

Electrical properties of UHMWPE/graphite nanoplates composites obtained by in-situ polymerization method

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ABSTRACT

There are described nanocomposites based on ultra high molecular weight polyethylene and graphite nanoplates prepared by in-situ polymerization method. It is carried out a comprehensive study of electric properties of these composites, including direct current (dc) and alternating current (ac) properties. There is explored dependence of the conductivity and dielectric permeability on filler concentration, temperature, deformation and frequency of electric field. These relationships are compared with those for composites based on other carbon fillers including both nanoscale (carbon nanotubes, carbon black) and micron-sized (graphite, schungite) fillers. More specific electrical properties of investigated materials such as lower percolation threshold and higher dielectric permittivity compared to those for composites based on other carbon fillers are attributed to the plate-like shape of graphite nanoplates. These materials are distinguished also by their high electrical stability against temperature and deformation. Therefore, it makes graphite nanoplates the most preferable conductive filler for some practical applications. Some possible application areas for UHMWPE/graphite nanoplates nanocomposites will be also discussed. **Polyolefins J (2017) 4: 1-12**

Keywords: Ultra-high molecular weight polyethylene; in-situ polymerization; composite materials; graphene; electrical properties.

INTRODUCTION

Carbon fillers have always attracted the attention of both researchers and developers of new composite materials together with special electric properties. The reason for this is that composites with carbon fillers have a lower density than composites with metal fillers [1]. This is why the discovery of new carbon fillers, namely fullerene in the eighties, and carbon nanotubes

(CNT) in the nineties of the last century has caused a wave of fundamental as well as application original articles and reviews describing the electrical properties of composites improved with the addition of a new filler. The emergence of another new carbon filler, namely graphene at the beginning of 2000 was no exception. Graphene consists of one or more two-dimensional sp²-bonded carbons. In addition, the term graphite nanoplates (nanosheets) is also used for graphene consisting

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of several layers [2]. Particles of this filler have high aspect ratio and a relative high electrical conductivity of 6×10^5 S/m [3]. This is the reason that a small concentration of such filler can significantly modify the electrical properties of polymer dielectrics [4]. Besides, it increases strength [5, 6] and thermostability [6, 7] of polymer matrix and reduces its permeability for gases [8] and flammability [9].

A significant number of articles concerning composites with graphene filler describe physical, mechanical and thermal properties of these materials. The study of electrical properties (dielectric permeability and electrical conductivity or electrical modules in alternating field) of graphene-filled composites is not conducted intensively [10]. Nevertheless, available articles allow us to make the first, but not exhaustive conclusions on the advantages and disadvantages of graphene as conductive filler.

Authors of articles use various types of graphite nanoplates (GnP) for manufacturing composites. The most widespread are thermally expanded graphite and chemically and thermally reduced graphene-oxide. The graphene types mentioned above have different properties [6, 11]. Electrical properties of polymers filled with nanoplates of various types may differ essentially, sometimes several times or even by an order of magnitude at the same filler volume content [6, 10, 11].

The electrical properties of composites with graphene are dependent not only on the type of graphene, but also on the method of the introduction it into the polymer matrix. All available methods almost have by now been used for the synthesis of composites: mixing components in polymer solution [12, 13], introducing graphene into thermoplast melt [14], co-extrusion of polymer melt with masterbatch having high graphene concentration [15] and different types of polymerization-filling techniques. One of the main tasks is to prevent the aggregation of filler particles with which the authors of articles faced in each of these case [6, 7]. The strong interfacial interaction between the matrix polymer and the graphene is another important factor to be considered in the design and manufacturing of high performance composites [6, 7].

According to published data, in-situ polymerization is one of the effective methods for uniform dispersion

of graphene particles and providing a strong interaction between them and the polymer matrix. Composites based on epoxy resin [16], polyurethane [17], polymethyl methacrylate [18] and polyvinylidene fluoride [19] are produced with this method. There are several publications related to synthesis of nanocomposite materials based on graphite nanoplates and polyolefines [4, 20-23]. However, these publications contain insufficient information about electric properties of obtained materials.

Analysis of the entire body of literature data allows us to conclude that the composites with graphenes are characterized by low percolation threshold if they are introduced into a polymer matrix uniformly. The reason for this is a high aspect ratio of graphene particles [2]. However, the use of graphene does not allow obtaining higher level of composite conductivity than that for other carbon fillers (carbon black (CB), graphite and CNT). Maximal levels of composite conductivity achieved in experimental works vary from 10^{-1} to 10 S/m for different graphene types and various methods of composites synthesis. More high values have been obtained for systems analogous to graphene paper only [13]. But their strength is not sufficient for most of practical applications.

