

ELECTRO-PHYSICAL PROPERTIES OF PTFE/BRONZE COMPOSITES

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Abstract

Electret state of polymer/metal composite based on polytetrafluoroethylene (PTFE) and bronze powder was investigated. It was found that bronze/PTFE composites have very long lifetime ($2 \cdot 10^{12}$ s) of charge stored in the bulk, which is of the same order of magnitude as the most stable polymeric electrets.

Introduction

We have investigated one of the types of active PTFE/bronze composites that has specific properties to accumulate space charges. The electret state of composite was characterised by measurements of equivalent voltage U_{eq} [V] and total charge density q_{stot} [C/m²]. Thermally stimulated voltage TSV technique was applied to estimate local state parameters of composite and to evaluate electret lifetime at room temperature τ_{293} [s].

Experimental

Samples

Bronze dust particles of average diameter 5 μ m were mixed with PTFE powder and hot-pressed at 380°C to obtain sheets from which the samples were cut. Diameter of circular samples equalled 50 mm. Thickness of samples varied from 150 – 500 μ m. Cross-section near the non-metallized surface of composite sample is shown at Fig. 1(a). Bronze grains are indicated by bright spots, and polymeric PTFE areas are in black. Bronze grains are randomly distributed in composite material. Grains do not create any conducting paths. Unevenness of sample surface can be observed. Roughness can be estimated as 10 μ m. The aluminium electrodes are strongly bonded to the sample surface. Fig. 1 (b) presents the filler analysis of bulk material. The investigated composite sample contains 40 weight % or 13.8 vol % of bronze.

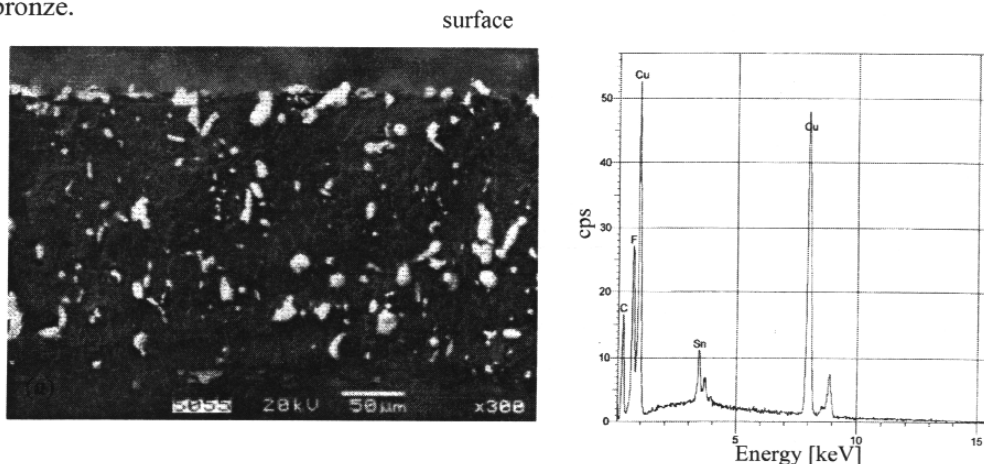


Fig.1(a). Cross section near the non-metallized surface of composite sample

Fig.1(b). Filler analysis of bulk of TB40/PTFE composite

Results and Discussion

Relaxation Properties

The temperature dependencies of dielectric constant and dissipation factor are shown in Fig. 2a (ϵ_r) and Fig. 2b ($\text{tg}\delta$). Relative permittivity of the composite is approximately twice that of PTFE. Losses in composite material are more than one order of magnitude higher than in PTFE. Loss curve has its minimum at about 370 K.

