SVENSK STANDARD
SS-EN 15857:2010

Fastställd/Approved: 2010-02-01
Publicerad/Published: 2010-02-23
Utgåva/Edition: 1
Språk/Language: engelska/English
ICS: 19.100

Oförstörande provning – Akustisk emission – Provning av fiberarmerade polymerer – Specifik metodik och allmänna utvärderingskriterier

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

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EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 15857

January 2010

ICS 19.100

English Version

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

Essais non destructifs - Émission acoustique - Essai des polymères renforcés par des fibres - Méthodologie spécifique et critères d'évaluation généraux

Zerstörungsfreie Prüfung - Schallemissionsprüfung - Prüfung von faserverstärkten Polymeren - Spezifische Vorgehensweise und allgemeine Bewertungskriterien

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Ref. No. EN 15857:2010: E

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Foreword

This document (EN 15857:2010) has been prepared by Technical Committee CEN/TC 138 “Non-destructive testing”, the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by July 2010, and conflicting national standards shall be withdrawn at the latest by July 2010.

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Introduction

The increasing use of fibre-reinforced polymer materials (FRP) in structural (e.g. aerospace, automotive, civil engineering) and infra structural 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, AE testing 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 inspection and periodic or continuous, real-time monitoring (health monitoring) of pressure vessels, storage tanks and other safety-relevant FRP structures.

AE testing shows potential where established non-destructive test methods (e.g. ultrasonic 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, etc.).

The general principles outlined in EN 13554 apply (as stated) to all classes of materials but the document in fact emphasises applications to metal components (see Clause 6 "Applications of the acoustic emission method").

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

FRP structures are inherently inhomogeneous 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 AE 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 direction of fibre orientation, plate-wave mode, frequency and temperature dependent relaxation behaviour.

Therefore, successful AE testing 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, etc.), different from that applied to metals.

Most evaluation criteria for AE tests on FRP components and structures to date are either empirical (derived from comparative tests on a limited number of specimens) or else classified (proprietary, unpublished data banks).

The time and effort to establish qualified evaluation criteria for specific AE test applications may be too costly to make it worthwhile.

Generally applicable evaluation criteria for a class of materials – FRP – will help to pave the way for the development of new applications.

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

In particular, feature extraction and pattern recognition techniques seem promising for achieving, among others, improved source location and damage mechanism discrimination in materials that show complex wave propagation behaviour and signals originating from multiple mechanisms acting simultaneously, such as FRP.

1 Scope

This European Standard describes the general principles of acoustic emission (AE) testing of materials, components and structures made of FRP with the aim of:

— materials characterisation;

— proof testing/manufacturing quality control;

— retesting/in-service inspection;

— health monitoring.

When AE testing is used to assess the integrity of FRP materials, components or structures or identify critical zones of high damage accumulation or damage growth under load this standard further describes the specific methodology (e.g. suitable instrumentation, typical sensor arrangements, location procedures, etc.).

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

NOTE The structural significance of the AE may not in all cases definitely be assessed based on AE evaluation criteria only but may require further inspection and assessment (e.g. with other non-destructive test methods or fracture mechanics calculations).

This standard also recommends formats for the presentation of AE test data that allow the application of qualitative and quantitative evaluation criteria, both on-line during testing and by post test analysis, and that simplify comparison of AE test results obtained from different test sites and organisations.

2 Normative references

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

EN 473, *Non-destructive testing — Qualification and certification of NDT personnel — General principles*

EN 1330-1:1998, *Non destructive testing — Terminology — Part 1: List of general terms*

EN 1330-2:1998, *Non-destructive testing — Terminology — Part 2: Terms common to the non-destructive testing methods*

EN 1330-9:2009, *Non-destructive testing — Terminology — Part 9: Terms used in acoustic emission testing*

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

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

EN 13554, *Non-destructive testing — Acoustic emission — General principles*

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

EN 15495, *Non-destructive testing — Acoustic emission — Examination of metallic pressure equipment during proof testing — Zone location of AE sources*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1330-1:1998, EN 1330-2:1998 and EN 1330-9:2009 and the following apply.

3.1
fibre
slender and greatly elongated solid material

NOTE 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 Polymer matrices are usually thermosets (e.g. epoxy, vinylester 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, ageing 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 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 Those are usually continuous fibre laminates. Typical as-fabricated geometries of continuous fibres include uniaxial, cross-ply and angle-ply laminates or woven fabrics. FRP 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 propagation) in composite materials under different modes of loading

NOTE 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 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 certify the personnel in accordance with EN 473.

5 AE sources and acoustic behaviour of FRP

5.1 AE 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 common failure mechanisms in FRP detected by AT are:

a) matrix cracking;

b) fibre/matrix interface debonding;

c) fibre pull-out;

d) fibre breakage;

e) 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, defects, applied load, geometry and environmental test conditions (temperature, humidity, exposure to fluid or gaseous media or ultraviolet radiation, etc.). 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, may 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 optimised composites may 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, beside of 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 characterised 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.