So the use of composites with graphene in areas demanding high values of dc-conductivity is limited. According to opinion of authors of [24], composites having conductivity level of less than 10 S/m can be used as antistatic material only. This dc-conductivity level is not sufficient for using them as conductive coatings, screens for electromagnetic waves, electroconductive paints and glues and transparent electrodes. For example, the use of composites with graphene concentration of 5% mass having conductivity of 3 S/m as materials for electromagnetic waves shielding is proposed in work by Eswaraiah [25]. It has been demonstrated that such shield attenuates microwave electromagnetic radiation by 20 dB, i.e. by 100 times. At the same time, available composites based on other fillers provide attenuation of 1000 and 10000 times at the same shield thickness because they have higher conductivity.

Nevertheless, the most of the works concerning graphene-filled composites are focused on the dc-conductivity level. Based on results of these studies, the

authors of some of the reviews [6] claim that composites with graphenes are still far away from practical applications.

However, some authors [2, 5, 7] consider that graphene will be a good alternative to carbon black and CNT as a filler for polymers in the near future. Indeed, not just dc-conductivity value but its functional dependence on various parameters, e.g. temperature, pressure, deformation, filler concentration and electromagnetic field frequency is important for many applications.

Thus, for example, composites having a narrow area of dielectric-conductor transition at dependence of conductivity on filler concentration may be used as sensitive elements of sensors, while composites having a broad region of above mentioned transition are prospective for using in applications where stability of electric properties is demanded [26]. The information about temperature dependencies of electrical properties is extremely necessary if composites are used outdoors. Materials having certain dependencies of conductivity and dielectric permeability on frequency as well as definite ϵ'/ϵ'' ratio are necessary for broadband absorbers of electromagnetic waves [27].

But the number of works in which the functional dependence of the electrical properties of composites with graphene is studied is rather small. It was pointed out in [28] that composites with graphenes have high values of dielectric permeability. Such materials can be used for manufacturing artificial muscles, high capacitance capacitors or high-k gate dielectrics for flexible electronics [28]. However, dielectric permeability which is considered irrespective of other electrical properties of material does not provide full information either on its potential practical applications or on usage restriction.

Dependences of composites conductivity on temperature were studied in [29] in addition to concentration dependence of dc-conductivity. The temperature coefficient of resistance for composites based on functionalized graphene sheets may be positive or negative depending on the polymer matrix.

This information is extremely necessary for correct choice of graphene type if composites are used outdoors. Dependence of dc-conductivity on filler concentration was studied in [1, 12, 13, 30]. Dependences

of dielectric permeability and dielectric losses of composites on frequency have been studied in [10] in details. Unfortunately, obtained functional dependences of electrical properties of investigated composites are given irrespective of their possible practical applications.

Therefore, comprehensive study of functional dependencies of electrical properties of graphene-based composites as well as analysis of potential application areas for materials with the revealed set of properties is an actual task.

In this work, a comprehensive study of electrical properties of polymerization-filled composites based on polyethylene and graphite nanoplates including measurement of dc- as well of ac-electrical properties was carried out. It was studied dependence of electrical conductivity and dielectric permeability on filler concentration, temperature, frequency and deformation. Comparison of these dependencies with the properties of composites based on other carbon fillers both nanoscale (CNT, CB) and micron-sized ones (graphite, schungite) was examined. It was first established some features of the investigated composites. We discussed possible application areas for the investigated nanocomposites.

EXPERIMENTAL

Materials

For the PE nanocomposites synthesis, VCl_4 (Acros Organics) as catalysts, and $Al(i-Bu)_3$ (Aldrich Co.) as a cocatalyst were used. Ethylene (PJSK Kazanorgsintez, 99.9%) was used without further purification. Expandable graphite EG350 (WellChem(group) Ind. Co.Ltd, China) was used as a precursor for preparation of graphite nanoplates.

Preparation of graphite nanoplates

The graphite nanoplates were prepared by thermal exfoliation of EG 350 at 500°C, followed by ultrasonication in ethyl alcohol within 8 h. The resulting dispersion was filtered and dried in a vacuum oven at 60°C. The GnP prepared had a specific surface area of 25.6 m²/g measured by BET method, a thickness of about 30 nm and the lateral dimensions of 1-5 μm. A more

detailed study of the structure and chemical composition of graphite nanoplates using SEM techniques, X-ray diffraction analysis, X-ray spectroscopy and BET method is presented in [31].

