Review paper

Sensing with Carbon Fibres in Polymer Composites

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Abstract: Carbon-fibre-reinforced polymer (CFRP) composites derive their excellent mechanical strength, stiffness and electrical conductivity from carbon fibres. The mechanical deformation and electrical resistance are coupled in these fibres that make them inherently sensors. Thus CFRPs can be considered as a self-monitoring material without any need for additional sensing elements. However, for this to become reality the conductivity map of the entire structure needs to be constructed and the relationships between the conductivity and various use- and damage-related variables need to be established. Experimental results demonstrate that internal damage, such as fibre fracture and delamination, decreases the conductivity of composite laminates. In general, the information about the damage size and position can be obtained by utilising electrical impedance tomography (EIT)..

Key words: Health monitoring, Electrical conductivity, CFRPs, Electrical impedance tomography, Non-destructive testing

1. INTRODUCTION

Fibre-reinforced polymers (FRP) are known as materials with excellent specific mechanical properties, which are adjustable to a wide range of applications. Because of their anisotropy, an exact adaptation to the needs of an application is possible. However, FRP are a very young group of materials compared to metals, and this leads to a gap in knowledge about properties, failure mechanisms and failure criteria. This, in turn, leads to the use of higher safety factors for FRP and therefore to a still preferred choice of metals related to FRP.

The fatigue properties of carbon-fibre-reinforced polymers (CFRP) are superior to those of metals, but as yet they are still not as well understood. One well-known problem in improving the use of CFRP is the 'sudden death' problem [1] of FRP parts, which makes it difficult to develop a trustworthy failure prediction. One possibility to improve the use of the material's potential is an in situ observation of a possible degradation of parts in order to be able to predict serious damage or failure under static or fatigue loading. Special attention has to be paid to the load-carrying fibres, as failure in FRP is always associated with fibre failure. The observation of load-carrying fibres principally offers the possibility to predict the component failure.

Carbon-fibre-reinforced polymers (CFRPs) consist of electrically conductive carbon fibres and a polymeric matrix, which is an insulator. The carbon fibres are responsible for both the strength and the electrical conductivity of the composite material. Thus the stiffness and strength as well as the conductivity is much higher in fibre direction than in the transverse direction. Many investigators have suggested optical fibres and other sensors as smart sensing constituents for health and usage monitoring of CFRP laminates. Instead of introducing additional devices into the laminate, our approach suggests that the load-carrying carbon fibres themselves can be utilised for self-monitoring of the CFRP laminates. It

is further possible to extract the stress/strain field as well as the damage state by mapping the specimen electrical resistivity (or impedance) information.

Previous work has focused on the basic electrical properties of CFRP laminates for electromagnetic shielding purposes and the prevention of electrostatic charging [2,3]. The detection of damage by electrical resistance measurements in unidirectional laminates under tensile stress was reported by Schulte and Baron [4]. Their experimental technique with electrodes positioned at the fibre ends is mainly sensitive to fibre rupture and strain. Other groups have reported on the electrical properties during fatigue [5,6] and on the a.c. (alternating current) behaviour of CFRP during tension [7]. Only a few papers report on the comparison of acoustic emission (AE) and electrical response of CFRP during mechanical testing [8].

A good deal of work has already been done on the characterisation and analysis of damage mechanisms in CFRP laminates, reviews thereon having been published by Schulte et al. [9] and Jamison et al. [10]. Our goal was to correlate the measured change in the electrical resistance of the carbon fibre composite with the state of mechanical damage in the composite material. We have therefore investigated the resistivity vs. strain behaviour of various CFRP-laminates under quasi-static cyclic tensile load.

1.1. d.c. Electrical Measurements

One such technique, if the electrically conductive carbon fibres are used as electrical resistors, is the d.c. (direct current) electrical measurement. As a consequence of an applied strain, the overall cross section of the carbon fibres decreases as a result of the Poisson effect and this facilitates the correlation between strain and measured resistance [4]. If carbon fibres fail, a jump in resistance is observed. Taking into account the conductivity variation transverse to fibre direction via connecting points of the carbon fibres, it is also possible to observe

delamination processes and even to separate these from other damage mechanisms [11]. The d.c. electrical method can also be used for electrically conductive polymers or composites as carbon black filled glass-fibre-reinforced polymers (GRP), where the electrically conductive carbon black network in the epoxy matrix plays the role of the electrical resistor. It is therefore possible to monitor strain and matrix failure through the load induced disorder or failure within the conductive network, respectively.

