The effect of barium titanate on the dielectric constant of a composite based on an epoxy press material

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Abstract. The paper considers the effect of the introduction of barium titanate (BaTiO₃) on the dielectric properties of a composite material based on an epoxy press material. The technology for preparing a composite material with a high dielectric constant is presented. The physicomechanical and dielectric properties of the composite are presented. The possibility of increasing the dielectric constant of the material is shown, as well as the technology of manufacturing the housing elements of spiral antennas. It was found that filling with 30% of the BaTiO₃ mass increases the dielectric constant by 1.5 times.

1. Introduction

The creation of new materials with specified functional properties continues to be one of the most important directions in the development of modern radio equipment. This is due to the increased technical requirements for microwave devices. So, for example, antennas are required to maximize bandwidth with minimal dimensions. One of the options for solving this tactical and technical problem is the use of materials with increased dielectric constant. Besides, these materials should provide a specified operating temperature range, moisture resistance, have sufficient mechanical strength and shock resistance, and also have a significant service life [1].

Traditionally, for the manufacture of helical antenna housings, a press material based on the epoxy resin is used [2]. Due to this, the antenna elements have good mechanical properties, low water absorption, and shrinkage. However, the dielectric constant of this material is 4.2-4.4. Various methods can be used to increase this material characteristic, for example, the introduction of a filler with a higher dielectric constant [3]. Barium titanate can be used as such a filler since Ti-rich compounds in the BaO-TiO₂ system show high relative permittivity and low dielectric losses. Consequently, the introduction of barium titanate into the press material should make it possible to obtain composite materials with high radio-technical characteristics (RTC). Besides, titanium compounds increase the strength, impact resistance, and heat resistance of the composite [4, 5].

To determine the dielectric constant of the mixture, the Lichtenecker ratio is used [6]. It links the dielectric constant of the components and their proportions in the system and allows you to calculate the assumed dielectric constant of the composite.

The paper [7] presents the results of using barium titanate as a filler for a composite based on polymethylsiloxane. It is shown that the maximum introduction of BaTiO₃ into the polymer base promoted an increase in the dielectric constant by 20%. However, for the manufacture of body elements, more durable structural materials have been used that work under vibration loads.

In connection with the above, the purpose of this work was to test the possibility of increasing the dielectric constant of a structural press material by introducing barium titanate. It is also necessary to
assess the possibility of manufacturing antenna elements from a composite material with improved RTC.

2. Objects and research methods
The object of the study was a composite material based on ED-8 epoxy-diane resin. As a hardener - diaminodiphenylmethane, as well as dye and accelerator UP-0632 [2]. The filler was barium titanate with a BaO/TiO$_2$ molar ratio of 0.95. The average particle size of the filler is 0.5 μm [5].

The composite material was prepared by mixing the components in a laboratory mill with stainless steel balls 15 mm in diameter for 5 min. Thus, experimental samples of a composite material with a barium titanate content of 7, 15, 30 wt % were prepared. Further introduction of the filler into the material was not technological due to the uneven impregnation of the composite.

Then, by injection molding, plates were made from the obtained composite samples, and then antenna elements. Manufacturing modes are presented in table 1.

| Table 1. Sample preparation modes. |
|------------------------------------|
| Pressing temperature, °C          | 125-145 |
| Specific pressure, MPa            | 20-35   |
| Number of pre-pressing, pcs       | 2-3     |
| Holding under pressure, min       |         |
| – plate                           | 14      |
| – antenna element                 | 25      |
| Heat treatment:                   |         |
| – time, h                         | 8       |
| – temperature, °C                 | 155-165 |

Measurements of the dielectric constant of the samples of composite materials were carried out in the X-range of the microwave. For the measurement, we used a P2M-18 transmission and reflection modulus meter in the voltage standing wave ratio (VSWR) measurement mode, matched load, 10 × 23 waveguides. Flat samples were made with dimensions (5-7) × 23 × 10 mm (see figure 1).

**Figure 1.** Samples of composite material for determining the dielectric constant.

The hardness of flat samples was measured with a TH 210 hardness tester on a «TIME High Technology Ltd.» test bench. The measurements were carried out following GOST 24621-2015 (ISO 868: 2003) [8], load – 4.5 kgf.

Statistical processing of the results of experimental studies was carried out using the software «STATIC-2» [9].
3. Results and discussion

The results of the experimental work to check the effect of introducing barium titanate into an epoxy material were the following results.

The dielectric and physical-mechanical properties of the obtained samples of composite materials are presented in table 2.

| Indicators                        | Filler content BaTiO₃, wt. % |
|-----------------------------------|-----------------------------|
|                                   | 0                          | 7                          | 15                         | 30                         |
| Appearance and color              | Green powder                | Light green powder          | Creamy powder with a light green tint |
| Dielectric constant, at a frequency of 10¹⁰ Hz | 4.4                        | 5.1                        | 6.5                        | 7.6                        |
| Shore hardness, HD                | 80                         | 82                         | 84                         | 87                         |
| Shrinkage, %                      | 0.5                        | 0.2                        | 0.1                        | 0.1                        |

From the data obtained, it follows that with the introduction of a dielectric filler into the composite material, an increase in the hardness of the samples is observed - at a content of 30 wt % BaTiO₃ the hardness is maximum and is equal to 87 HD.

From the data in table 2, it can be seen that when barium titanate is introduced into the composite material, the dielectric constant increases significantly from 4.4 to 7.6 - at the maximum filling. The measured values of the dielectric constant of the samples correspond to those calculated by the Lichtenecker formula. The correspondence between the values of the dielectric constant of the samples calculated and obtained experimentally is shown in figure 2.

![Figure 2](image_url)

**Figure 2.** The dielectric constant of composite material samples:
- I – Lichtenecker equation; II – experimental data
- a) UP-284; b) UP-284 + 7% of the BaTiO₃ mass;
c) UP-284 + 15% of the BaTiO₃ mass; d) UP-284 + 30% of the BaTiO₃ mass.

Then, from the obtained composite material, body elements of the antenna were made by injection molding. Technological modes are shown in table 1. The polymer base of the composite material, diane resin ED-8, impregnates the BaTiO₃ filler, thereby ensuring excellent fluidity of the composite and uniform filling of the mold.

The shrinkage of the samples decreases with an increase in the content of barium titanate to 0.1 %, which has a positive effect on the manufacture of structural elements. The body elements of spiral antennas were manufactured in amount of 5 pieces. All parts fully complied with the technical requirements of regulatory documents and had no defects.

Thus, the results of this research work show that by introducing barium titanate, it is possible to create a new technological composite material with an increased dielectric constant. It should be noted that this composite is suitable for the manufacture of structural parts by injection molding.

4. Conclusion
As a result of the research work, the possibility of increasing the dielectric constant of the composite by introducing barium titanate has been shown.

It was found that the introduction of barium titanate made it possible to increase the dielectric constant of the composite material by 50 % at a filler content of 30 wt %.

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