Synthesis of PE/GnP nanocomposites

All oxygen- and moisture-sensitive manipulations were carried out in argon atmosphere. The catalyst immobilization procedure included the treatment of a preliminarily dehydrated GnP by vapor of VCl_4 and then by vapor of $Al(i-Bu)_3$. The treatment was carried out at temperature of $23 \pm 1^\circ C$ and at the components saturated vapor pressure. After VCl_4 absorption, the filler was evacuated at $100^\circ C$ and $P=10-3$ mm Hg. GnP and the supported catalyst were placed in the glass reactor in an atmosphere of argon, and gas-phase polymerization of ethylene was carried out at a temperature of $23 \pm 1^\circ C$ and a monomer pressure of 50 kPa. The polymerization activity was 10000 kg/mol $[C_2H_4]$ h. The polymer composite prepared was washed in ethanol and dried in vacuum at $60^\circ C$. The nanocomposites with GnP loading in the range of 1.5-12.5 vol% were synthesized. The average molecular weight of the synthesized polymer matrix was 2×10^6 g/mol, according to the viscosimetric data. The degree of polyethylene crystallinity, according to DSC data, was 40-42%.

The structural, thermal and mechanical characteristics and gas permeability of similar composites obtained in mode of slurry polymerization in n-heptane are given in [31].

Electrical properties measurements

The following electrical properties of composites were determined: direct current conductivity along ($\sigma_{dc//}$) and perpendicular ($\sigma_{dc\perp}$) to the plane of compression of the sample, alternating current conductivity (σ_{ac}) and dielectric permittivity ($\epsilon'_{ac\perp}$) perpendicular to the plane of compression of specimens in the frequency (f) range of 10^2-10^6 Hz, as well as dielectric permittivity ($\epsilon'//$) and loss ($\epsilon''//$) along to the plane of compression of specimens in the super-high frequency range (11 GHz).

Direct current conductivity was measured by four probes method, which allows one to exclude the influence of contact resistance [32]. Four copper electrodes

were attached to the sample in the form of a rectangular plate ($40 \times 5 \times 0.5$ mm) with electroconductive adhesive Dottite based on silver particles (conductivity 10^6 Sm/m). The error of measurements was equal to 5% and was determined mainly by geometry measurement accuracy.

AC-conductivity and permittivity were measured using a wide-range dielectric spectrometer BDS-40 (Novocontrol). For measuring electrical properties of composites samples, they had the shape of a disk with thickness of 0.35 mm and diameter of 20 mm. The electroconductive adhesive Dottite, was applied on the flat sides of the sample and served as electrodes. For the same samples, the conductivity $\sigma_{dc\perp}$ was also measured by two-electrode methodology [33]. The error of measurements was equal to 5% and was specified mainly by geometry measurement accuracy. The dielectric permittivity ($\epsilon'//$) and loss ($\epsilon''//$) in ultra-high frequencies range were measured by resonance method at frequency of 11 GHz with accuracy of 15-20%. Rectangular plates with length of 15 mm, thickness of 0.5 mm and width of 1 mm were used as the samples.

RESULTS AND DISCUSSION

Structure of composites based on UHMWPE and GnP

As stated above, the UHMWPE/GnP nanocomposites were prepared by ethylene polymerization on the GnP surface, activated by the catalyst, and the matrix UHMWPE was formed directly on the filler particles surface. Figure 1 shows SEM images of nascent samples of nanocomposites with 2.5 vol% of GnP. It can be seen that graphite nanoplates are really uniformly covered by the polyethylene layer formed during polymerization. As a result, filler is dispersed on individual nanoplates and homogeneously distributed within the polymer matrix [31].

Electrical properties

DC-electrical properties

The composites with traditional carbon fillers (carbon black, graphite, etc.) obtained by the most common method, mechanical mixing of the components in a polymer melt, are widely used in practice. Their elec-