1.2. a.c. Electrical Measurements

Usually a.c. electrical measurements are known as a method to monitor curing and aging processes of thermoset matrix systems [12]. It has been shown, that it is also possible to perform damage detection and strain recording for CFRP with that method [7]. The laminate is taken as a dielectric material, where both the measured capacitance and dissipation are changing with the applied strain and damage.

1.3. Electrical Impedance Tomography (EIT)

The electrical impedance tomography (EIT)-method gained wide recognition in the 1920s by geophysicists who placed arrays of electrodes into the ground [13,14]. Oil-bearing rocks under the surface were identified by injecting current through a pair of electrodes and measuring the resulting voltage at other electrodes. In our case, we would like to determine the resistivity distribution in a laminate sheet. Various electrodes are connected to the edges of the sample. An electrical current is injected via two electrodes and the potential difference between all other neighbouring electrodes is measured. By taking various combinations of current-injecting electrodes and repeating the potential difference measurements at the remaining electrodes, a wealth of information can be obtained. This information can be utilised to extract resistivity distributions inside the sample using a reconstruction algorithm based on fundamental electrodynamic equations. Once refined, the EIT has practical applications in monitoring laminated CFRP structures. The technological and manufacturing hurdles do not appear to be barrier in implementation of the technique.

2. EXPERIMENTAL DETAILS

2.1. d.c. Electrical Measurements on CFRP

Figure 1 schematically shows the experimental setup to measure the d.c. electrical resistance. A constant current I of 50 mA was applied through the end faces of the sample, for this current level no heating was observed. The voltage U was monitored with an accuracy of 0.01 mV. The resistance R of the sample could be calculated by Ohm's Law, known as

$$R = \frac{U}{I}. \quad (1)$$

End tabs of glass-fibre-reinforced polymer were used for electrical insulation against the grips and easy load

Fig. 1. Schematic illustration of the experimental setup for monitoring electrical resistance, temperature and strain of CFRP samples.

Fig. 2. Schematic illustration of the electrodes placement for a.c. electrical measurements.

transfer. Electrical contact between the copper plate and the carbon fibres was realised with conductive silver paint that covered both copper plate and carbon fibres. The tests were performed in static tension and tension - tension fatigue at a constant R ratio ($R = \sigma_u / \sigma_o$, where σ_u is the minimum and σ_o the maximum stress in a load cycle) of 0.1 at a frequency $f = 10$ Hz. All tests were performed with different carbon fibres and epoxy matrix systems. Further details can be found in [15 - 17].

2.2. a.c. Electrical Measurements on CFRP

The electric a.c. field was applied through two electrodes on both sides of the sample. These electrodes build a plate condenser where the sample acts as a dielectric material as shown in Fig. 2. The electrical measurements were performed by using an HP4284A impedance analyser with four-point probe technique. A voltage amplitude of 1 V was applied and the complex impedance Z vs. the frequency f was recorded from 75 Hz to 1 MHz.

2.3. Electrical Impedance Tomography

There are different strategies for collecting experimental data for EIT. One of them is the adjacent strategy, where current injection is done at two adjacent electrodes (see Fig. 3) and the voltage is measured between all other

Fig. 3. Schematic representation of EIT set-up to a rectangular specimen using the adjacent data collection strategy.

adjacent electrodes. This gives N^2 measurements, where N is the number of electrodes, from which $N(N-1)/2$ are independent. The use of the current electrodes is often omitted due to possible contact resistance at these points which could be a source of an error. This reduces the number of independent measurements to $N(N-3)/2$. For 16 electrodes this is equal to 104. In EIT we measure the potential and current distributions on the electrodes placed at the boundary of a specimen to determine the internal conductivity distribution.

