14
40-…		0,27
0-20	2400	0,07
20-23		0,1
23-…		0,35

3. Results and discussion

Figure 1 shows the temperature distributions on the top, center and bottom of the part at 55 minutes of heating. Initially, heating was carried out to a temperature of +120°C. It was assumed that the heating duration would not exceed 30 min. Figs. 2 and 3 show how the temperature value changes along the thickness of the GFRP part depending on the power of the IR unit used for heating.

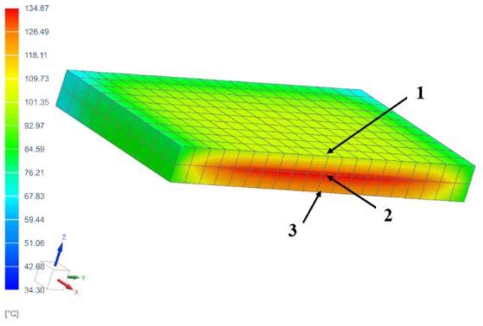

Figure 1. Example of temperature calculation on different parts of the part: 1 - top; 2 - middle; 3 - bottom

As a result of calculations, it was found that at the power of the heating unit of 1600 W (Fig. 2) it is not possible to provide heating to the required temperature for a given period of time (30 min) and therefore we limited heating to a temperature of +110°C. At 35 min, the heating was turned off, resulting in the top of the part cooling very quickly to a temperature of +80°C. However, at the same time, an exothermic reaction began, which actually provided an additional source of heat, allowing the temperature in the middle part of the part to reach +130°C at 55 minutes. The exothermic reaction provided heating of the middle and bottom parts of the part, e.g., the temperature on the bottom part of the part reached a temperature of +100°C only by 60 min. Thus, the use of an IR unit for heating, with a power of 1600 W not only does not provide uniform heating of the fiberglass part thickness, but also does not allow to reach the required heating temperature in a given period of time. At 60 minutes of heating, the difference between the top and bottom of the GFRP part was just over 20 °C.

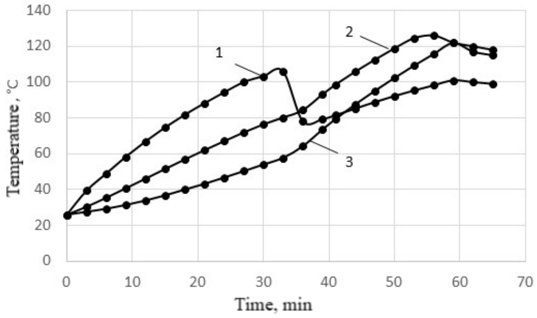

Figure 2. Temperature gradient along the thickness of the specimen at 1600W heater power for different parts of the part: 1 - top; 2 - middle; 3 - bottom.

Analysis of the results shown in fig. 3, allows us to draw the following conclusions: at a power of 2400 W the fiberglass part is heated significantly faster and reaches the temperature +160°C within 30 min. However, the character of temperature distribution in different parts of the part is completely similar to that presented in Fig. 2, i.e. immediately after switching off the heating source, there is a rapid cooling of the upper part of the part, while the middle and lower parts, on the contrary, are heated. Thus, at the peak of the exothermic reaction, a more uniform heating of all layers and reaching the required temperature values is observed over the entire time interval. At 50 minutes of heating, the difference between the upper and lower parts of the GFRP part was about 10°C.

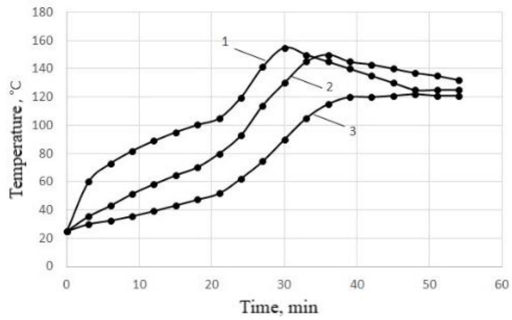

Figure 3. Temperature gradient along the specimen thickness at 2400W heater power for different parts of the part: 1 - top; 2 - middle; 3 - bottom

As the thickness of the part decreases, there is a proportional decrease in the values of the temperature gradient along the thickness, and for fiberglass parts, 5 mm thick, it is not more than 15°C, and for parts, 10 mm thick, it does not exceed 26°C.

4. Conclusion

A model of isotropic fiberglass plastic was developed and calculations were performed to determine the kinetics of temperature changes in different parts of the part (top, middle and bottom) when using infrared units for heating.

As a result of these calculations it was found that for an isotropic fiberglass part with a thickness of 20 mm, it is not possible to ensure its uniform heating along the thickness when using infrared heating units with a given power of 1600W and 2400W. The comparative analysis of two considered installations showed that only the installation with the power of 2400W allows to provide heating of the upper part of the fiberglass part up to the set temperature of +130°C for 22 min, but the values of temperature gradient along the thickness amounted to 45°C.

Thus, only the IR-heating unit with the power of 2400 W can be used for curing of GFRP parts with the thickness of 20 mm and more.

The structural properties are much better for composite parts with foam filler. While the Airex is about 1.5 times thicker, it is 4 times lighter than impregnated non-woven reinforcement material.

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