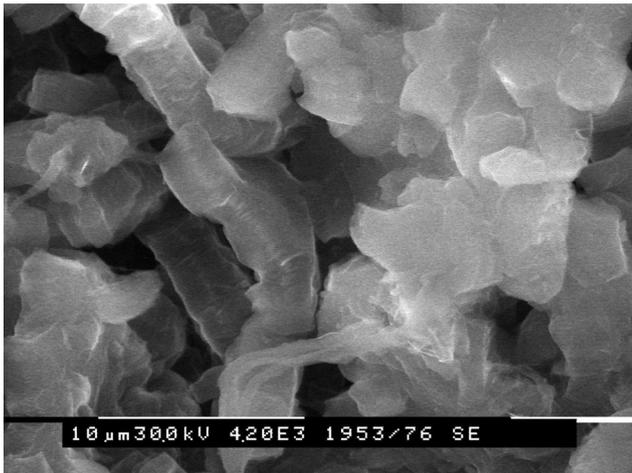


Figure 1. SEM image of nanocomposite nascent particles with 2.5 vol% of GnP.

trical properties are discussed in detail in the literature. The graphene is a new type of filler and a comprehensive study of the electrical properties of composites based on it is of great interest. Especially important is the comparison of the electrical properties of composites based on graphene with the properties of traditional composites. Such comparison will help to identify the distinctive features of GnP-containing composites and to understand in what applications they may be preferred.

However, UHMWPE with a molecular weight more than 1 million does not allow to obtain composites with a homogeneous distribution of the filler using mechanical mixing. Therefore, for comparison, we used composites prepared with another polyolefin matrix, polypropylene. Electrical properties of polymer composites containing conductive filler depend primarily on the type of filler, and much less on the type of the polyolefin matrix [26, 34-36]. Indeed, a comparison of dependencies $\sigma_{dc}(\Phi)$ of composites based on PP and various carbon fillers (Figure 2) shows that they are significantly different despite the same matrix and preparation method. The difference in σ_{dc} can reach 15 orders at the same filler concentration for different fillers. Replacement of the polyolefin matrix cannot give comparable effect.

The concentration dependency of σ_{dc} for the UHMWPE/GnP composites is also shown in Figure 2. All concentration dependencies presented on Figure 2 have a shape typical for polymer composites containing a conductive filler. At a certain concentration,

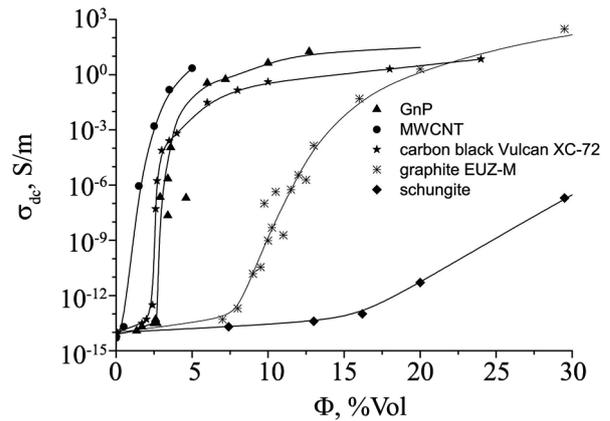


Figure 2. Concentration dependencies of σ_{dc} for composites based on different carbon fillers.

called the percolation threshold, there is a sharp increase of conductivity (the so-called transition insulator-metal). For all considering carbon fillers, the concentration dependencies of conductivity showed percolation with an obvious percolation threshold. The value of percolation threshold is 1.5 vol% for MWCNT/PP, 2.7 vol% for carbon black/PP, 7.1 vol% for graphite/PP and 28 vol% for schungite/PP composites [34,37].

As is known from the published literature [38] the dependence of conductivity of conductive filler-containing composites on filler concentration above percolation threshold is described by scaling relation:

$$\sigma_{dc}(\Phi) \sim (\Phi - \Phi^*)^t \quad (1)$$

where Φ^* is the percolation threshold and t is a critical index.

The experimental data for GnP/UHMWPE composites, which are plotted in Figure 2, were fitted to the scaling relation (1) to determine percolation threshold and critical index. Because relation (1) is a straight line in coordinates $\log(\sigma_{dc}) - \log(\Phi - \Phi^*)$, fitting was made using the least-squares method. The value of percolation threshold as defined in this procedure was 2.7%. The value of the critical index t will be discussed below.

