ELECTROACTIVE POLYMER COMPOSITES WITH SEGREGATED STRUCTURE

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The purpose of the work was to develop a new method of processing samples with a piezoresistive effect that will be sensitive to cyclic mechanical loads. The sensor material was based on ground vulcanizate, which was coated with a solution of an adhesive thermoplastic carrier-polymer containing different types of carbon filler. The samples were formed by hot compaction method. As a setup for the experiment, an adapted apparatus for TMA analysis (by TA instruments) was used. It was found that the proposed composites have a linear electrical response on mechanical load, operate at different frequencies in a wide temperature range. The effect of filler hybridization on response was also investigated.

Keywords: conductive polymer composites, segregated structure, piezoresistivity

Development of electroactive composites (elastic polymer matrix filled with conductive fillers) shows their potential for creating various electromechanical sensors (accelerometers, pressure sensors, etc.). The polymer matrix of such composite has high elastic characteristics, so applying even small force leads to polymer deformation and, due to this, the number of contacts between dispersed conductive particles changes (the so-called piezoresistive effect). This reflects in a significant change in the electrical conductivity of the composite that opens up wide possibilities for use as sensors with an electrical response to mechanical action.

The composites with sensor properties were based on a polymer matrix made of elastomer, in which the conductive filler was distributed in an ordered manner in the form of a framework (so called segregated structure). Segregated structure is characterized by high electrical conductivity with a small filler content due to a high local concentration of the filler in the walls of the conductive framework. Carbon black, carbon nanotubes, and graphene nanoplates were used as conductive fillers. The mixtures of carbon black with carbon nanotubes or mixtures of graphene with carbon nanotubes were also used as hybrid conductive fillers.

The composites were subjected to cyclic mechanical impact on compression, the change in force was set in the range of 0.05–1.0 N, and the deformation, and change in the electrical characteristics (current through the sample and its resistance) of the sample were recorded. The relative deformation reached 3% at maximum force. Experimental measurements were performed using the thermomechanical analysis device TMA Q400E (TA Instruments, USA).

In such a piezoresistive system, small deformations of the composite cause a large change in the current, when the value of the Gauch factor $G = dL/dR \approx 1000$ (where dL is the change in relative strain, dR is the change in relative resistance). Such a large value of G indicates a very high sensitivity of the sensor material in the range of small applied forces, so the developed composites are sensitive to small values of external pressure in the range of 0.01…0.5 MPa. The cyclic studies of electric response, depending on the applied external load, showed a linear relationship between composite deformation and current changes through the sample. Also, the composites demonstrated stable long-term stability. The study of the piezoresistive effect in a wide temperature range (-40…+50°C) showed the stability of the main characteristics and the possibility of exploiting a sensor based on the piezoresistive composite in a wide temperature range.

Mathematical modeling of the electrical and mechanical characteristics of the sensor composite material under the action of cyclic mechanical loads was carried out.

The influence of the type and concentration of conductive filler on the characteristics of the sensor material was also studied. It has been shown that the use of carbon black gives stable sensor parameters, but the sensitivity of such composites is low, $G \approx 20$. Composites containing graphene and hybrid filler graphene/carbon nanotubes have the highest sensitivity, the latter providing the best response stability in cyclic tests. It was also found that too high filler concentration reduces the sensitivity of the composites; while the highest electrical response parameters, also combined with stability, are achieved at a filler content slightly above the percolation threshold.

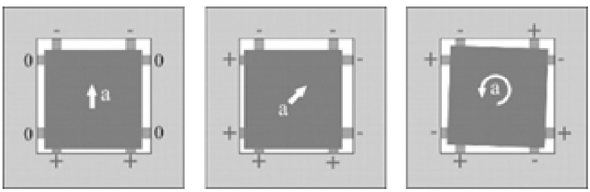

Fig. 1. Scheme of application of the developed composites as the acceleration sensor.

Thus, the developed composites with a segregated structure show a high sensitivity to low loads and a linear relationship between the applied force and the current, which is a result of the elasticity of the conductive structure of the filler. Such systems can be widely used in sensors for industrial and medical devices as acceleration sensors (Fig. 1), pressure sensors, etc.