BS ISO 18249:2015

BSI Standards Publication

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

bsi.

...making excellence a habit.™

National foreword

This British Standard is the UK implementation of ISO 18249:2015.

The UK participation in its preparation was entrusted to Technical Committee WEE/46, Non-destructive testing.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Published by BSI Standards Limited 2015

ISBN 978 0 580 81080 0

ICS 19.100

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 April 2015.

Amendments/corrigenda issued since publication

Date	Text affected

INTERNATIONAL STANDARD

ISO 18249

First edition
2015-05-01

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

Reference number
ISO 18249:2015(E)

Contents

Page

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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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.

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*

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 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, 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, 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.

Polymer matrix composites are inhomogeneous and often anisotropic materials and, in many applications, designed as thin plates or shells. Wave propagation in thin plates or shells is dominated by plate wave modes (e.g. Lamb waves). The anisotropy is mainly the result of volume and orientation of fibres. This affects wave propagation by introducing directionality into the velocity, attenuation, and large dispersion of plate waves.

Propagation of acoustic waves in FRP results in a significant change of amplitude and frequency content with distance. The extent of these effects will depend upon direction of propagation, material properties, thickness, and geometry of the test object.

Attenuation characterization measurement on representative regions of the test objects in accordance with EN 14584 shall be performed.

The shadowing effect of nozzles and ancillary attachments shall be quantified and transmission through the test fluid shall be taken into consideration.

The attenuation shall be measured in various directions and, if known, in particular parallel and perpendicular to the principal directions of fibre orientation. In the case of a partly filled test object, the attenuation shall be measured above and below the liquid level.

For FRP laminate structures, losses of burst signal peak amplitudes might be in the range of 20 dB to 50 dB after wave propagation of about 500 mm. Attenuation perpendicular to the fibre direction is usually much higher than in the parallel direction.

NOTE The peak amplitude from a Hsu-Nielsen source can vary with specific viscoelastic properties of the FRP material in different regions of a structure.

5.3 Test temperature

The mechanical (stiffness, strength) and acoustical (wave velocity, attenuation) behaviour of FRP structures and, hence, their AE activity and AE wave characteristic (waveforms, spectra) strongly changes if the test temperature approaches transition temperature ranges of the matrix, such as the ductile-brittle transition (ß-relaxation of semi-crystalline matrices) or the glass-rubber transition (α-relaxation of amorphous matrices).

Therefore, the test temperature has to be considered for data evaluation and interpretation of AE test results, as well as in the loading procedure.

5.4 Source location

Accurate source location in FRP structures is difficult. Due to the high attenuation in composite materials, the AE hits only the nearest sensor in most practical monitoring situations on structures. For this reason, zone location is usually the main source of location information. The use of zone location, however, does not prevent linear or planar location of AE sources that have sufficient energy to hit several sensors to allow location by time arrival differences. Linear or planar location is a useful supplement, predominantly for the location of higher energy emissions. Great care shall be taken with both methods where timing information is used for location since the velocity of sound and attenuation will usually change with the direction of propagation in FRP.

An additional caution when using location methods on FRP has to be taken because of the very high emission rates (hit overlapping).

Bearing in mind the above sensor separation and positioning should be set appropriately taking the following into account:

a) sensor frequency range:

Lower frequencies give a larger detection range but might result in the pickup of unwanted noise sources. Practical FRP testing typically uses high-frequency sensors (100 kHz to 300 kHz) to provide local area monitoring of high stress areas and low-frequency sensors (30 kHz to 60 kHz) to provide global coverage. It is common to use two frequency ranges simultaneously.

Typical detection ranges on FRP plates are as follows: 150 kHz for 400 mm to 700 mm, 60 kHz for 600 mm to 1200 mm, and 30 kHz for 900 mm to 2000 mm or more, depending on the material.

For research into AE source mechanisms, use of wideband sensors might be preferable.

b) directionality of propagation and attenuation:

More sensors might be required in one direction as a result of higher attenuation. Application of location techniques that meet direction-dependent wave velocities will achieve better location accuracy. Where the system software cannot handle directional velocities, the use of virtual sensor positioning might improve location performance. Checking source location with Hsu-Nielsen or other simulated acoustic emission sources is recommended to achieve useful results.

c) location performance:

Where planar location of lower energy emissions is a requirement, more sensors are necessary to obtain the required three hits.

Planar location is especially useful on small specimens or in the case where a local area of a structure is of particular interest.