Thereby the values of percolation threshold decrease in the order:

$$\Phi^*_{\text{MWCNT/PP}} < \Phi^*_{\text{GnP/UHMWPE}} < \Phi^*_{\text{CB/PP}} < \Phi^*_{\text{graphite/PP}} < \Phi^*_{\text{schungite/PP}} \quad (2)$$

The percolation threshold defines the relative position of σ_{dc} concentration dependencies, and in wide range of filler loading, the electrical conductivity for composites with different carbon fillers are ordered as follows:

$$\sigma_{dc \perp \text{MWCNT/PP}} > \sigma_{dc \perp \text{GnP/UHMWPE}} \sim \sigma_{dc \perp \text{CB/PP}} > \sigma_{dc \perp \text{graphite/PP}} > \sigma_{dc \perp \text{schungite/PP}} \quad (3)$$

The differences in percolation thresholds and electrical properties of composites are mainly determined by the aspect ratio of filler particles [39] after their dispersion within polymeric matrix. So, in spite of equal percolation thresholds values, the conductivity of GnP composites in a range of high loading is significantly higher compared to that of CB composites. It is connected not only with slightly higher dc conductivity of GnP but also due to the fact that, in case of GnP the less quantity of filler particles is necessary to form the conductive paths within the matrix, and thereby less sum of contact resistances between filler particles takes place in comparison with that in CB composites.

Equation (1) is a general one for electrical properties of heterogeneous percolation systems [38]. According to percolation theory for 3D systems, $t = 2$. This critical index value is observed for many traditional heterogeneous systems [40-42]. However, a non-typical critical index value of 5.18 has been obtained for σ_{dc} dependence on graphene concentration for the composites studied in the present work. It should be noticed that abnormally high t index value was observed in some works [1, 4, 13, 25] concerning experimental study on the electrical properties of graphene-filled polymer composites as well. Value of t index was 2.66 for PVDF/graphene system [25] and 5.37 for epoxy/graphene system [1]. High t index value of 3.6 has been obtained in [30] for polymer/graphene composite material which has been studied by computer simulation method (Monte-Carlo). It has been found out that the conditions necessary for tunneling exist in the system near percolation threshold for such system.

Abnormally high values of t critical index denotes that transition insulator-metal is less abrupt compared to other carbon fillers. It allows to guess that graphene-filled nanocomposites would demonstrate good stability of electric properties at temperature variation

as well as at deformation. The reason for this is that variation of effective filler concentration takes place in both cases either because of difference of thermal expansion ratios of filler and matrix or at extension/compression of matrix. It will be demonstrated below that assumptions on enhanced stability of electric properties of materials being studied were confirmed by direct experiments.

AC-electrical properties

The dependences of conductivity (σ_{ac}) and permittivity (ϵ') on the electric field frequency for the UHMWPE/GnP composites with different GnP loadings are illustrated in Figure 3. The type of dependencies is typical for composites having electric conductive fillers. The electric conductivity in alternating fields $\sigma_{ac \perp}$ is a sum of two terms, a direct current conductivity $\sigma_{dc \perp}$ and a relaxation term ($\sigma_{rel \perp}$) that is proportional to

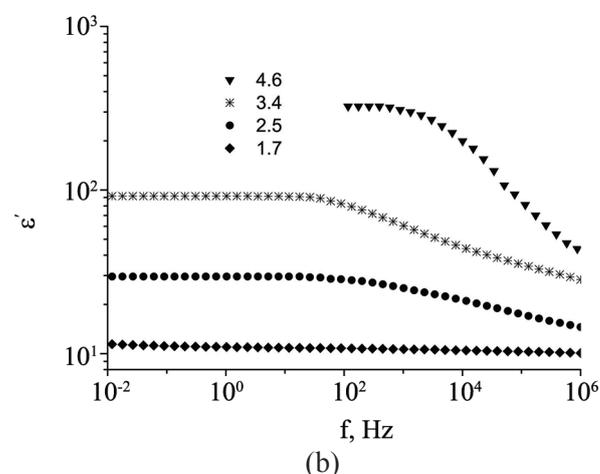
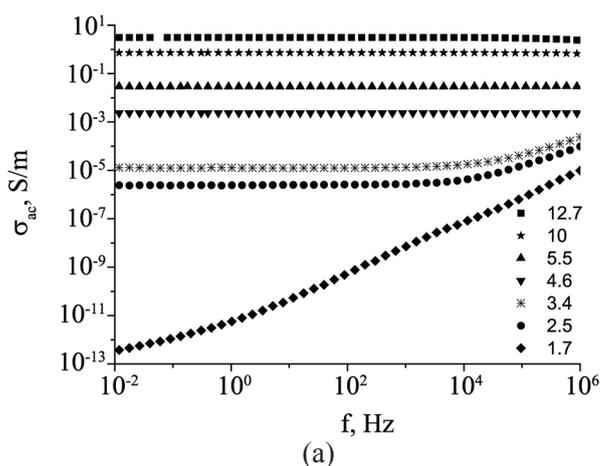


