Influence of microwave electromagnetic field on the structure of polymers

E Vasinkina, S Kalganova, V Alekseev, Yu Kadykova, S Arzamastsev, A Dolzhikova
Yuri Gagarin Saratov State Technical University, Saratov, 410054, Russia

Abstract. The results of experimental studies of the microwave electromagnetic field effect on the structure and physical and mechanical properties of polymeric fibrous materials are presented. These methods and tools for studying the microwave effect on this object. The possibility for the nonthermal microwave modification of thermoplastic polymers has been proved.

Introduction
Treatment with high-frequency and ultrahigh-frequency (microwave) electromagnetic field (EMF) is used in a metallic materials processing, particularly when modifying the surface of small-sized titanium products, and polymeric materials, in particular for synthetic fibers nonthermal modification [1,2]. However, an information on this modifying effect mechanism of the microwave electromagnetic field on polymeric materials is fragmentary. In the authors opinion, this explanation of the non-thermal microwave modification nature of polymers can be found in polarization effects, their specific features at ultrahigh frequencies. Due to this effect of an external microwave electromagnetic field, without disruption of chemical bonds, conformational changes occur in the polymer macromolecules. They are related to a change in the interdomain regions molecular packing density, as a result which the crystallinity degree of the polymer changes and, as a consequence, these properties are modified. Obtaining the experimental studies results showing this influence of the nonthermal microwave treatment technological regimes on its structure and the physical and mechanical properties of polymer materials is an actual and important scientific research component.

Methodology
To conduct research on this modifying microwave effect on dielectrics, an automated microwave conveyor system was developed (Figure 1). A source of microwave energy with a 3 kW power and a 2450 MHz frequency is applied. The power supply is equipped with a rectifier and a filter, which ensures a stable continuous operation mode of the magnetron [3].

At this magnetron exit the protecting ferrite gate for the generator of microwave oven is used. The microwave power adjustment is carried out smoothly with the help of a thyristor converter and is registered by the anode current magnitude. This exact microwave power is set using a variable attenuator (Figure 2 a). At the entrance to the microwave module there are devices for measuring the incident and reflected power (Figure 2 b). Through the microwave camera passes a transport tape from the radio-transparent material located at the maximum of the electric field E of the electromagnetic wave.
The study objects was synthetic chemical fibers with anisotropic properties. To study the structure of polymer materials, the following methods were used:
- IR spectroscopy using the «Specord-75 IR» spectrophotometer and the «Infraium FT-801» Fourier spectrometer in the 400-4000 cm\(^{-1}\) region;
- the method of electronic raster microscopy using the YSM-5300 LV microscope from JEOL (Japan); gold was deposited in a plasma discharge vacuum at a temperature of 25 ± 2 °C to create a conductive layer on the sample surface, the elemental composition was studied using an analytical attachment to the Microscope Link OXFORD (England) [4].

**Results**

We studied this non-thermal microwave modes effect on fiber polycaproamide. It has been found that unit tenacity of fiber increases by 12-15 % and thermal stability, on average, by 4.6 times (Figure 3 a). The effect is observed under the short-term microwave influence for 5-10 seconds, while the object temperature remains steady. This fact indicates non-thermal nature of microwave electromagnetic field modes influence on polymeric structure of polycaproamide fiber. It was found a slight relaxation of unit tenacity by 3-6 %, though the value of residual effect points to polycaproamide non-thermal modification.

As the microwave treatment result of the textured polycaproamide fiber, an increase in the fiber specific breaking load is observed in comparison with the original fiber not processed in microwave
fields by 11-19% at 500-800 W power levels and the microwave exposure time in 20-30 s (Figure 3b). The fiber relative elongation decreases after microwave exposure and to a greater extent with the microwave treatment time of 30-40 s [5].

![Figure 3 (a, b). (a) Specific strength of fiber; (b) Effect of microwave power on the heat resistance of fiber](image)

We studied the use efficiency of microwave electromagnetic field non-thermal effect on polycaproamide fiber, doped with fire retarder T-2, that is due to the increase of fiber sorption capacity by 14%. According to electron microscopy, under microwave effect fire retarder penetrates into the fiber volume and lays on the surface as 0.5-8.0 nanometers fine particles, whereas without microwave effect fire retarder mainly lays on the fiber surface as more coarse 0.20-0.30 mm particles and aggregated forming of fire retarder molecules (Figure 4) [6,7].

![Figure 4(a, b). Fire retarder T-2 distribution on the surface of polycaproamide fiber: processed in microwave electromagnetic field (a); without microwave processing (b), (2000 x)](image)

**Conclusions**

By infrared spectroscopy method it was found that non-thermal microwave effect leads to the change in the polycaproamide structure connected both with intramolecular and intermolecular hydrogen bonds and conformational changes in polymer molecule. These infrared spectroscopy results fit the electron microscopy data. We discovered the order increase in the polycaproamide structure which can
cause the fiber hardening and the increase of its sorption capacity under the non-thermal microwave effect.

This experimental study proved the existence of microwave electromagnetic field non-thermal modulating effect on polymeric materials. We studied the influence of duration and microwave electromagnetic field effect power on physical and mechanical properties of objects. We obtained calculated values of electric field intensity at which best modulating effect is achieved after the processing in a microwave electromagnetic field.

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