FEATURES OF THE STRUCTURE AND PHYSICAL PROPERTIES OF EPOXY COMPOSITES CURED UNDER THE INFLUENCE OF PHYSICAL FIELDS

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Composite materials are one of the important classes of materials that play a significant role in current and future aerospace components. These materials are particularly attractive to aviation and aerospace applications because of their exceptional strength and stiffness-to-density ratios and superior physical properties. The most widely employed matrix system for composites in aerospace structural components is the epoxy system [1].

Epoxies exhibit excellent properties such as excellent adhesion to different materials, high resistance to chemical attacks, and excellent mechanical and electrical properties. In addition to the abovementioned properties of epoxy resins, they are used due to their diverse characteristics, such as high strength, good stiffness, good thermal stability, antibacterial properties, low contractibility, and strong adherence chemical resistance. They are used widely in industrial applications, such as coatings, adhesives, aerospace structures, electronics, potting, composites, laminates, and the encapsulation of semiconductor devices. Because of their excellent and attractive mechanical and chemical properties, epoxies are the dominant matrix material for structural composites of light-weight polymer–matrix [2, 3]. Consequently, one of the main tasks of modern materials science is to create new materials with improved performance characteristics [4].

Until very recently, polymers were generally considered to be unaffected by physical fields. However, it is now known that they are weakly magnetized because they are diamagnetic materials, and therefore do respond to physical fields (e.g. magnetic field) [5]. The main ways in which polymer composites are magnetized are by melting the polymers or placing them in a liquid suspension to break up the cross-links, so that when the magnetic field is applied, the fibers within the polymer composites realign. There are other methods in which various industries have tried to assemble the fibers within materials. These include mechanisms such as shear, electrical and ultrasonic alignment.

Magnetic alignment has gained the most attention and has been proven to be the top choice to achieve alignment for a few reasons. Firstly, magnetic forces are contactless, so will not produce any chemical alteration within the material, but still allow the orientation of anisotropic particles. Secondly, permanent magnets and electromagnets are easy to come by and still produce strong enough fields for reorientation. Thirdly, the magnetic fields can be homogeneous, inhomogeneous, rotating or oscillating, and each allows a variety of responses and therefore a variety of structures produced. Fourthly, the response depends on the magnetism of the material, which depends on the susceptibility (e.g. whether the material is ferromagnetic or diamagnetic etc.). Lastly, magnetic fields are not sensitive to surface changes or pH, unlike electric fields [6, 7].

Therefore, this research work is devoted to the study of the effect of external constant magnetic, electric fields on the structure, thermophysical, dielectric properties of epoxy polymers (EP) and their nanocomposites containing metal oxides [8].

Samples of composites were formed from EP with was 3 vol. % CdO, PbO or Cr_2O_3. Samples of composites were subjected to curing with different conditions. The influence of constant magnetic (MF), electric (EF) fields were $2 \cdot 10^5$ A/m and $1.5 \cdot 10^4$ V/m, respectively. All curing processes were done at 20 – 25 °C for 24 hours.