Figure 3. Frequency dependencies of conductivity (a) and dielectric permittivity (b) for UHMWPE/GnP composites with different filler concentrations (vol%).

f^h for composites containing conductive fillers:

$$\sigma_{ac\perp} = \sigma_{dc\perp} + \sigma_{rel\perp} = \sigma_{dc\perp} + Af^h \quad (4)$$

For composites with a filler content below the percolation threshold, only the relaxation part of σ_{ac} can be seen because of the low σ_{dc} value. The exponent n in Eq. 4 for such composites is equal or close to 1. For composites with a filler content above the percolation threshold, the σ_{dc} values are high, and on their background the relaxation component is not visible. For composites near the percolation threshold, both σ_{dc} and σ_{ac} are clearly distinguishable (Figure 3a).

It was shown [43] that the frequency dependencies $\sigma(f)$ and $\varepsilon(f)$ have a linear part in double logarithmic coordinates. For the filler concentration corresponding to the percolation threshold Φ^* , the slope ratio of these linear parts with respect to x-axis (the so-called critical indices x and y) characterizes the structure of conductive paths in the composite material.

If the filler particles arrange a 3D-irregular net in composite, $x=0.73$ and $y=0.27$ [43]. If conductive pathways represent fractal structure, the x value decreases, and the y value increases; these values depend on fractal dimension, and as a rule, for composites with conductive filler, $x=0.57$, $y=0.43$ [43].

The micron-sized filler particles, for example, graphite and shungite [37], arrange a 3D-irregular net within the polymer matrix. Fractal structures are mainly typical for composites filled with nanoparticles, such as some type of carbon black [44], metals and alloys in nanocomposites derived by vacuum evaporation for example systems $Co + SiO_2$, $(CoTaNb) + SiO_2$ and $(CoFeB) + SiO_2$ [45]. The data of Figure 3 allowed us to clarify what kind of conductive structure is formed in the polymer matrix by the graphite nanoplates, which have nanometer sizes in one direction and micrometer sizes in two other.

We have determined the critical indices x and y for the composites with filler concentrations close to the percolation threshold (2.5 vol%). Their values which are equal to 0.79 and 0.20, respectively, correspond to the systems with the 3D irregular net structure of infinite conductive cluster skeleton.

In Figure 4 the concentration dependencies of dielectric permittivity ε' and loss ε'' in super-high

frequency range for composites based on different carbon fillers are shown.

As can be seen, for dielectric loss the relation is similar to relation of electric conductivities, because the loss values are proportional to the ac electric conductivities:

$$\varepsilon''_{MWCNT/PP} > \varepsilon''_{GnP/UHMWPE} \sim \varepsilon''_{CB/PP} > \varepsilon''_{graphite/PP} > \varepsilon''_{shungite/PP} \quad (5)$$

Thereby, the loss values correlate with percolation threshold similar to σ_{ac} .

The ratio between the values of the dielectric permittivity for composites with different carbon fillers are absolutely not the same as that of the conductivity and dielectric loss (Figure 4). The dielectric permittivity of UHMWPE/GnP composites is significantly