3. RESULTS AND DISCUSSION

3.1. d.c. Electrical Measurement on CFRP

3.1.1. Tests under static loading

Carbon fibre fracture can be expected in CFRP laminates under static loading [4]. The in situ observation of fibre fracture is, in general, not possible during a load test except the fibres split off the specimen surface and are visible with the naked eye. However, the variation in electrical resistance during static loading is a clear indicator of fibre fracture as shown in Fig. 4. It shows a stress/strain curve as well as a resistance/strain curve of a unidirectional $[0_s]$ specimen. The electrical resistance first increases approximately linear with increasing fibre strain. After about 0.7% strain the electrical resistance no longer varies linearly, which can be related to fibre fracture. Above 1.2% strain the electrical resistance rises in stepwise manner to higher values. This can directly be related to fibre fracture, that is partly indicated - with a much lower resolution - in the stress/strain curve. The d.c. resistance measurements on CFRP, however, cannot only indicate strain and fibre fracture, but also delamination, one of the most pronounced damage mechanisms [11]. In Fig. 5 is shown the result of a tensile test on a unidirectional $[0_s]$ specimen. The third ply (centre ply) was cut through. During initial loading linear elastic deformation occurs, following Hook's law, leading to a linear increase in electrical resistance. In the cut third ply shear stresses transfer the loads from one ply end to the other through the matrix and neighbouring intact plies. When the shear stress exceeds the matrix properties a delamination initiates and a plateau is formed in the stress/strain curve. Subsequently the electrical resistance increases smoothly. When the delamination growth comes to an end, i.e. when the third (centre) ply is completely separated from

Fig. 4. Tensile test of a unidirectional laminate, showing the stress/strain curve and dependent electrical resistance of a CFRP specimen.

Fig. 5. Tensile test of a unidirectional laminate. Centre ply was cut through to initiate delamination process. Stress/strain curve and dependent variation of electrical resistance are both indicating delamination growth.

the neighbouring plies, a further increase in the stress/strain curve is observed (now with a lower slope, indicating that one ply is not any more contributing to the specimen strength) and the electrical resistance vs strain curve is changing the slope, that is now more stepwise as seen in Fig. 4.

3.1.2. Test under fatigue loading

In cyclically loaded CFRP laminates a variety of damage mechanisms can be observed [10,18]. Fibre fracture is observed comparatively early in a test. It was shown in previous studies that the variation of specimen stiffness is an indicator sensitive to damage accumulation, especially fibre fracture. However, identification of various damage mechanisms is not possible with this method. In Fig. 6 is shown the result of a fatigue test on a $[0_2, 90_2, 0_2, 90_2]$ cross-ply laminate. Specimen temperature, electrical resistance and stiffness (normalised secant modulus) were simultaneously measured and correlated with fatigue life. Additionally shown is the corrected electrical resistance. Fig. 6 suggests the following:

Fig. 6. Variation of secant modulus, temperature and electrical resistance during cycling loading (% of fatigue life). Electrical resistance corrected for temperature variation.

Fig. 7. Stress versus strain and resistance versus strain response of quasi-isotropic laminate filled with 1.0 phr carbon black. Experimental curves are shown bold, whereas approximations for the curve sections and (2) are fine-drawn.

- (1) The secant modulus, i.e. the stiffness, is decreasing during fatigue life, especially at the beginning (transverse cracks in 90° plies), above 60% fatigue life (0° fibre fracture) and at the end of fatigue life (failure).
- (2) The specimen temperature increases during fatigue due to damage accumulation. Especially at the beginning and above 70% fatigue life a strong increase is observed.
- (3) The measured electrical resistance increases over the entire fatigue life. Due to the temperature development the resistance sometimes decreases and only when fibre fracture is observed it increases in a stepwise manner.
- (4) The corrected electrical resistance shows a continuous

increase or is constant during fatigue life; a decrease is no longer visible. It is reflecting the damage accumulation, but it is especially sensitive to 0° fibre rupture; usually the most important damage mechanism observed which can be used to predict component failure.

3.2. d.c. Electrical Measurements on GRP

A technique as in Subsection 3.1.1 can be applied to conductive GRP. While in CFRP the carbon fibres provide the conductivity, in GRP it is the carbon-black-filled matrix [19, 20]. Thus matrix cracks and not fibre breaks should lead to an increase in electrical resistance. Figure 7 shows the stress/strain curves and the relative resistance increase of a quasi-isotropic laminate. The carbon black content in the resin is 1.0 phr (phr: parts per hundred resin). A profound piezo-resistive effect is revealed. At a strain of about 2% the resistance increases 45%, which is fairly high even compared to materials designed for piezo-resistive strain sensors [21]. The stress/strain curve shows the typical knee, known for cross-ply and quasi-isotropic GRP laminates. At a strain of about 0.5% multiple matrix cracks in the 90° - layers occur causing a drop in the laminate stiffness. Above and below this knee the curve can be approximated by a straight line. A similar bend can be observed in the relative increase of the resistance. The course above and below this bend can be described by

