Thermophysical Analysis of Thermal Polymerization of Silica-Organic Cladding for Silica Fibers

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Synopsis

The paper shows the advantages of graded furnaces for the thermal polymerization of a silica-organic polymer cladding for silica fibers. Owing to the optimal longitudinal distribution of the heaters a fivefold increase of the fiber drawing speed can be achieved using heaters of the same lengths and power.

INTRODUCTION

Nowadays high-speed fiber drawing is receiving much attention.[1-3] High speed improves reliability and fabrication efficiency of the fibers. One of the main factors limiting the speed of fiber drawing is the rate of the cladding polymerization. Silica-organic polymer polymerization is performed in few-meter long furnaces, the drawing speed being as high as 600 m/min, at the temperatures up to 800°C.[3] The aim of this work is first to measure the polymerization speed of the Soviet industrial silica-organic polymer SIEL, depending on the temperature, up to its destruction, and, second to develop longitudinal heaters of optimal temperature profile for the fiber cladding polymerization using furnaces of the same length and power.

THE SPEED OF HEAT POLYMERIZATION OF A SILICA-ORGANIC POLYMER FILM

The speed of polymerization depends significantly on the temperature of the compound mass. The temperature dependence of the polymerization speed of the silica-organic polymer SIEL in early works has been measured only in the low temperature region and for large compound masses.[4] The polymer sewing up is characterized by the polymer being a thin film (~ 100 μm) and the temperatures actually being higher than those available in literature.[4] The dependence of polymerization speed (A) on T for thin films has been measured experimentally and is presented in Figure 1, polymerization time (A^{-1}) being taken as the minimum time which is necessary to provide the mechanical strength of a fiber.

FIBER CLADDING POLYMER TEMPERATURE IN THE HEATER WITH UNIFORM TEMPERATURE PROFILE

According to our evaluations the polymer heating is mainly achieved owing to the heat transfer. The polymer temperature on a moving fiber at the

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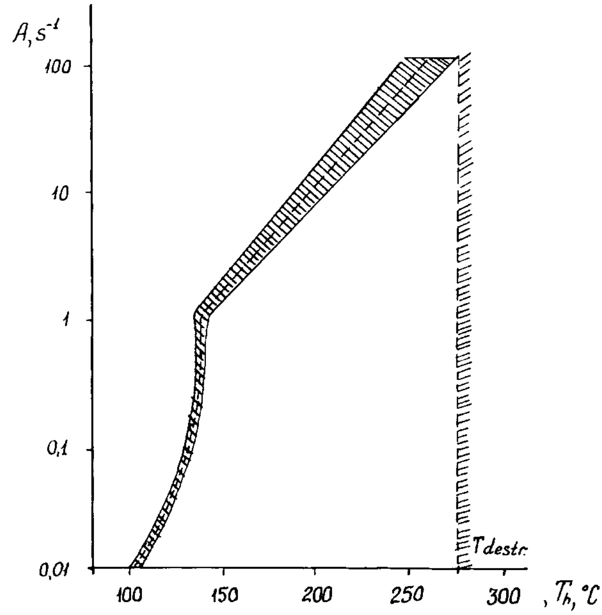

Fig. 1. The dependence of the polymerization speed of the SIEL silica-organic polymer on the temperature.

environmental temperature T_h will be described by the law[5]

$$T = T_h\left[1 - \exp\left(-\psi\frac{\alpha}{c\rho}\frac{2}{R}t\right)\right] \tag{1}$$

where t is the heating time, ψ is the ratio of the polymer average surface area to the average fiber volume, C and ρ are some relevant values of the heat capacity and density calculated from the thermophysical characteristics of a polymer and a fiber, R is the outer radius of the fiber, and α is the heat exchange coefficient of the fiber coated by a polymer, which can be calculated using the cooling curves of the heated samples. As the measurements show, its value is

$$\alpha = 4 \times 10^{-3}\Delta T \tag{2}$$

where ΔT is the temperature difference of SIEL and the environment.

It is clear from (1) and (2) that the real temperature of SIEL is lower than that of the environment (T_h). Heating is quick only when this difference is significant.

OPTIMAL LONGITUDINAL DISTRIBUTION OF THE HEATER TEMPERATURES FOR THE SILICA-ORGANIC POLYMER POLYMERIZATION

Assuming that the polymer temperature and, consequently, its polymerization speed increases greatly with the increase of the heater's temperature, we propose a design of a furnace with high temperature in its front part and with a relatively low temperature in its other parts. For a detailed analysis of the process of polymer heating on a fiber, a model of a two-step furnace with the heater temperatures T_{h1} and T_{h2} and lengths $l_1 < l_2$ has been used. Turning our attention to the furnace of a small length and a not very high average temperature (300°C), we can use the temperature dependence of SIEL polymerization speed in order to calculate the time of fiber cladding polymerization in such a furnace for the different correlations of T_{h1} and T_{h2}. Thus Figure 2 shows that the first and short step of a furnace significantly improves the efficiency of low-power furnaces.