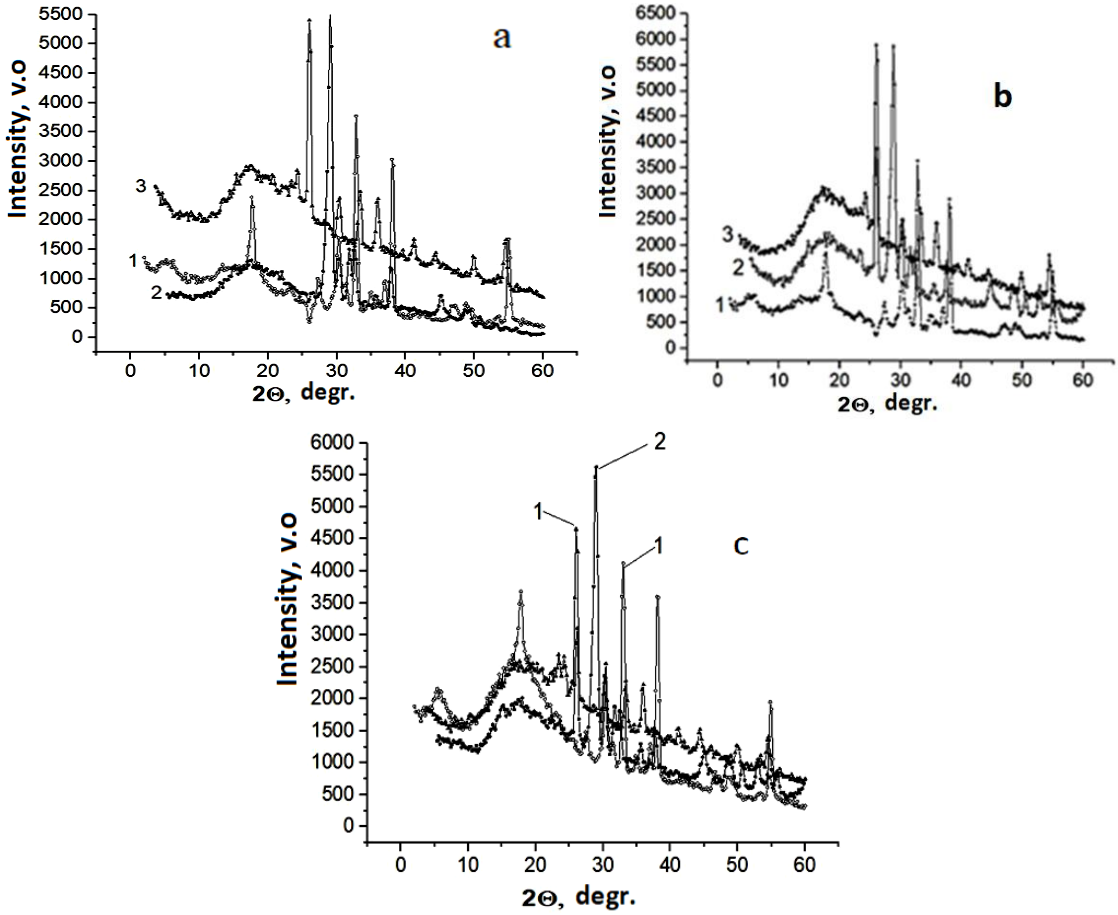
Differential scanning calorimetry experiments were carried out with an TA Instruments DSC Q 2000 (USA), at a sample heating rate of 20 °C/min under nitrogen atmosphere. All samples were weighed as 10 - 20 mg.

The curves of wide-angle X-ray scattering were obtained in the range of angles $2\theta = 2 – 60^o$ in the mode of stepwise 0.2^o scanning of the scintillation detector using DRON 2.0 diffractometer and filtered Ni radiation of the copper anode. The collimation of the output beam was formed by a slit of 0.25 × 0.25 × 0.5 mm, the receiving slit was equal to 1 mm. The obtained scattering data arrays after background removal were normalized by the camera according to the thickness of the sample and the X-ray attenuation coefficient.

The dielectric characteristics of the nanocomposites were determined by dielectric spectroscopy in an air medium at T = 20 ± 2 °C. The dielectric permittivity was observed at a frequency of 1 kHz for 4 s. Investigation of the temperature dependence of conductivity was carried out at a linear warming speed of the sample of 3 °C / min. The research was conducted in the temperature range from 20 to 150 °C.

Samples of epoxy polymer had an amorphous structure and samples of epoxy composites had amorphous-crystalline. In the scattering region $2\theta = 26.11^o$ and $2\theta = 29^o$ in the structure of the crystalline phase CdO the disappearance of part of the reflexes was observed, and for others the change in intensity after the influence of constant physical fields. However, reflexes $2\theta = 30.2^o$; 33.0^o; 38.3^o and 55.24^o with the highest intensity remained unchanged, which indicated the stability of the CdO crystal system in the composition of composites. Composites with PbO were characterized by the presence of 17 main reflexes in the range $2\theta = 28 – 58^o$. New reflexes in areas $2\theta = 26^o$, 50.6^o, 54.6^o appeared after the influence of constant physical fields. This indicates a redistribution of intensities and a partial angular shift of the maxima of certain reflexes. Comparison of changes in the intensities of reflexes $2\theta = 26.11^o$ and $2\theta = 29^o$ shows that $I_{26.11}/I_{29}$ for EP - PbO_{MF} was 59/100; for EP – PbO_{EF} - 8/100 and for sample EP – PbO $I_{26.11}/I_{29}$ was 6/100. Significant changes in the angular position and intensity of the main maxima of hexagonal syngony were not observed for composites with Cr_2O_3. But the intensity for the reflexes d_{014}, d_{111} and d_{110} varied depending on the curing conditions of the composites. The average crystallite size for these samples was 6 – 18 nm (Fig. 1).