$$\frac{\Delta R}{R_0} = Y \cdot \varepsilon^\beta \quad (2)$$

with R : resistance, ε : strain and Y, β : parameters. For both curve sections β equals 1.5. Similar to the slope of the stress/strain curve Y decreases from 0.251 below the bend to 0.127 above. The size of Y thus reduces according to the damage of the material. This reduction of Y is irreversible as can be seen in Fig. 8. This sample was strained to 1.7%, released and then strained to failure. After the first load cycle the knee at a strain of 0.5% vanishes, since the matrix cracks already exist and the Young's modulus is reduced due to the previous damage. The resistance versus strain curve also shows a bend for the first load cycle. Here, too, the bend disappears at the second load cycle, so that the entire course can be approximated with only one set of parameters. Furthermore it can be seen that a reduction in stiffness goes along with a reduction of Y . Therefore it can be stated that a decline of Y indicates a degradation of the material.

3.3. a.c. Electrical measurements on CFRP

The observed effect of an increasing load and strain on the capacitance and dielectric dissipation of a CFRP cross-ply laminate is shown in Fig. 9 [15]. While generally the capacitance decreases, the dissipation increases with increasing load and strain. In Fig. 10 the condition in a CFRP specimen is schematically demonstrated [15]. The high resistivity of the matrix causes a capacitance between the fibres. Close or touching fibres cause current flow between fibres which results in a resistance. From

Fig. 8. Stress/strain and resistance/strain response of quasi-isotropic laminate filled with 1.5 phr carbon black, which is loaded twice. Experimental curves are shown bold, whereas approximations for the curve sections (1) and (2) are fine-drawn.

basic equations it is possible to derive that the capacitance decreases because the dielectric constant of the CFRP material decreases, too. A reason for this effect may be that the conductive, load bearing fibres get closer during loading due to the high Poisson ratio of the epoxy matrix. Other parameters such as the vacuum permittivity and the electrode area remain constant during loading. The electrode distance, i.e. the specimen thickness, decreases due to the Poisson ratio, causing an opposite behaviour, an increase in capacitance. Furthermore matrix cracks lead to an increase in capacitance due to the formation of new surface within the material. These effects may be the reason for the observed irregularities and slope changes in the capacitance curve in Fig. 9, especially at lower loads where transverse matrix cracks appear in the 90° plies. From fundamental equations it can be seen that the dissipation behaves inverse to capacitance C and laminate transverse resistance. Like the capacitance, the resistance decreases because the insulating matrix between fibres gets thinner during loading (elastic deformation), enabling a current flow between fibres. Thus the dissipation reflects two different physical properties C and R which are affected by load and strain

with the same tendency. At about 1% strain of the tensile test shown in Fig. 9 fibre fracture occurred in the specimen right between the electrodes. This rupture of load bearing fibres leads to a stiffness loss and thus to a sudden drop in load during a displacement controlled test. The former stress of the broken fibres is locally transferred into neighbouring fibres, resulting in stress concentration and thus an increasing local stress and strain. Because the fibre fracture was observed to be in the electrode area, the dissipation reacts very sensitively by jumping to a higher level.

It is of interest if the specimen can be recognised in a.c. electrical measurements. An incremental cyclic tensile test with increasing load maxima equivalent to 0.3% strain and an increase of 0.2% in each subsequent cycle was performed. The preliminary measurements showed that up to frequencies of 1 MHz the a.c. electrical response was dominated by the ohmic resistivity of the carbon fibre network. Therefore, we chose a frequency of 75 kHz for the electrical measurements to ensure a quasi d.c. resistance value.

Figure 11 shows the simultaneous change in the electrical resistance and of the accumulated AE as a function of the laminate strain. The resistance increases during tensile loading and decreases during unloading. However, during loading and unloading the resistance follows different curves, leading to a hysteresis behaviour in the resistance vs. strain dependence. When the previous load

Fig. 9. Tensile test of a cross-ply laminate, showing the stress/strain curve and dependent capacitance and dielectric dissipation (at 1 MHz and 100 mV) of a CFRP specimen.