In order to check these calculations, experiments were conducted on a laser drawing set up[6] with the length from the heating zone up to tuning roller not exceeding 3 m.

For the polymerization of the silica-organic cladding a heater was used consisting of 3 steps: 0.1 m, 1 m, and 0.1 m long, respectively. Such a three step furnace was used in order to simplify the technique of the experiment. At first the temperature of the whole heater (first, second, and third steps) was the same (300°C); and the maximum fiber drawing speed which could be achieved without the increase of losses (V) was about 25 m/min. Then the

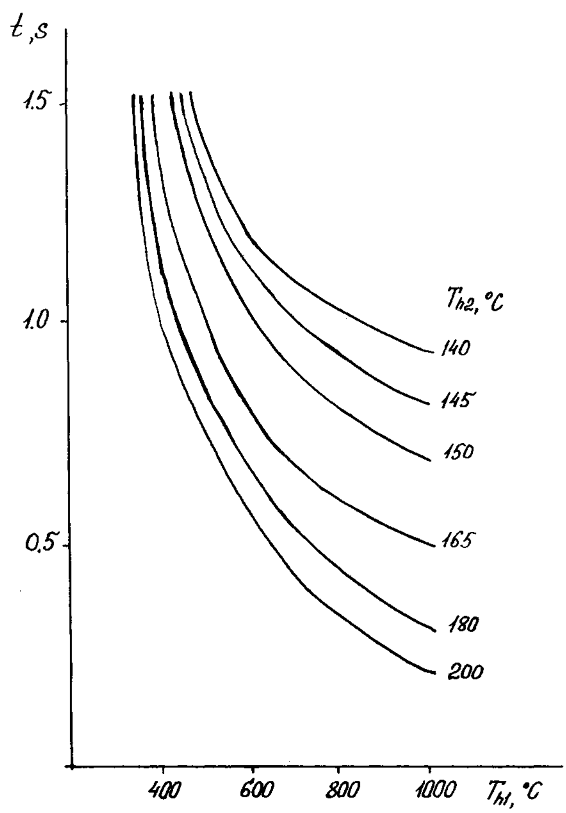

Fig. 2. The time of polymerization of fiber silica-organic cladding, passing the first step of the heater at the temperature T_{h1} and the second one is at the temperature T_{h2}. The total length of the heater is 1 m; its average temperature, 350°C.

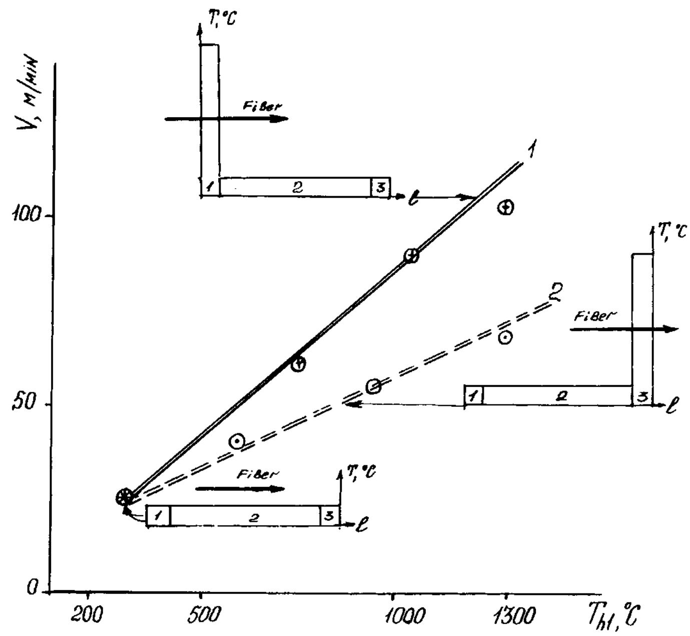

Fig. 3. The theoretical and experimental results of polymerization in a two-step furnace. The temperature in the low temperature fonts (steps 2 and 3 for case 1; steps 1 and 2 for case 2) is 200°C; the temperature in the variable temperature one (step 1 for case 1, step 3 for case 2) is marked at the abscissa axis.

first step was heated up to T_{h1}; the second and the third ones had the temperature of 200°C. Thus we can consider the temperature profile of a furnace to be of two steps.

Figure 3 (curve 1) shows the dependence of the drawing speed increase on the temperature of the first step of the heater, the temperature of the other part of the furnace (200°C) being constant. When the temperature of the first step was $T_{h1} \cong 1200$°C, the speed became as high as 100 m/min.

Then the third step of a furnace was heated up to T_{h3}, the temperature of the first and second ones being 200°C. The fiber drawing speed did not increase so significantly as in the first case with the temperature increase in the last step T_{h3} (Fig. 3, curve 2). The experimental data shows good agreement with the numerical calculations.

CONCLUSIONS

Thus we showed the expediency of the graded furnace usage for the high-speed thermal polymerization of a fiber silica-organic cladding, though we did not aim to achieve top speeds of the fiber drawing.

It is shown that a four- to fivefold increase of the fiber drawing speed can be achieved without a significant increase of the power as a result of the optimization of the furnace longitudinal profile.

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