Analysis of physical mechanical and structural characteristics of microwave cured organic polymer parts

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Abstract. This paper presents experimental research which has confirmed the benefits of the new technology of curing polymer matrix for both laboratory and full-scale components, and compares with polymerization in an electrical-heated oven. Strength tests of small size specimens made of organic polymer determined that after microwave heating samples are capable of withstanding 1.3 greater loads than after heating in an electric furnace. Flexural modulus of full-scale specimens of organo-plastic, which were cured in a microwave radiation field showed greater modulus than samples which were polymerized in an electrical-heated oven at 40\% and 20\% respectively. The microstructure of the samples treated in the electric furnace were found to be porous, inhomogeneous, binding in large portions mixed up with pores spotted, accumulates on the edges and a separate central zones. Polymerization in microwave oven however, gave a microstructure which is more uniform and the binder distributed throughout the volume.

1. Introduction

With regard to practical application it is important to experimentally verify the benefits of microwave curing polymer binders in full-scale specimen compared to the conventional method of curing in electric furnaces.

As is well-known, microwave technologies have a number of advantages compared to traditional methods such as: two and more order reduction of technological processes time, lower energy consumption, improved ecological state and cleanliness at the place of production, possibility of developing new products of better quality.

This article presents experimental confirmation that the quality of the finished product, which were cured in a microwave oven, is higher than that of product which was polymerized in an electrical furnace. Specifically, the microstructure of these samples and also mechanical characteristics are studied.

2. Preparation of experimental samples

In the course of the experiment small-size samples (Figure 1) and organic polymer tubes were wound over the dielectric expander made of cardboard. The original dimensions of full-size component is: length -1200 mm, inner diameter - 85 mm, outer diameter – 94 mm, gauge – 4.5 mm (Figure 2). Specimens were made from aramid fibers Armos 100A with a density of 1450 kg/m\textsuperscript{3} and the elastic modulus of 140 GPa, epoxy amine resin with active thinner was used as the polymer matrix.

Curing for full-size tubes was performed on the experimental plant with rectangular microwave cavity equipped with four magnetrons with 2400 W maximum total capacity of and the operating frequency of 2450 MHz. The combination of chamber dimensions, magnetrons layout and a U-shaped thin-walled steel mandrel provided uniform heating across the length and thickness of the tube wall.
due to retroflection and superposition of electromagnetic waves. The temperature was measured by thermocouples fixed in an isothermal plane at a short distance from the front surface inside the sample. The heated tube was placed in the central part of U-shaped mandrel with the open side facing to the magnetrons at a distance of several tens of millimeters from the bottom by applying radio-transparent plastic bearing (Figure 3).

**Figure 1.** The received experimental sample. **Figure 2.** Winding pipe machine RPN 380.

Besides experimental confirmation of the benefits of microwave curing in comparison with a traditional method for tubes from organic polymer, it is also necessary to compare weight and mechanical characteristics of the tubes made of fibreglass and organic polymer.

Geometrically similar tubes made of fibreglass and organic polymer were produced to compare weights (Figure 4). The weight of organic polymer tube in comparison with a similar fiberglass tube was lower by 24% and amounted to 1.91 kg and 2.52 kg respectively.

**Figure 3.** Location and spacing of blanks inside U-shaped mandrel microwave heating chamber. **Figure 4.** Tubes from organic polymer and fibreglass.
3. Experimental determination of mechanical properties of samples

Strength tests of small size specimens from organic polymer demonstrated (Figure 7) that after microwave heating samples are capable of withstanding 1.3 times greater loads than after heating in the electric furnace. The plant and the test circuit used for the small size specimens are shown in Figures 5 and 6.

![General view of plant STATIGRAF M.](image)

**Figure 5.** General view of plant STATIGRAF M.

![Test circuit.](image)

**Figure 6.** Test circuit: 1 – fixed clamp; 2 – specimen; 3 – movable clamp.

![Comparison of durability of organo-plastic part blank.](image)

**Figure 7.** Comparison of durability of organo-plastic part blank.

![Bending test.](image)

**Figure 8.** Bending test.

During the bending tests on the tubes of polymer composite materials (Figures 8 and 9), the amount of change in the diameter along the line of force exertion was determined. The error of measurement was ±1%.

The destruction of specimens from organic polymer continued to a quasi-plastic ball joint formation in a section. For identical fiberglass samples the experiment was carried out before destruction with crack formation.

It was found that the flexural modulus of full-scale specimens of organic polymers, which were cured in microwave radiation field is greater than the same modulus of samples made of fiberglass and organic polymers, which were polymerized in electrical-heated oven at 40% and 20% respectively (Figure 10).
4. The definition of the structural characteristics of organic polymer.
Examination of the microstructure and porosity of samples was performed using inverted-stage microscope of the flat field Neophot-21 working in reflected light.

The microstructure was studied in cross-sections of model samples and natural products from organic polymer.

In Figure 11, 12 results of the analysis of a microstructure of samples from organic polymer are represented. By means of the KSLite 2 program processing of the received results was carried out.

The microstructure of the samples cured in the electric oven is more porous and heterogeneous; the resin is unevenly distributed across the bulk tending to be located at the edges and several large areas in the center. In the case of the microwave cured samples the structure is more uniform and the resin is distributed evenly across the bulk.

5. Conclusions
As a result of the analysis of literary sources it was found that the value of the flexural modulus for the PCM based on fibreglass and epoxy resin, as well as organic fibres and epoxy resin is 25-35 GPa and 15-30 GPa, respectively. After manipulation of the experimental data presented in this paper, the modulus of elasticity is: 28.8 GPa for tube made of organic polymer, which was cured in a microwave oven and 16.2 GPa for the same tube cured in an electric furnace; 25.1 GPa for fibreglass tube, which was cured in an electric furnace. The results show good consistency of the experimental data with the data available in literature.

After testing and calculations it was established that the modulus of elasticity for tube from organic polymer cured by microwave radiation is higher than the modulus of elasticity for the same tube cured by traditional method by 40%. It is also possible to see that the modulus of elasticity of a tube from organic polymer which was polymerized in the field of microwave radiation is higher than the modulus of elasticity of a fiberglass tube which was cured in an electrical furnace by 13%.

All this is confirmation of the benefits of polymerization products of PCM in the chamber of microwave radiation compared to curing of PCM in a conventional furnace. By comparing results of the tubes from organic polymer cured in a microwave oven with fiberglass tubes it was found out that the weight of organic polymer tube was lower by 24%.
The results of structural analysis have shown that in the sample 1 (curing in a microwave oven) the percentage of pore is almost 20 times less than in the sample 2 (curing in an electric furnace), indicating that sample 1 cured more efficiently.

![Microstructure of organic polymers in ring specimens](image1)

**Figure 11.** Microstructure of organic polymers in ring specimens: a) - treated in a microwave oven, b) - treated in an electric furnace; 1-epoxy binder, 2 – pores.

![Microstructure of organic polymers in tubular samples](image2)

**Figure 12.** The microstructure of organic polymers in tubular samples: selection pore spaces and unreinforced binder:
- a) - Sample 1 (cured in a microwave oven);
- b) - Sample 2 (cured in an electric furnace); 1 - pores 2 - unreinforced binder.

6. References

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