Fig. 10. Condition in a CFRP laminate and a possible equivalent circuit.

maximum is exceeded the slope of the resistance - strain curve increases. At this point a strong increase in the AE occurs, this is shown in the upper part of Fig. 11. This behaviour is known as the Kaiser effect for the AE in composites [21, 22] and has also been used to describe the electrical response of composite materials [23]. The increase in AE is due to further damage progression in the composite sample. This causes the rupture of bonds in the material, thus releasing a portion of the deformation energy into energy of elastic waves. The opening of previously formed cracks and crack closing does not create significant AE. The strong correlation of the acoustic emission and the increase in the resistance - strain slope indicate a similar origin of both effects.

Figure 12 shows the electrical response and AE during a second block of cyclic loading for the specimen of Fig. 11. The electrical and acoustic behaviour of the sample is significantly different to that in the first block of cycles. The total AE activity is about eight times less compared to that of the first block. There is an onset of AE at lower strain values, and there is no pronounced increase in the number of AE events when a previous load maximum is exceeded, indicating no further damage development at this point. For the electrical resistance we observe initially an increase in the resistance-strain slope up to a strain of 0.2% for all cycles, which is a result of the elastic deformation of the specimen and the opening and closing of existing cracks in the material. However, a further load increase leads to a reduced gradient of the curve, which can be explained by continued opening of cracks without the appearance of additional damage. There is no characteristic rise in the slope of the resistance vs strain curve after a previous load level is exceeded, while the hysteresis in the electrical resistance over a load cycle is still present. The observed resistance variation is mainly caused by the opening and closing of fibre-fibre contacts and to a lesser degree by the rupture of load bearing 0°- fibres.

3.4. Electrical Impedance Tomography (EIT)

It has been shown by experiments that the resistivity of CFRP increases with the appearance of internal damage, such as fibre breakage and delamination. These experiments proved that the change in electrical resistivity is a viable manifestation of damage in CFRP. The natural extension of this method is a determination of damage class, e.g. fibre breakage or delamination, and damage size and position. However, additional information is needed to quantify these aspects rather than just the gross resistivity change. A promising method for the evaluation of at least the damage size and position is the EIT [17, 25-28].

Usually, EIT is applied to materials with an isotropic conductivity. CFRP has a highly anisotropic conductivity. Therefore, it is necessary to assign at least two conductivity values to each element. In the case of low anisotropy, the conventional EIT can be applied to obtain a resistivity distribution of specimen with a minor modification. Until now conductivity of only isotropic materials, i.e. direction independent but position dependent, has

Fig. 11. (a) Resistance-strain behaviour for the first five cycles of across-ply laminate. (b) Correspondent accumulated AE.

Fig. 12. (a) Resistance-strain behaviour for the second block of cycles of the same sample as in Fig. 11. (b) Correspondent accumulated AE.

been examined using this technique. That means the reconstruction algorithm developed for the isotropic case has to be expanded to account for anisotropy. In practice, the accuracy of this method is limited by the experimental resolution of the potential and current. As will be shown later, this becomes more difficult with increasing anisotropic resistivity, since in this case very small voltages have to be resolved beside large peaks. An arbitrary practical limit for using the traditional EIT method is an estimated anisotropy-ratio of 100. At high ratios the traditional data-collection method has to be adjusted. Instead of equidistant electrodes along all four sides, it is advantageous to place the electrodes only along the sides that are perpendicular to the fibre direction. It is possible to determine the position and the size of a hole in an conductive sheet with a large anisotropy (>100). The hole position in a direction transverse to the fibres could be easily determined by using more finely spaced electrodes on sides transverse to the fiber direction. The position of the hole in the fibre direction could be obtained by comparing the potential difference between the electrodes on the current injection side and the electrodes on the opposite side of the specimen. That means a fine array of electrodes have to be applied to the specimen, but only on two sides. In contrast, in the case of low anisotropy, electrodes have to be attached to all specimen edges, but with a larger spacing. However, this method has a theoretical limitation as it requires the shape of the hole (damage) to be known a priori. This requirement is too restrictive for practical implementation of the method. A method to overcome this restriction is proposed in the next section.

3.4.1. Resistor network representation

It is mentioned above that CFRP has a highly anisotropic conductivity. It is much higher in the fibre direction than in the transverse direction. Therefore, the approximation of setting the conductivity in the fibre direction to infinity seems feasible. The procedure to calculate the hole position and size by assuming that the conductivity in the fibre direction (y direction) is infinite is described elsewhere [17]. With this assumption, the sample can be represented by a simple resistor network as shown in Fig. 13.

