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Impact Of Bi_2Te_3 Semiconductor Filling Material On Electrical And Strength Properties Of High Pressure Polyethylene

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***Abstract*—The paper presents the results of an investigation of the temperature dependence of the resistivity of LDPE + x vol% Bi2Te3 composites. The investigations were carried out in the temperature range 20-1500C, for composites with fillers 5, 7, 10, 15 and 20 vol% Bi2Te3. It was found that the increase in the volumetric content of the filler decreases the specific resistance of the composites. The dependences of the electrical and mechanical strengths of LDPE + x vol% Bi2Te3 composites with the above fillers, polarized at 360 K, on the polarization intensity were studied. It was found that with increasing electric field strength it is characteristic for all investigated composites of bulk content of Bi2Te3 in the composition of the composite mechanical and electrical strengths from the beginning increases, and at high strengths decreases.**

Introduction

Combination of physicomechanical and electrical properties of polymeric materials makes it possible to use them more widely as electrical insulation and dielectrics in the cable industry of capacitor engineering as well as in the production of electrical machines and apparatuses [1-8]. Effective use of polymers and polymer based composites is impossible without in-depth knowledge of their electrical properties that depend on their structure and operating conditions. The study of the change of mechanical and electrical strength of low density polyethylene compounds under mechanical stress is of practical scientific interest when using different equipment with polymer elements. Strength properties of polymer compounds depend on the volume content of individual components, their structure, inter-phase interactions, and volume content of the filling material. Therefore, electret piezoelectric composites must meet special requirements such as easy recyclability, high flexibility, mechanical and electrical strength, enhanced dielectric permittivity, and special conductivity [9-11]. An analysis of physicomechanical properties of polymers and polymer based composites shows that the requirements specified above are met to the fullest extent by composites with semiconductor filling materials.In this regard, this study is aimed at investigating the impact of Bi_2Te_3 semiconductor filling material on electrical conductivity and strength properties of high pressure polyethylene (HPPE).

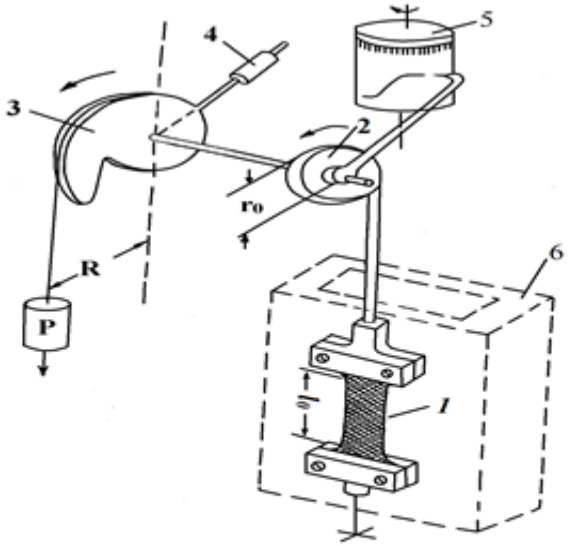

Figure 1. Test rig for determining the mechanical strength of composites 1 – sample under test; 2 – block; 3 – rotating plate; 4 – compensator weight; 5 – clock; 6 – thermal chamber.

Test Procedure

Electrical conductivity was determined based on the residual current set 1-2 hours after the voltage of 100 V was applied to the composite. The resistance of the samples was measured with a E6-13A teraohmmeter within the interval of 20-150^{0}C under linear heating with a speed of 3 degrees per minute on a test rig similar to the dielectric parameters test rig. The samples for the mechanical strength dependence test were cut out of film with a special double-blade knife with the working length and width of 10 mm and 3 mm, respectively. To compensate for the voltage during the test the weight P is fixed to the sample by means of a shaped lever rather than directly. The arm of the lever automatically decreases as the sample gains length. If we suppose that the sample cross section decreases proportionally to its elongation which means that the volume remains unchanged, then, in case of an arm that automatically changes as the length of the sample increases, the sample cross section decreases proportionally to elongation which means that the volume remains unchanged and, in case of σ=const, the arm must decrease with the information gain according to the formula

$$R = R_0\left(\frac{1}{1+\varepsilon}\right),$$

where ε is elongation, R_0 and R are radius vector projections on the horizontal axis in the initial and submerged positions. The thickness of the samples before the test was measured with an IZV-2 meter to within 1 μm.

Test Results and Discussion

The temperature dependences of the specific resistivity of LDPE + x vol.% Bi_2Te_3 composites were tested in the temperature interval of 20-150^{0}C. Tests were made for composites with 5, 7, 10, 15 and 20 vol.% Bi_2Te_3 filling material. The results are given in figure 2. It can be seen from the figure that in the temperature interval of 20-80^{0}C ρ, which is typical of all tested composites, decreases. With low content of the filling material, deep minimums at 80^{0}C and distinct maximums at 100^{0}C are observed on the ρ(T) curves. With further increase in the temperature of the composites with 5, 7 and 10 vol.% Bi_2Te_3 filling material the specific resistivity of the composites decreases.

