
**Non-destructive testing — Acoustic
emission testing — Specific
methodology and general evaluation
criteria for testing of fibre-
reinforced polymers**

*Essai non destructif — Essai de l'émission acoustique —
Méthodologie spécifique et critères d'évaluation générale d'essai des
polymères renforcés de fibre*

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Preview



Reference number
ISO 18249:2015(E)

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Published in Switzerland

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT), see the following URL: [Foreword – Supplementary information](#).

The committee responsible for this document is ISO/TC 135, *Non-destructive testing*, Subcommittee SC 9, *Acoustic emission testing*.

Introduction

The increasing use of fibre-reinforced polymer (FRP) materials in structural (e.g. aerospace, automotive, civil engineering) and infrastructural applications (e.g. gas cylinders, storage tanks, pipelines) requires respective developments in the field of non-destructive testing.

Because of its sensitivity to the typical damage mechanisms in FRP, acoustic emission testing (AT) is uniquely suited as a test method for this class of materials.

It is already being used for load test monitoring (increasing test safety) and for proof-testing, periodic testing and periodic or continuous, real-time monitoring (health monitoring) of pressure vessels, storage tanks, and other safety-relevant FRP structures.

Acoustic emission testing shows potential where established non-destructive test methods (e.g. ultrasonic testing or water-jacket tests) are not applicable (e.g. thick carbon-fibre reinforced gas cylinders used for the storage and transport of compressed natural gas (CNG), gaseous hydrogen).

The general principles outlined in EN 13554 apply to all classes of materials but this International Standard emphasizes applications to metallic components (see EN 13554:2011, Clause 6).

However, the properties of FRP relevant to AT testing are distinctly different from those of metals.

FRP structures are inherently non-homogeneous and show a certain degree of anisotropic behaviour, depending on fibre orientation and stacking sequence of plies, respectively.

Material composition and properties, and geometry affect wave propagation, e.g. mode, velocity, dispersion, and attenuation, and hence the AT signals recorded by the sensors.

Composites with a distinct viscoelastic polymer matrix (e.g. thermoplastics) possess a comparatively high acoustic wave attenuation which is dependent on wave propagation parallel or perpendicular to the direction of fibre orientation, plate wave mode, frequency, and temperature-dependent relaxation behaviour.

Therefore, successful AT of FRP materials, components, and structures requires a specific methodology (e.g. storage of complete waveforms, specific sensors and sensor arrays, specific threshold settings, suitable loading patterns, improved data analysis), different from that applied to metals.

There are recent developments in acoustic emission testing, e.g. modal AT (wave and wave mode analysis in time and frequency domain) and pattern recognition analysis.

Voorbeeld
Preview

Non-destructive testing — Acoustic emission testing — Specific methodology and general evaluation criteria for testing of fibre-reinforced polymers

1 Scope

This International Standard describes the general principles of acoustic emission testing (AT) of materials, components, and structures made of fibre-reinforced polymers (FRP) with the aim of

- materials characterization,
- proof testing and manufacturing quality control,
- retesting and in-service testing, and
- health monitoring.

This International Standard has been designed to describe specific methodology to assess the integrity of fibre-reinforced polymers (FRP), components, or structures or to identify critical zones of high damage accumulation or damage growth under load (e.g. suitable instrumentation, typical sensor arrangements, and location procedures).

It also describes available, generally applicable evaluation criteria for AT of FRP and outlines procedures for establishing such evaluation criteria in case they are lacking.

This International Standard also presents formats for the presentation of acoustic emission test data that allows the application of qualitative evaluation criteria, both online during testing and by post-test analysis, and that simplify comparison of acoustic emission test results obtained from different test sites and organizations.

NOTE The structural significance of the acoustic emission cannot in all cases definitely be assessed based on AT evaluation criteria only but can require further testing and assessment (e.g. with other non-destructive test methods or fracture mechanics calculations).

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9712:2012, *Non-destructive testing — Qualification and certification of NDT personnel*

ISO 12716:2001, *Non-destructive testing — Acoustic emission inspection — Vocabulary*

ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories*

EN 13477-1:2001, *Non-destructive testing — Acoustic emission — Equipment characterisation — Part 1: Equipment description*

EN 13477-2:2010, *Non-destructive testing — Acoustic emission — Equipment characterisation — Part 2: Verification of operating characteristics*

EN 14584, *Non-destructive testing — Acoustic emission — Examination of metallic pressure equipment during proof testing — Planar location of AE sources*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12716:2001 and the following apply.