3.4.2. Results and discussion

For the experimental investigation specimens with a ply thickness measured to be 0.16 mm were cut into squares of 52 mm-52 mm. To perform the electrical characterisation, 16 razor blades pressed to the specimen edges every 13 mm, were used as electrodes (shown in Fig. 14).

In Fig. 15 numerical as well as experimental results for a specimen with a hole in the centre (hole 1), at the right side (hole 2) and at the top (hole 3) are shown. The positions of these holes are shown in Fig. 14. Experimental results are presented with voltage amplified by a factor of 10. For clarity, only the difference in potential between the damaged and the intact specimen is presented. In each case, only one measurement is significantly different from the others. For hole 1 and hole 3 this is, when current is applied between the electrodes 2 and 3

Fig. 13. Resistor-network representation of an unidirectional CFRP specimen with a hole.

Fig. 14. Schematic of specimen used for experiment and calculations.

and the voltage is measured between 10 and 11. For hole 2, the peak shift to the current electrodes 3-4 and potential electrodes 9-10. These peaks indicate the hole position in 90° direction. Peaks for holes 1 and 3 reveal that the entire holes are between $x=1.5$ and $x=2.5$, whereas the peak for hole 2 shows that entire hole is between $x=2.5$ and $x=3.5$. Using more electrodes with smaller distances, the hole position transverse to the fibre direction could be easily determined accurately. The peak height provides information about the amount of conductivity drop in the 'examined specimen section'. For instance, by applying current at electrodes 2 and 3 and measuring the voltage between electrodes 10 and 11, this section would be the rectangle spanned between these corners (2-3-10-11). For the intact specimen the voltage is 0.482 compared to 0.518 with hole 1. That means the conductivity decreased by 7%. In fact, we reduced the conductive area by the hole size, which is about 6%. As this rough estimate shows, the height of the difference peak indicates, in fact, the conductivity drop. The hole position in 0° -direction is still required to be determined. Since specimens with holes 1 and 3 show the same peak no distinction can be made (see Fig. 15). The potential difference between electrodes 10 and 11 does not provide enough information to calculate the hole position in 0° -direction, 90° -direction and the hole size. Therefore, the determination of the potential difference between electrodes 10 and 11 on a finer scale is needed.

The difference in the potential curve between specimens with holes and the intact specimen is shown in Fig. 16. Current was applied between electrode 2 ($x=1.5$) and 3 ($x=2.5$). The differences of these curves are accentuated in the derivatives of these curves (see Fig. 17). When the hole is in the middle of the specimen, the potential curves which are determined on the current electrode side and on

the opposite side are identical. If the hole moves toward the opposite side (holes 4 and 3) the peak decreases on the current electrode side. Simultaneously the peak on the opposite side increases and form adjacent minima. After obtaining a calibration curve, the exact hole position can be revealed from these data. Further, it can be noticed that the width of the peaks is almost the same as the

Fig. 15. Numerical (a, c, e) and experimental results (b, d, e) for specimen with hole in the centre (a, b), at the right side (c, d) and at the top (e, f).

Fig. 16. Calculated difference in the potential curves between specimen with holes at various positions (see Fig. 14) and the intact specimen.

Fig. 17. Derivatives of the calculated difference in the potential curves between specimen with holes at various positions (see Fig. 14) and the intact specimen.

width of the holes. These results are obtained with a priori knowledge of the shape of the hole. The resistor network representation method is described in this paper to overcome this restrictive assumption. However, this method is applicable to highly orthotropic material.

4. CONCLUSIONS

Measurements of both the d.c. and a.c. electrical properties (capacitance and dissipation) can be used to in situ detect damage in FRP components. In the case of CFRP the carbon fibres are used as an electrically conductive phase. If GRP are used with carbon black as a matrix filler material for electrical conductivity, the d.c. technique allows to monitor strain and damage. Dependent on the load applied, the d.c. electrical resistance, a.c. capacitance and dissipation vary as a result of the actual load or strain. The measurement of d.c. and a.c. electrical properties of a FRP component is a non destructive evaluation (NDE) technique to inspect composite parts even when they are in use.

Damage detection and its location in CFRPs can be estimated with the electrical impedance tomography. Depending on the anisotropy of CFRPs, electrodes have to be positioned either at all specimen edges or only at two opposing sides. For the case of high anisotropy, a method was outlined to determine the damage size and position in real time. In spite of the relatively simple resistor model the calculations of hole position and size are accurate. These preliminary results show that EIT is a promising method for structural health and usage monitoring.

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