DAMAGE SENSING WITH NANOCOMPOSITE/GLASS-FIBRE HYBRID COMPOSITES VIA ELECTRICAL CONDUCTIVITY METHODS

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ABSTRACT

In the presented work, the potential of a carbon nanoparticle modified epoxy matrix system was investigated to act as self-sensing material for damage monitoring in fibre reinforced composite structures. Electrical conductivity methods were used for in situ measurements of applied stresses/strains and the apparent damage situation in a glass-fibre reinforced epoxy composite. It is possible to sense as well load as damage in conductive glass fiber epoxy composites by monitoring the electrical resistance of the material. Additionally, the nanoparticles have a positive influence on the mechanical properties of the investigated materials. Interlaminar shear strength tests (ILSS), 90°-Tensile tests and fatigue tests on the materials were performed using nanomodified matrix systems. The modified materials showed better mechanical properties then the unmodified reference materials.

1. INTRODUCTION

Glass fiber reinforced epoxy laminates with a nanoparticle modified matrix system were investigated in combined electromechanical tests, i.e. mechanical tests with in situ electrical resistance measurement. The epoxy matrix was modified with nanoparticles by using a shear mill process described in [1-] to achieve a good dispersion of the particles. As nanoscopic fillers, three types of carbon particles and one type of spherical silicon dioxide particles were used. Multiple walled carbon nanotubes (MWCNTs) provided by Arkema, exhibiting diameters of 10-30 nm, double wall carbon Nanotubes by Nanocyl, exhibiting diameters of ca. 5 nm, and carbon black by Degussa (spherical particles, diameter ~ 30 nm) as well as spherical SiO_2 particles by Degussa (diameter ~ 7 nm) were blended into the resin with a high-shear mixing process. Glass fibre composite materials were then produced by using a modified vacuum assisted resin transfer moulding process. For the electrically conductive nanofillers (MWCNT, DWCNT and carbon black), the matrix system exhibited filler contents above the electrical percolation threshold (0.3 wt.%). The specific electrical conductivity of the materials ranged from 10^{-4} to some 10^{-2} S/m.

2. EXPERIMENTS

The composites were tested in various combined mechanical/electrical tests. The specimens were isolated electrically against the loadframe and contacted with conductive silver paint for the resistance measurements. An exemplary visualisation of the contacted specimen is shown in figure 1. Mechanical load was applied to the materials and the DC electrical resistance was measured in situ. For this study, quasistatic tensile tests, ILSS tests and fatigue tests were performed on the materials to show the self-sensing potential.

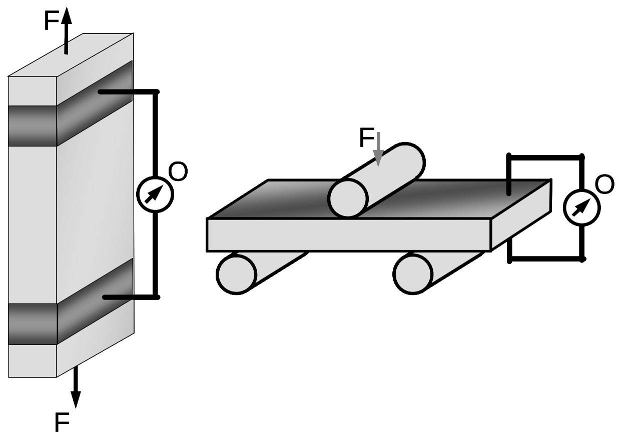

figure 1 – Schematic visualisation of the electrical contacts on a tensile test specimen (left) and ILSS specimen (right)

Dynamic tensile tests were performed in order to investigate electrical resistance change of the materials in the elastic deformation regime, as well as the effect of an apparent mechanical damage. In these tests, electrical measurements were also performed in both 0°- and through-thickness-direction of the specimen.

3. EXPERIMENTAL RESULTS

All mechanical properties that have been investigated showed a significant improvement. For example, the stress to first inter fibre-fracture could be increased by 8% - 16%, as shown in figure 2.

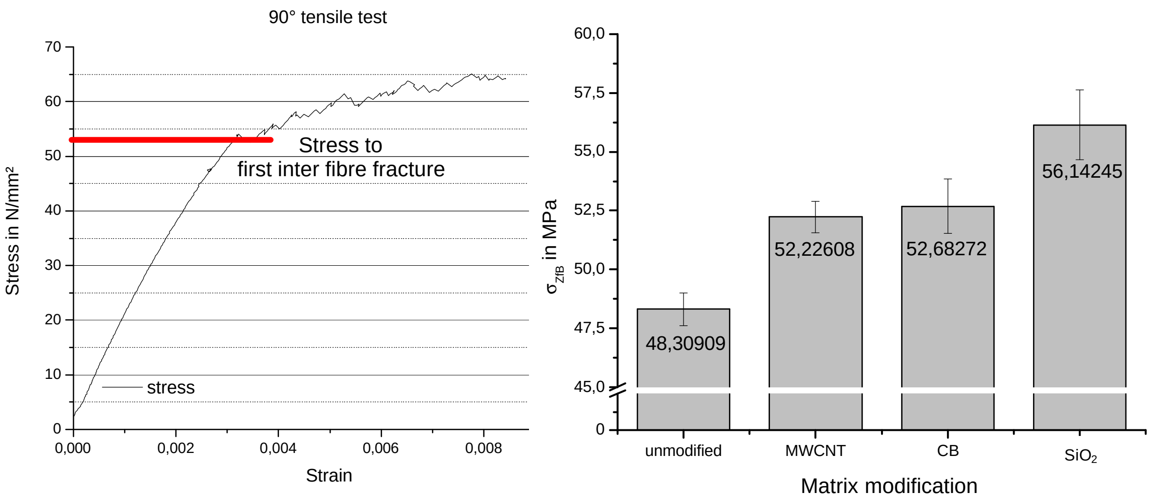

figure 2 -Increased inter-fibre-fracture strengths due to nanoparticle modification [3]