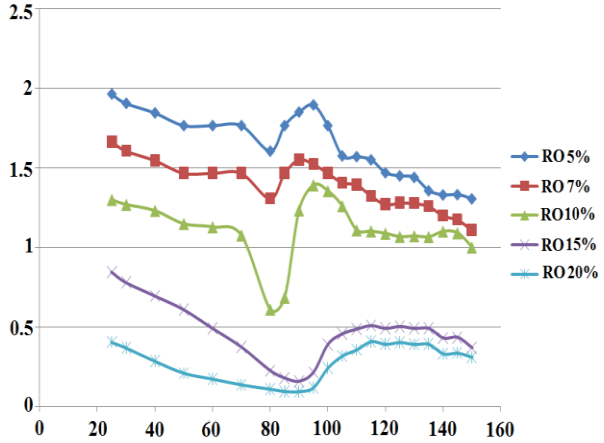

Figure 2. Temperature dependences of the specific resistivity of LDPE + x vol.% Bi_2Te_3 composites

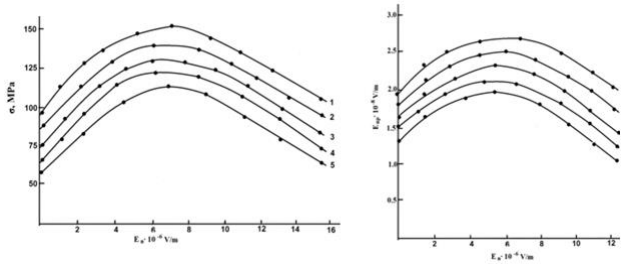

Figure 3. Dependences of the electrical and mechanical strengths of LDPE + vol% Bi2Te3 composites, polarized at 360 K, on the polarization intensity where 1-x = 1; 2-x = 3; 3-x = 5; 4-x = 7; 5-x = 10.

For the composites with 15 and 20 vol.% Bi_2Te_3 filling material in the temperature interval of 90-110^{0}C a low increase in ρ is observed. With further increase in the temperature the specific resistivity of the samples remains to be almost constant. It should be mentioned that the specific resistivity of the composites regularly decreases with increase in the volume content of the filling material. At 20^{0}C the specific resistivity of the composites with 5, 7, 10, 15 and 20 vol.% Bi_2Te_3 filling material appears to be 1.963; 1.663; 1.299; 0.843 and 0.402 Ohm·m, respectively, and at 150^{0}C the values of the specific resistivity appear to be 1.305; 1.105; 0.999; 0.368 and 0.308 Ohm·m, respectively. The maximums on the ρ(T) curves are the results of the development of a new area of dipole-segmental losses.

The results of the study of the electrical (E) and mechanical (σ) strengths of LDPE + vol % Bi2Te3 composites are shown in figure. It can be seen from Figure 3 that, with increase in the electric field strength, the electrical and mechanical strength and the amount of accumulated charge increase to the maximum and then decrease. In our opinion, the change of the accumulated charge with an extreme in accordance with the time under discharge is due to the formation of new centers for electrical charge localization that results in the degradation of the electrical thermopolarization process. The change of electrical and mechanical strength with an extreme is first explained by the merging of polymer chains based on the intensity of discharge treatment and then by their oxidation.

The results of the study of the electrical (E) and mechanical (σ) strengths of LDPE + hob% Bi2Te3 composites as a function of the volume content of the Bi2Te3 semiconductor filler are shown in figure. 4. It follows from this that with increasing volume content of filler up to 5 vol% Bi2Te3, mechanical and electrical strengths increase, and subsequently decreases. Oxidation causes the destruction of polymer chains, therefore, mechanical and electrical permittivity decreases. It is known that introducing supplements to a polymer matrix results in a supermolecular formation in the shape of a small spherulitic structure obtained by means of adding structure forming agents to the alloy. Destruction of a non-oriented sample mainly occurs by groups of spherulitic formations. The strength of these areas depends on the number of tie molecules that simultaneously participated in the crystallization of two middle spherulites .

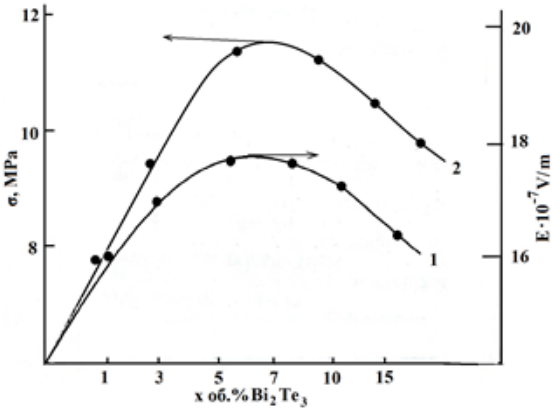

Figure 4. Mechanical (1) and electrical (2) strength of LDPE + x vol. % Bi2Te3

The nature of these molecules depends both on the content and the number of modifying supplements. When the content of the filling material increases, the distance between them increases, which leads to the decrease in the number of tie chains and to the reduction of strength. The increase in electrical strength is explained by the fact that semiconductor supplements within HPPE cause the formation of a homogeneous, stable polymer structure as well as create additional centers of structure formation, the electrical properties considerably improve herewith. Therefore, for modified HPPE the density of a molecular structure of a small spherulitic space increases, the diffusion constant for electron free path length decreases and, therefore, the electrical strength improves.

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