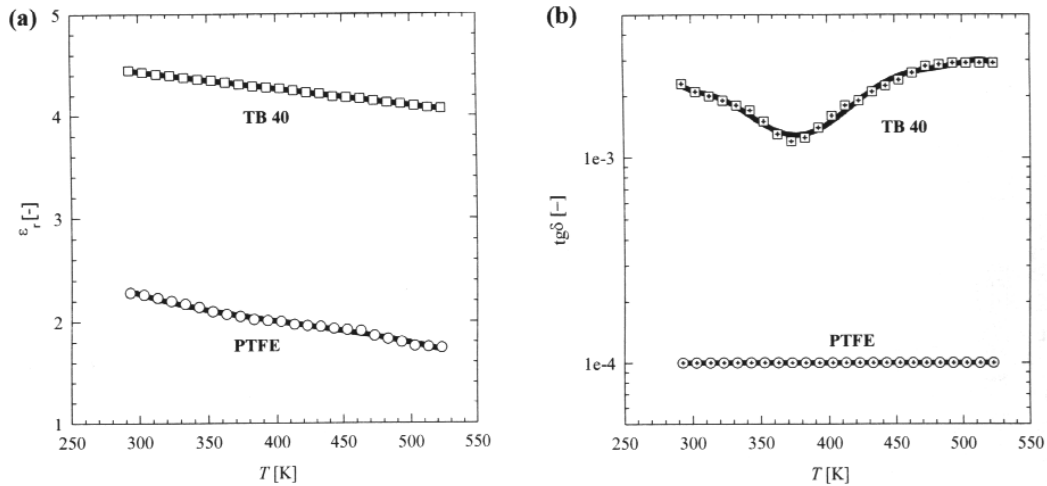


Fig. 2. Temperature dependence of dielectric constant – (a) – and dissipation factor – (b) – for composite TB 40 and PTFE hot pressing samples.

Electrical Conductivity

Bronze powder causes an increase in electrical conductivity of PTFE by approximately two orders of magnitude from $2 \cdot 10^{-18}$ S/m to $3 \cdot 10^{-16}$ S/m at room temperature. Conductivity of TB 40 equals about $4 \cdot 10^{-15}$ at temperature 510 K.

Charge Measurements

The values of equivalent surface charge density $q_{\text{seq}}[\text{C}/\text{m}^2]$, total or net surface charge density $q_{\text{stot}}[\text{C}/\text{m}^2]$ and equivalent voltage $U_{\text{eq}}[\text{V}]$ are shown in Table 1. The effective surface charge density $q_{\text{seq}}[\text{C}/\text{m}^2]$ was measured for one-sided metallized electrets by using contactless compensation method with vibrating electrode. The total charge density q_{stot} was measured by dropping nonmetallized electrets into a Faraday cup. Samples were charged in corona triode system [2]. It can be seen from Table 1, that q_{stot} is one order of magnitude higher than q_{seq} , so the real charges are sources of electrical field. In case of composite samples the values of equivalent surface charges and voltages are rather low, but total charge is comparable to that in PTFE sample.

Table 1. Equivalent surface charge density q_{seq} , total charge density q_{stot} and equivalent voltage U_{eq} in TB40 and PTFE samples after corona charging at room temperature, $U_{\text{g}} = +3\text{kV}$, $I_{\text{c}} = 8\mu\text{A}$, $t_{\text{c}} = 1200$ s.

	q_{seq}	U_{eq}	q_{stot}
Material	$[\text{mC}/\text{m}^2]$	$[\text{V}]$	$[\text{mC}/\text{m}^2]$
TB40	0.06	710	2.7
PTFE	0.32	2340	2.2

Isothermal Charge Decay

Fig. 3 shows the decay of the equivalent voltage in investigated samples at room temperature. The equivalent voltage U_{eq} is higher in PTFE samples than in TB40. Isothermal charge decay process at room temperature is rather slow. In order to increase the rate of charge, decay samples were discharged at higher temperatures. In case of PTFE, isothermal discharging was conducted at temperature 486 K, i.e. at half decay temperature, which was evaluated from thermally stimulated discharge experiment (Fig. 5). The temperature of half decay for TB sample could not be evaluated from Fig. 5, because of limited temperature range. That is why it was taken arbitrarily and set as 526 K. From experimental data (Fig. 4) presented in the $\log U - t$ plot the relaxation times at higher temperatures can be evaluated. The times of half decay were: $\tau_{TB40} = 2900s$, $\tau_{PTFE} = 5000s$.

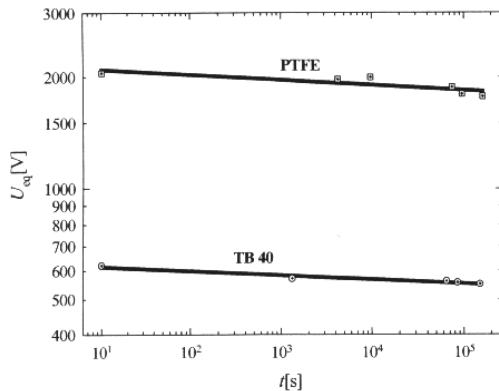


Fig. 3. Temporal changes of equivalent voltage at room temperature on composite TB 40 and PTFE samples after corona charging in triode system, $U_g = 3$ kV.