3.1 fibre

slender and greatly elongated solid material

Note 1 to entry: Typically with an aspect ratio greater than 5 and tensile modulus greater than 20 GPa. The fibres used for continuous (filamentary) or discontinuous reinforcement are usually glass, carbon, or aramide.

3.2 polymer matrix

surrounding macromolecular substance within which fibres are embedded

Note 1 to entry: Polymer matrices are usually thermosets (e.g. epoxy, vinyl ester polyimide, or polyester) or high-performance thermoplastics [e.g. poly(amide imide), poly(ether ether ketone), or polyimide]. The mechanical properties of polymer matrices are significantly affected by temperature, time, aging, and environment.

3.3 fibre laminate

two-dimensionally element made up of two or more layers (plies of the same material with identical orientation) from fibre-reinforced polymers

Note 1 to entry: They are compacted by sealing under heat and/or pressure. Laminates are stacked together by plane (or curved) layers of unidirectional fibres or woven fabric in a polymer matrix. Layers can be of various thicknesses and consist of identical or different fibre and polymer matrix materials. Fibre orientation can vary from layer to layer.

3.4 fibre-reinforced polymer material FRP

polymer matrix composite with one or more fibre orientations with respect to some reference direction

Note 1 to entry: Those are usually continuous fibre laminates. Typical as-fabricated geometries of continuous fibres include uniaxial, cross-ply, and angle-ply laminates or woven fabrics. FRPs are also made from discontinuous fibres such as short fibre, long-fibre, or random mat reinforcement.

3.5 delamination

intra- or inter-laminar fracture (crack) in composite materials under different modes of loading

Note 1 to entry: Delamination mostly occurs between the fibre layers by separation of laminate layers with the weakest bonding or the highest stresses under static or repeated cyclic stresses (fatigue), impact, etc. Delamination involves a large number of micro-fractures and secondary effects such as rubbing between fracture surfaces. It develops inside of the composite, without being noticeable on the surface and it is often connected with significant loss of mechanical stiffness and strength.

3.6 micro-fracture (of composites)

occurrence of local failure mechanisms on a microscopic level, such as matrix failure (crazing, cracking), fibre/matrix interface failure (debonding), or fibre pull-out, as well as fibre failure (breakage, buckling)

Note 1 to entry: It is caused by local overstress of the composite. Accumulation of micro-failures leads to macro-failure and determines ultimate strength and life-time.

4 Personnel qualification

It is assumed that acoustic emission testing is performed by qualified and capable personnel. In order to prove this qualification, it is recommended to qualify the personnel in accordance with ISO 9712.

5 Acoustic emission sources and acoustic behaviour

5.1 Acoustic emission source mechanisms

Damage of FRP as a result of micro- and macro-fracture mechanisms produces high acoustic emission activity and intensity making it particularly suitable for acoustic emission testing (AT).

The following are the common failure mechanisms in FRP detected by AT:

- matrix cracking,
- fibre/matrix interface debonding;
- fibre pull-out;
- fibre breakage;
- intra- or inter-laminar crack (delamination/splitting) propagation.

The resulting acoustic emission from FRP depends on many factors, such as material components, laminate lay-up, manufacturing process, discontinuities, applied load, geometry, and environmental test conditions (temperature, humidity, exposure to fluid or gaseous media, or ultraviolet radiation). Therefore, interpretation of acoustic emission under given conditions requires understanding of these factors and experience with acoustic emission from the particular material and construction under known stress conditions.

Fracture of FRP produces burst type acoustic emission, high activity; however, might give the appearance of continuous emission.

For certain types of construction, widely distributed AE sources from matrix or interfacial micro-failure mechanisms under given conditions commonly represent a normal behaviour. This particularly appears during the first loading of a newly manufactured FRP structure, where the composite strain for detection of first significant acoustic emission is in the range of 0,1 % to 0,3 %.

High stiffness optimized composites might shift the onset of first significant acoustic emission towards comparatively high stresses due to the low matrix strain in the composite.

In the case of high-strength composites, acoustic emission from first fibre breakage, apart from other sources, is normally observed at stress levels of about 40 % to 60 % of the ultimate composite strength.

A normal behaviour of FRP structures is also characterized by the occurrence of different regions with alternating higher and lower AE activity, particularly at higher stress levels due to redistribution of local stress.

In the case of a serious discontinuity or other severe stress concentration that influence the failure behaviour of FRP structures, AE activity will concentrate at the affected area, thereby providing a method of detection.

Conversely, discontinuities in areas of the component that remain unstressed as a result of the test and discontinuities that are structurally insignificant will not generate abnormal acoustic emission.

5.2 Wave propagation and attenuation characterization

Acoustic emission signals from waves travelling in large objects are influenced by dispersion and attenuation effects.

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