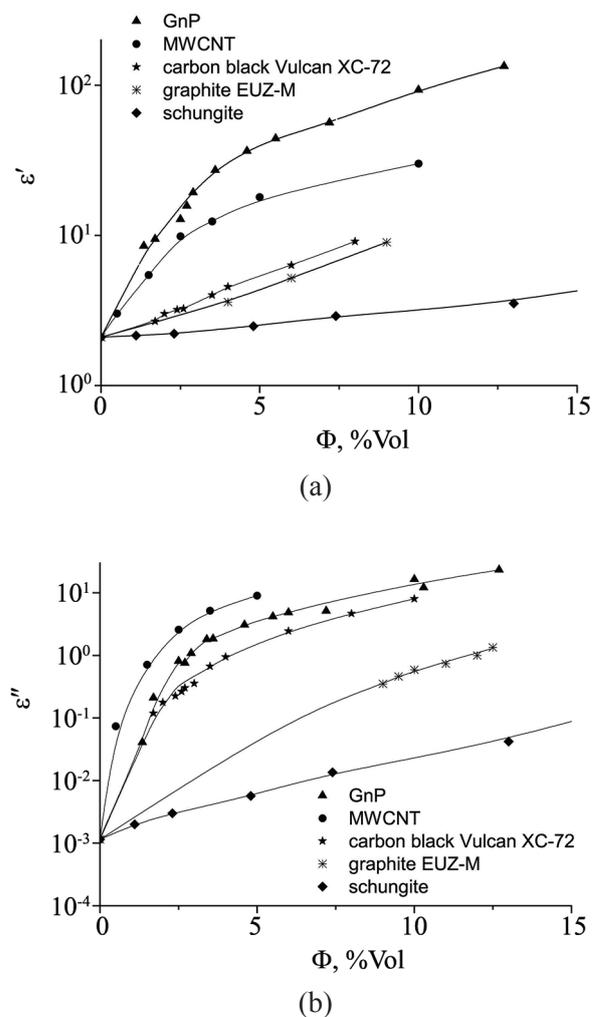


Figure 4. Concentration dependencies of dielectric permittivity ε' (a) and loss ε'' (b) at frequency 11GHz for composites based on different carbon fillers.

higher in comparison with composites based on other carbon fillers. This is due to the fact that the microcapacitors, formed by neighboring graphite nanoplates in composites, have the larger area of electrodes, and, as result, high capacity values; that is, the comparison of composites with the same values of conductivity and dielectric loss shows the higher dielectric permittivity values for UHMWPE/GnP composites than those for composites filled with other carbon fillers (Figure 5). Only the composites with graphite have a permittivity close to the permittivity of materials having GnP, obviously, owing to scaly shape of particles.

Temperature and deformation dependencies of electrical properties

The stability of the electrical conductivity of the composites against temperature (T) and the deformation (Δl) is very important for their practical application. In this work, the dependence of conductivity on T and Δl for UHMWPE/GnP composites and composites based on PP and various carbon fillers were studied.

In Figure 6 the relative temperature dependencies ($\sigma/\sigma_{25} = \sigma_{dc}(T)/\sigma_{dc}(25^\circ\text{C})$) of conductivity for composites with different carbon fillers and $\sigma_{dc\perp} \sim 10^{-4}$ S/m are presented. Here, the $\sigma_{dc}(T)$ is the conductivity at temperature T and $\sigma_{dc}(25^\circ\text{C})$ is the conductivity at temperature 25°C . The conductivity of composites is decreased with temperature in the considered temperature region due to the large difference of thermal expansion coefficients between the matrix and filler. Above the percolation threshold, electrical properties

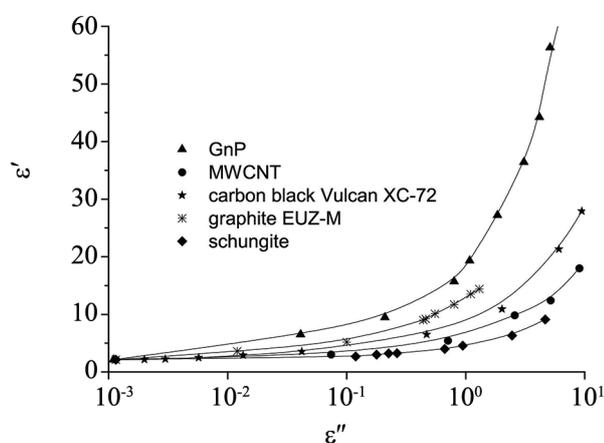


Figure 5. Dependency of dielectric permittivity versus dielectric loss for composites based on different carbon fillers.

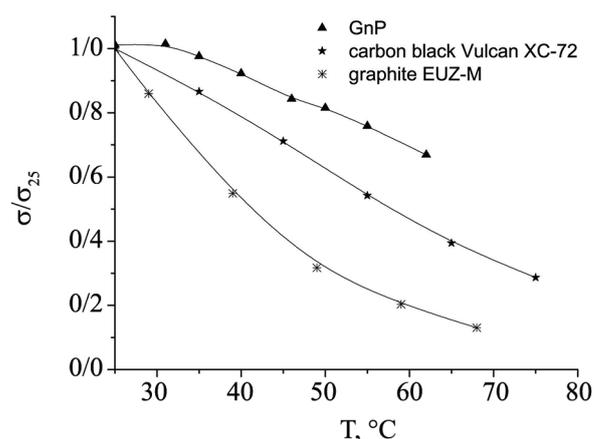


Figure 6. Relative temperature dependencies of conductivity for composites based on different carbon fillers with a conductivity $\sigma_{dc\perp} \sim 10^{-4}$ S/m.

of the composite are determined by filler particles conductive chains which can break during heating, resulting in positive temperature coefficient for resistance. According to Figure 6, the composites having GnP demonstrate the most stable electrical properties than the composites filled with other carbon fillers. Apparently, the scaly form and flexibility [46] of graphite nanoplates provide more stable electrical contact between neighboring filler particles in the conditions of thermal expansion of the polymer matrix.