Additionally, it was possible to monitor stress/strain and damage by measuring the electrical resistance of the material. figure 3 shows an exemplary testing result from a 90°-tensile test with in situ resistance measurements. The electrical resistance of the specimen increases linear until the first inter fibre fracture in the specimen occurs. From that moment on the electrical resistance is increasing faster and the slope of the stress strain curve is decreasing. Thus, the appearance of inter fibre fracture can be monitored by measuring the electrical resistance of the specimen.

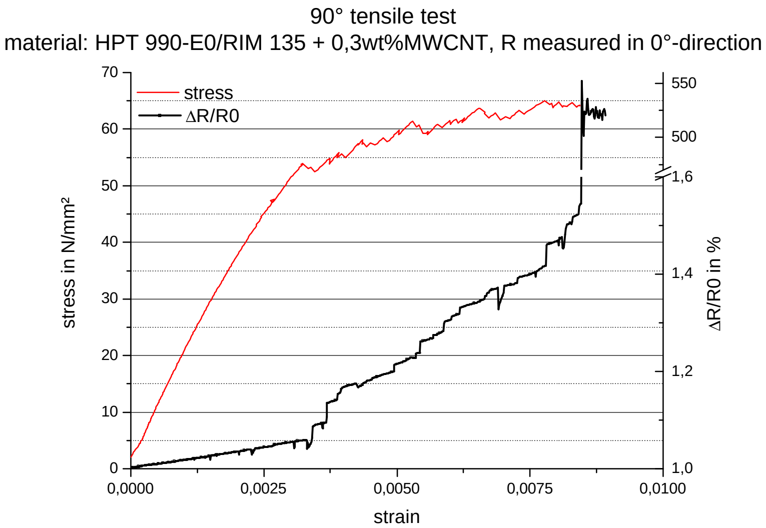

figure 3 - exemplary experimental result of 90° tensile test with in situ resistance measurement [3]

The interlaminar shear strength (ILSS) was measured with the three-point-bending loading method. Electrical conductivity measurements were performed in 0°-direction (in plane) as well as in z-direction. In these tests, the onset of delamination could be correlated to a spontaneous increase in electrical resistivity. This can be seen figure 4. The electrical resistance is not changing significantly as the specimen is loaded in the three point bending method. Then, at the situation of the maximum load, a spontaneous delamination occurs and the electrical resistance changes immediatly.

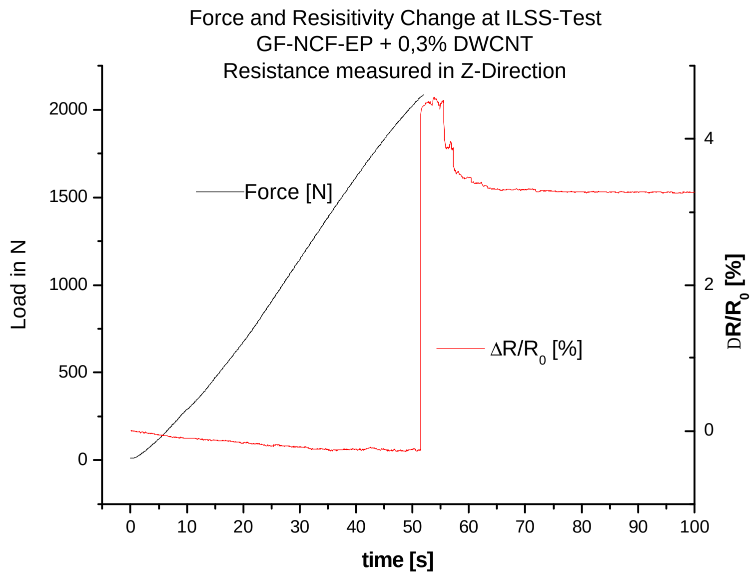

figure 4 - Force and resistivity change at ILSS test [2]

After unloading the specimen, a residual change in electrical reistance due to the interrupted nanocomposite matrix is clearly visible. Thus also for this example the potential of using electrical resistance methods as damage sensor for conductive composites is obvious.

4. CONCLUSIONS

For every conductive composite material that has been produced, a correlation between the change in electrical resistance and the state of loading/damage was found. This phenomenon was found to be independent on the type of mechanical test and the direction of the resistivity measurements. Additionally, the mechanical properties of the composites could be improved due to nanoparticle modification of the epoxy matrix. So, a promising future application of the damage sensing technology in glass fiber reinforced polymers could be found in the field of condition monitoring, e.g. for the online remote degradation monitoring of distributed composite structures, e.g. wind turbine rotor blades.

ACKNOWLEDGEMENTS

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