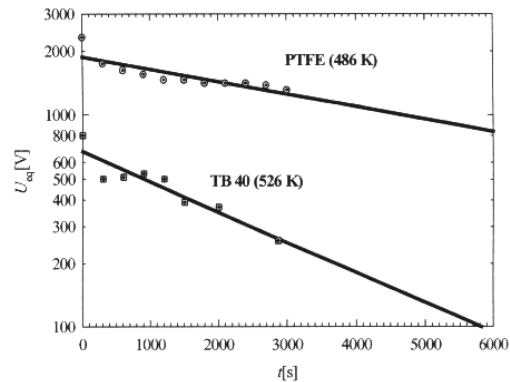


Fig. 4. Temporal changes of equivalent voltage at higher temperatures on composite sample TB 40 and PTFE sample after corona charging in triode system, $U_g = 3$ kV.

Thermally Stimulated Charge Decay

The equivalent voltage was measured as a function of temperature at constant heating rate $b = 2$ K/min. The results are presented in Fig. 5a for samples TB 40 and in Fig. 5b for PTFE samples respectively. The equivalent voltage in case of composite samples is lower than in PTFE samples and their relative changes in temperature are also smaller (Fig. 5b). The second feature makes composite samples more promising for electret applications.

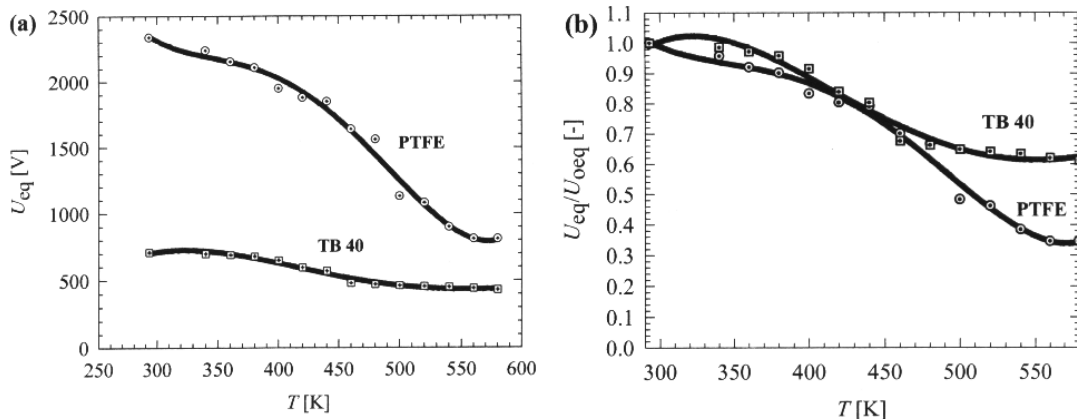


Fig. 5. The equivalent voltage measurement during thermally stimulated discharge of composite TB 40 and PTFE samples –(a). Relative changes of equivalent voltages –(b). Heating rate equalled $b = 2$ K/min.

Lifetimes of PTFE/bronze Composites

In this work the lifetime was evaluated on the basis of activation energy W , the temperature of halfdecay $T_{0,5}$ and time of halfdecay $\tau_{0,5}$ using (1) given in [3]:

$$\tau_{293} = \tau_{0,5} \exp \frac{W}{k} \left(\frac{1}{293} - \frac{1}{T_{0,5}} \right) \quad (1)$$

where k is Boltzmann constant. The following values of lifetime at room temperature were obtained: $2.5 \cdot 10^{12}$ s for TB40 and $2.0 \cdot 10^{10}$ s for PTFE. The above results cannot be explained on the basis of Maxwell relaxation time ($\tau_M = \epsilon/\sigma$). The latter values are $1.8 \cdot 10^7$ s and $1.8 \cdot 10^4$ s for PTFE and TB40 samples respectively.

Conclusions

The presence of bronze particles (18.3% vol.) in PTFE causes an increase in relative permittivity, (twice in comparison to PTFE), electrical conductivity (two orders of magnitude) and loss factor (one order of magnitude).

The charge stored in bronze/PTFE composite is lower in comparison to PTFE, but the composite lifetime is longer. The Maxwell relaxation time cannot explain the very long lifetimes in PTFE ($2.5 \cdot 10^{10}$ s) as well as in TB40 composite ($2 \cdot 10^{12}$ s) obtained from results of this work. The above results are consistent with literature data. The most stable polymeric foil electrets have lifetimes in order of 10^{12} s. The problem of very long lifetime in polymeric electrets has not been fully solved up till now. The most likely explanation is charge trapping at polymer-metal interfaces. In case of bronze/polymer composites such interfaces are randomly distributed in the bulk of the material. Creation of many interfaces in the bulk of polymer can be the means for building stable electrets with very long lifetimes.

Acknowledgements

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