This reason can explain also more stable electrical properties of graphene-filled composites under deformation as compared with traditional carbon fillers (Figure 7).

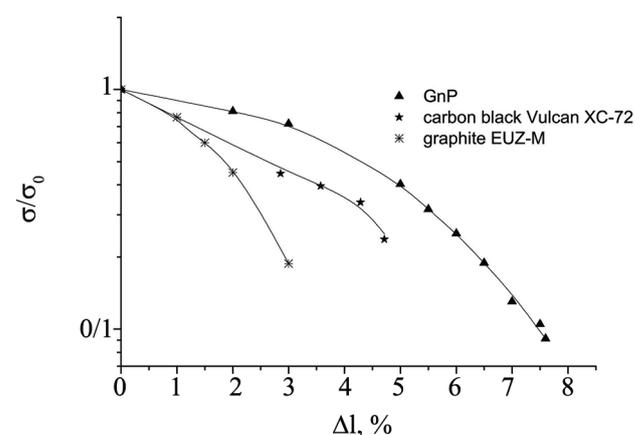


Figure 7. Relative deformation dependencies of conductivity for composites based on different carbon fillers with a conductivity $\sigma_{dc\perp} \sim 10^{-4}$ S/m.

Possible areas of practical application

Composite materials may experience fluctuations of temperature and deformation during their exploitation. Therefore, the higher stability of the electrical properties makes GnP more preferable as a conductive filler for practical applications. Hence, the differences in particles aspect ratio and structure of conductive pathways for composites containing different carbon nanofillers allow us not only to vary widely the electrical properties but also to get their necessary combinations that significantly expands the application of polymer composites filled with carbon conductive nanofillers. Materials with dc conductivity of $10^{-7} - 10^{-4}$ S/m are used as an antistatic for static charge dissipation. Composites with σ_{dc} in a range of $10^{-4} - 10^1$ S/m are applied in manufacture of parts for electrostatic painting. In addition, such composites are used as the separate layers in multilayered absorbers of super-high frequency range electromagnetic waves. If the electrical conductivity is above 101 S/m, the materials can be used for fabrication of thin screens reflecting electromagnetic waves of ultrahigh frequency range.

As can be seen from Figure 2, the conductivity of composite materials containing GnP varies in a wide range of $10^{-14} - 2 \times 10^1$ S/m. By this means, materials with the GnP loading of 2.9 – 5 vol% can be used in fabrication of products, on which the static charges accumulation is not desirable. These materials will be particularly useful in chemical and petrochemical industries, where flammable liquids and gasses are used, as well as for manufacture of racks and packaging products for storing and transportation of electronics components.

Composites with the GnP loading of 2.5-5 vol% are believed to be used in development of electromagnetic waves absorbers. Materials with the GnP concentration of 10 – 13 vol% can be applied as absorbing layers and with the concentration of 5 – 10 vol% as matching layers.

At GnP loading above 12 vol% the dc conductivity exceeds 10^1 S/m. These materials are promising for fabrication of thin and light reflecting screens for electromagnetic waves of super-high frequency range.

In addition, GnP-containing composites can be applied in areas where materials with high dielectric

permittivity in combination with low conductivity and loss are required, for example, in injection layers of power cables. The application of a conductive or semiconductive layer near the interface of solid isolation to the electrode prevents the concentration of electric fields in the places of cable inflection and, as a consequence, prevents electrical breakdown in cables.

CONCLUSION

In this work, the electrical properties of composite materials based on polyethylene and graphite nanoplates prepared by polymerization filling method (in-situ polymerization) were investigated depending on filler concentration, frequency, temperature and deformation. The experimental results demonstrated that the investigated composites had some peculiarities of electrical properties in comparison with composites contain other types of carbon fillers including both nanoscale (CNT, CB) and micron-sized (graphite, scungite) fillers.

The dielectric permittivity of UHMWPE/(graphite nanoplates) composites was significantly higher than that of composites based on other carbon fillers. In addition, composites filled with graphite nanoplates demonstrated the most stable electrical properties depending on such important exploitation parameters as temperature and deformation. These peculiarities are the result of method of preparation which allows us to achieve a uniform distribution of filler in a polymer matrix and specific properties of filler particles. It makes graphite nanoplates more preferable as conductive filler for some practical applications.

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