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Fracture related electromagnetic emission measurement and excess noise analysis of reinforced composites

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Abstract

Electrical properties of several types of reinforced composites were investigated. AC and DC resistivities were measured, and the frequency behavior along with parasitic components was put together in order to create equivalent electrical circuit. It was used for electrical noise measurement corrections. It turns out that samples produces high level Johnson-Nyquist noise and $1/f$ noise when current bias is applied. We have discovered that electrical contact metallization affects directly the $1/f$ noise and the bulk material is responsible for white-like Johnson-Nyquist noise. We managed to get information about the suitability of the various metals in view of noise generation and the silver conductive pint seems to be proper chose. Finally, the electromagnetic emission signal, which in turn depends on cracks, was measured and comparison with conventional acoustic emission was put forward.

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Keywords: Reinforced composites; electromagnetic emission; excess noise; contact noise.

1. Introduction

The polymer based reinforced composites are very promising materials now. The reason is tailoring of its properties to the specific application with specific requirements, Greenhalgh (2009). Nevertheless, materials with wide variability in production require new methods for the quality control immediately after fabrication as well as

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during their application. It is also necessary to encourage fundamental material research in order to understand complex microstructure material properties. Our aim is put forward new methods or its combination for a fast scientific testing to determined degradation and live-time reduction. Very promising approach is the electromagnetic emission and the excess electrical noise measurement when the sample is kept at the constant physical conditions. The electrical noise is often used as an indicator of specific imperfections just by its level monitoring, Dutta (1981). This method is technically relatively easy to implement but it lacks information about the nature of imperfections and their causes or area of occurrence. For this reason, we use several different techniques and we observe the correlations between them. Methods that we use are acoustic emission (AE) and electromagnetic emission (EME) when sample is mechanically stressed, Koktavy (2009). Furthermore, we use electrical resistance measurement and electrical noise measurement when samples are without mechanical tension, Macku and Koktavy (2013).

2. Experimental methods and samples under investigation

The matrix used in this study is a vinyl ester, polyester and an epoxy polymer based on Bisphenol A resin. The lowest resin viscosity has a vinyl ester followed by polyester and epoxy. As reinforcement was used combination of E-glass, AR-glass, basalt and carbon fibres. The combination of matrix and reinforcement determine the interparticle contact, which affect the conductivity of the system and relating electrical properties. Carbon and E-glass fibres are approx. (300 – 700) nm in diameter (verified by SEM). Rectangular samples with varying dimensions were cut in order to distinguish between surface and bulk phenomena. The dimensions of samples are about (65, 50, 25) mm length, (50, 30, 20) mm width, and (20, 10, 5) mm thickness. Metallic contacts (cross-sectional areas) are prepared either as a full carbon layers with sheet resistance about 90 Ω/sq, silver layers with sheet resistance about 10 Ω/sq or copper foil. Each sample was cleaned by ethanol and stabilized by vacuum oven at 90 °C for 1 h to avoid moisture effects. The DC resistance temporal analysis was realized by the Keithley 6517B. The 2-terminal AC impedance spectroscopy was performed using an Atlas Sollich 0441 high impedance analyzer (frequency range from 10 μHz to 100 kHz). The noise-based measurement has been done by means of the Agilent 35670A two-channel FFT dynamic spectral analyzer. The analyzer is equipped by the custom made two-channel ultralow noise preamplifier (LNA) with high input impedance of about 200 MΩ and input capacitance of about 15 pF. The noise background of LNA is about 2.4 nV/√Hz at 100 Hz and the -3 dB bandwidth is 50 μHz ÷ 10 kHz. The characteristics of the spectral densities as a function of the bias current has been done by means of the Keithley 6220 precision current source. The EME measurement has been done by means of the National Instruments sampling unit PCI 6111 in continual acquisition mode and the EME signal was detected by the capacitance sensor.

3. Results and discussion

3.1. DC resistance and AC impedance spectroscopy

The DC resistance as well as AC impedance of the fibre reinforced polymers generally depends on the moisture (hydrophilicity), impurities, chemical properties, material crystalline or amorphous nature internal defects and reinforcement to matrix internal contact, Sandler et al. (1999), Pathania and Singh (2009). This measurement bears diagnostically interesting information and fundamentally defines requirements on the relating experimental set-up. For the DC measurement must be strictly used high resistivity meter or combination of the electrometer and the constant voltage source (e.g. Keithley 6517B). To ensure sufficient measurement accuracy the test voltage in the range (10 ÷ 40) V must be applied. A relatively high electric field introduces the dielectric polarization and the relaxation process taking place in the material, Jonscher (1983). In any case, the material is in the different state compared with the noise measurement without electrical excitation as well as the EME measurement with mechanical stress. The long term monitoring of the sample resistance development was measured for the each sample under investigation. It turns out that the sample resistance increase monotonically just like relaxation processes disappears. Characteristics reach a maximum after 4.5 hour measurement interval. Let's point out results related to samples mentioned before. We calculated DC volume resistivity from the resistance as is shown in Tab 1. Besides of that the AC impedance spectroscopy pointed out volume resistivity $\rho_{AC}(f)$ (it was calculated from real part of complex AC impedance). Measurement results are illustrated in fig. 1a.