Studies of the specific heat of epoxy polymers and their composites, depending on the composition and curing conditions, were performed. In this case, the introduction of fillers in the epoxy composite helps to reduce the specific heat (C_p) and increase the glass transition temperature (T_g) for the studied composites. This is due to the increase in the packing density of the EP macrochains and the free volume (Table 1).



1) CdO, 2) PbO, 3) Cr_2O_3;
a) without the influence of physical fields,
b) constant magnetic field,
c) constant electrical field.

Figure 1 X-ray diffraction patterns of epoxy composites with metal oxides formed under different curing conditions:

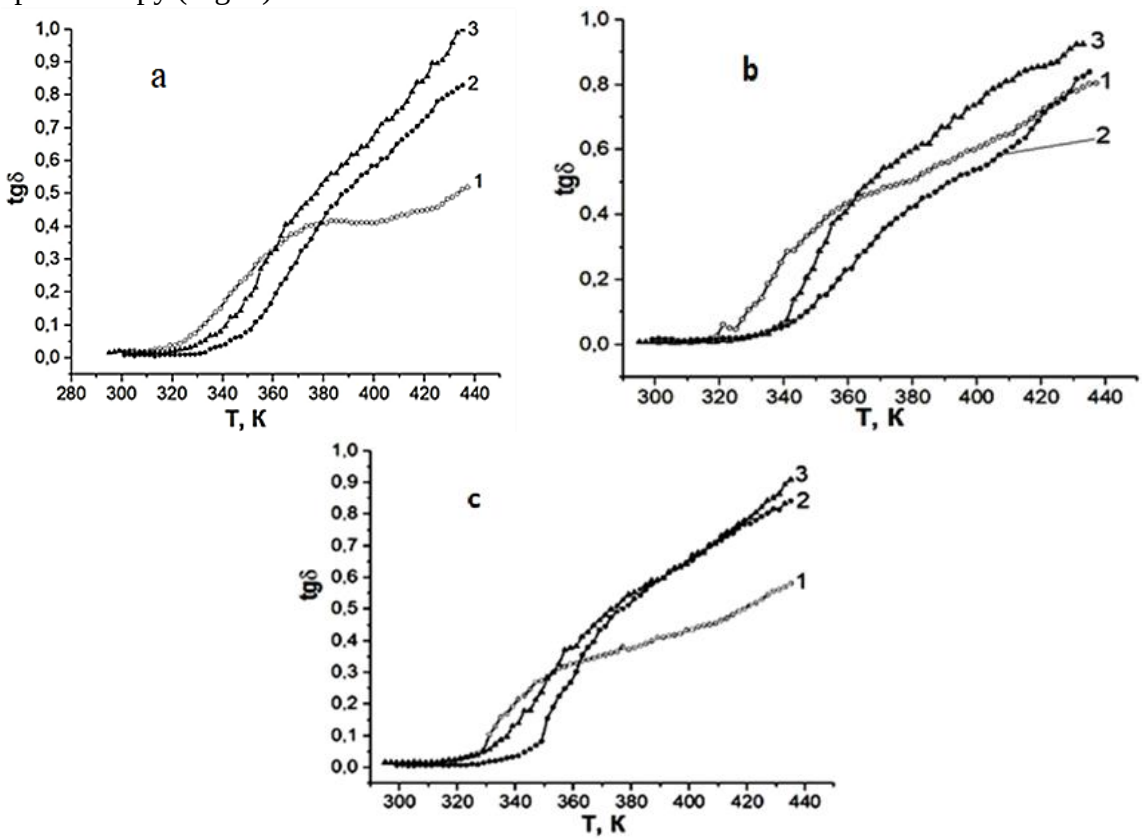
Table 1 Values of glass transition temperatures and specific heat for the studied samples

Samples	**without physical fields**		**MF**		**EF**	
	T_g, **K**	C_p, **J/(kg·K)**	T_g, **K**	C_p, **J/(kg·K)**	T_g, **K**	C_p, **J/(kg·K)**
EP	344	0,38	341	0,299	339	0,280
EP – CdO	329	0,193	332	0,268	334	0,164
EP – PbO	351	0,292	350	0,321	348	0,246
EP – Cr_2O_3	335	0,333	333	0,323	335	0,285

