NDT Methods For Evaluating Carbon Fiber Composites

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SUMMARY

A review of nondestructive testing (NDT) methods is presented. The review is aimed at finding testing methods that can be used for realtime condition monitoring of composite undergoing fatigue testing. The most common types of damages in composites and their causes are also identified. Two approaches stand out: methods based on acoustic emission and the electrical properties of composites. The potential of these two methods is discussed in greater detail.

1 Motivation

During the design phase of a prosthetic carbon fiber foot at Össur hf. [a], prototype models are built, evaluated, and improved to meet the design criteria. For evaluation three methods are used;

- Visual tests
- Stiffness measurements
- Fatigue testing

Feet are mainly subjected to dynamic loading, which sometimes requires low loads to initiate and propagate faults. Because of this, fatigue testing is extremely important part of the design process. Fatigue tests of composites can take very long time, up to several weeks. It is therefore valuable for an engineer to be able to see whether a prototype will fail, early during the test. The benefits from this, can be;

- Less design and development time
- Reduced production cost
- Improved quality
- Improved quality inspection tests.

In order to be able to predict the fatigue strength of a foot undergoing fatigue testing, NDT methods can be used for obtaining data.

[a]Össur's website: www.ossur.com

2 Faults and Damages in Composites

The following are the most common types of damages:

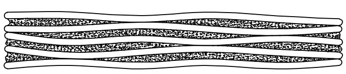
- Debonding – Stiffness reduction and changed damping characteristics.
- Delamination – Bonds between layers break resulting in weaker composite.
- Matrix failure – Unsuitable resin can fail to distribute stresses.
- Crazing – Fine cracks in the matrix weaken the matrix.
- Broken fibers – Will weaken the composite.

These damages can be caused by flaws, such as:

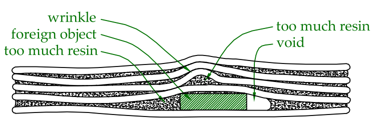
- Abrasion – Strength reduction of fibers due to scratches on their surface.
- Wrinkles – Cause voids and resin buildup.
- Voids and porosity – Weaken the composite, can induce damage.
- Fiber misalignment – Can cause catastrophic load distribution.
- Internal stresses – Affect strength, fatigue and chemical resistance.
- Foreign inclusions – Stresses can develop around trapped objects.
- Density variations – Too much/too little matrix increases risk of delamination.

They can also be introduced by:

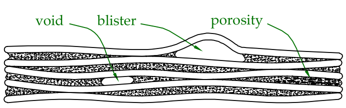
- Impact damage – Delamination, broken fibers, and generate cracks.
- Post processing methods – Forces perpendicular to the fibers.
- Fatigue – Changes matrix properties, damage can occur at low load levels.



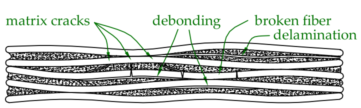
Normal laminate (Contact points)



Foreign inclusion / wrinkles



Air entrapment



Delamination /debonding / broken fibers / matrix cracks

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3 Non-Destructive Testing Methods

Composites can be nondestructively tested by using the following:

- Coin tapping – Simple, time consuming and not accurate.
- Vibration analysis – Hard to determine damage severity, realtime possibility.
- Thermography – Non-contact, fast detection, needs vibration free environment.
- Optical – Limited by the information obtained from the surface.
- Ultrasound – Time consuming, suffers attenuation, scattering and absorption.
- Radiography methods – High resolution, expensive and time consuming.
- Eddy Current testing – Limited penetration depth, surface must be accessible [?].

3.1 Electrical Properties

In composites, the carbon fibers are good conductors and the matrix acts as an insulator. However, the fibers touch and the composite anisotropically conducts electricity in all directions. The key points:

- Sensor – The composite is a sensor; cheaper, volume sensing, no embedding.
- Contact points – Will change due to loading and thermal changes.
- Realtime – Piezo behavior allows realtime strain and damage monitoring.
- Damage – Detects and locates; delamination, fiber breakage, volume fraction etc, .

Both AC and DC can be used for inspection:

- AC – Uses capacitance, is more suitable for delamination and crack detection.
- DC – Uses resistance, is more suitable for detecting fiber breakage.

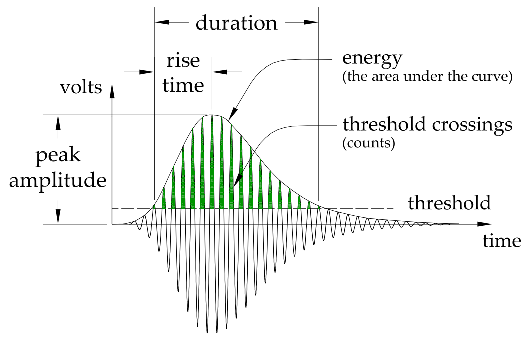
3.2 Acoustic Emission

AE signals in composites are generated by;

- Microstructural changes – Energy is released and AE waves are generated.
- Loading – Due to different material properties of fibers and matrix.
- Friction – Opening/closing of cracks, rubbing of surfaces and parts.
- Noise – Can come from machinery and electricity.

The four main approaches for AE analysis are;

- Activity analysis – AE activity used to detect defects, Felicity ratio, Shelby ratio
- Feature analysis – Features extracted from the signal; Amplitude, energy, etc.
- Frequency analysis – Associates different frequencies with different damage types.
- Modal analysis – Uses waveforms and propagation modes.



4 Conclusion

- All NDT methods have some limitations, i.e. some are time-consuming, some require fatigue tests to be stopped temporarily in order to make measurements and some suffer from difficult data interpretation.
- Two methods, one based on AE signals and the other one based on electrical properties are fast and can be used for realtime monitoring.
- AE is only emitted once when an damage occurs, however friction generates AE many times. This suggests that methods using friction generated AE will be more robust.
- Due to attenuation and the fact that the same source can emit AE signal with different amplitude, methods based on thresholds are not reliable.
- Electrical properties are interesting. They have mostly been studied for their potential use in smart materials. More research needs to be done regarding their use as a condition evaluation tool.
- Capacitance decreases gradually with each load cycle. It has been suggested that this behavior could be used for monitoring damage accumulation.
- Most research is based on simple composites. Because of this, and also because of inconsistent findings, it can be considered unwise to apply the methods blindly. They must be tested and their results compared.