It should be noted that changes in the topological structure were observed for unfilled epoxy polymer. This was due to the influence of external constant physical fields on the polycondensation reaction and the formation of a three-dimensional chemical network. Differences in the influence of physical fields were manifested after

reaching the range of 88 - 94 °C (relaxation of segments of intermolecular fragments of EP). Changes in the temperature range 97 - 167 °C indicate that the use of MP or EP to form the structure of the EP allows you to change the packing density of the chemical network relative to its initial state (without physical fields). The high-temperature transition in the range of 134–136 °C is associated with relaxation in the diphenylolpropane moiety, which persists regardless of external exposure conditions. Comparison of the temperature dependences of the dielectric loss angle tangent for EP and EP - CdO indicates an increase in the temperature to 98 °C. This indicates a limitation of the mobility of intermolecular fragments of the epoxy matrix and particles of the dispersed filler. Estimation of the influence of physical fields on the tangent of the dielectric loss angle of epoxy composite shows that the orientation influence of physical fields increases the free volume of molecular chains of the chemical network, resulting in a decrease in T_g by 8 °C and 14 °C for MF and EF, respectively. Changes in the region of high-temperature transition 134 - 136 °C were the result of orientation and polarization effects of MF, EF on the structure of the diphenylolpropane fragment in the epoxy matrix. The curves of the temperature dependence of the tangent of the dielectric loss angle for the samples EP and EP - Cr_2O_3 formed under different curing conditions are similar.

The dielectric characteristics of the composites were determined by dielectric spectroscopy (Fig. 2).



1) CdO, 2) PbO, 3) Cr_2O_3; a) without the influence of physical fields, b) constant magnetic field, c) constant electrical field

Figure 2 Temperature dependence of the dielectric loss angle tangent (tgδ) of epoxy composites with metal oxides formed under different curing conditions:

Fig. 3 shows curves of the temperature dependence of the tangent of the angle of dielectric losses for the EP - 3% PbO and EP. All this curves are similar.

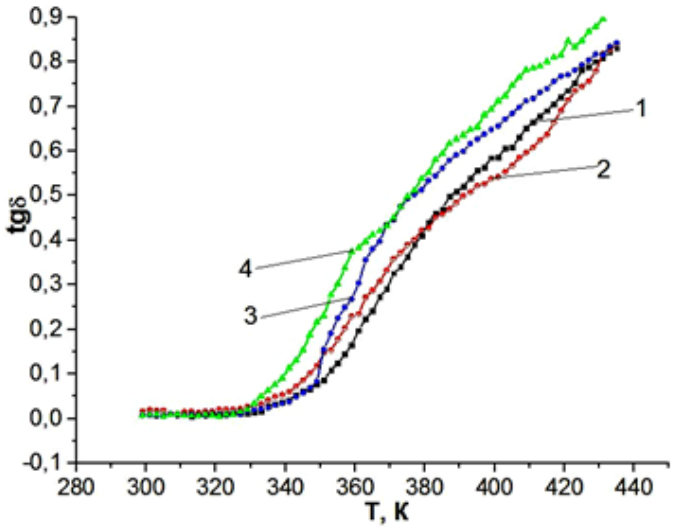


Figure 3 Temperature dependence of the tangent of the angle of dielectric losses for the EP - 3% PbO, formed under different conditions: 1) normal conditions; 2) magnetic field; 3) electric field; 4) EP.

Epoxy polymer, changes in the topological structure are observed. These changes are caused by the influence of external constant physical fields on the occurrence of the polycondensation reaction and the formation of a three-dimensional chemical grid. Differences in the influence of physical fields occur after reaching the region 88 - 94 °C (relaxation of segments of intermolecular fragments of EP). Changes in the temperature range 97 - 167 °C indicate that the use of magnetic or EF to form the structure of the EP can change the density of packaging of the chemical network relative to its initial state (normal conditions). The high-temperature transition in the region 134 - 136 °C can be related to the relaxation in the biphenylolpropane fragment, which is stored regardless of the external conditions of influence. However, the influence of the EF on the temperature dependence of the tangent angle of dielectric losses of the sample EP – PbO is more pronounced.

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