5.5 Analysis of acoustic emission from fibre-reinforced polymers

The following types of analysis are applicable:

a) hit, energy, and RMS based processing:

For most testing applications, where the component under test should not be close to failure, the signal processing of acoustic emission from FRP does not differ significantly from that required for metals. The main differences are that high-frequency signals are significantly shorter due to the absence of reverberation. Once damage initiates, the rate of emission will be significantly higher than for metals.

These factors require the monitoring system to be set so as to process appropriately, by using shorter discrimination times for example. It is possible that very significant damage might appear as a continuous signal on hit based analysis, for this reason, supplementary processing should always be used, using for example, the RMS or ASL levels, or the absolute energy measured as a continuous parameter.

b) real-time analysis:

Real-time analysis of the detected acoustic emission and the application of defined criteria is normal practice and essential whenever the monitoring is required to feedback for the safe progressive application of load. Real-time graphs shall provide all AE and other parameters that are necessary to make a decision about the need to stop the test, if necessary.

c) post-test analysis:

Post-test analysis is applied to obtain a more insight into the acquired data, to filter known noise sources, and in production applications where real-time analysis might not have been used.

6 Instrumentation and monitoring guidelines

6.1 Instrumentation

Instrumentation components (hardware and software) shall conform to the requirements of EN 13477-1 and EN 13477-2.

The equipment shall be able to fulfill the data acquisition and analysis according to the written test instruction in real-time.

6.2 Sensors

The selection of AE sensor frequency depends on aim of AT and the factors described in 5.4.

For the investigation of damage mechanisms and wave propagation, wideband sensors might be more appropriate; however, this also introduces the additional variable of plate waves travelling at different velocities as a function of frequency.

Care should be taken when selecting wideband sensors that their characteristics are appropriate for the laminate thickness and that their potentially lower sensitivity is taken into account.

6.3 Sensor location and spacing

The sensor location when not defined by an applicable code will generally be determined as follows:

a) 150 kHz sensors monitoring the high stress areas of the structure;

b) Where the 150 kHz sensors do not provide the full coverage, 30 kHz to 60 kHz sensors are used to monitor the remaining test areas, bearing in mind that these might be susceptible to extraneous noise;

c) The distance between sensors is determined based on attenuation measurement in different directions and shall follow the guidelines for maximum allowed sensor distance — dmax — for planar location (EN 14584) or zone location (EN 15495).

The evaluation threshold is defined in 6.5.

6.4 Sensor coupling and mounting

For good transfer of acoustic waves, sensors shall be coupled using agents that do not chemically or physically react with the composite (e.g. by causing crazing, swelling, cracking, or other micro-failure mechanisms). Suitable coupling agents are silicone-based high-vacuum grease or adhesives, e.g. cold hardening silicone rubber.

Composite structures shall not be machined to produce a flat and smooth surface at areas where sensors are attached. Hence, higher attenuation (e.g. by factor 2) as a result of the thicker coupling film used to smooth out surface roughness or curvature shall be accepted.

The choice of the coupling agent depends on test conditions (temperature, humidity, maximum surface deformation, surface roughness, etc.), as well as on necessary stability for long-term testing. It shall not produce acoustic emission itself at all possible test temperatures and maximum deformation states.

Application of adhesive tapes, fixed rings with springs, elastic rubber bands shall guarantee a stable mechanical mounting of sensors and shall prevent noise signals resulting from sensor movement at the surface of structure or by fixturing itself under loading.

Prior to the test, the correct functioning of equipment operation shall be verified in accordance with EN 14584 using a Hsu-Nielsen source or automated sensor test (AST) by electronic pulses. The average peak amplitude of a Hsu-Nielsen source should be, prior to the test, within ±6 dB of the average of all sensors. Any deviation beyond ±6 dB shall be investigated and corrected, if possible. The corresponding values shall be noted at the end of the test in consideration of possible damage induced increase in attenuation during the loading.

6.5 Detection and evaluation threshold

The detection threshold is set X dB above the peak background noise; this shall be less than the evaluation threshold.

The detection threshold shall be set to avoid excessive data from normal behaviour of certain laminate types.

High rates of micro-failure lead to a high AE activity in practice during the first loading of new (unstressed) structures. The definition of AE hits (and calculation of hit rates) from burst signals does not work under such conditions of an apparently continuous acoustic emission as a consequence of high AE activity and low detection threshold.

For this case, appropriate actions should be scheduled, for example, waveform streaming, increasing threshold (makes determination of arrival times more inaccurate and decline location performance), or using higher threshold channels in parallel or analysis of continuous signal parameters.

Extraneous noise caused by the loading process, e.g. pump noise or leakage from servo-hydraulic test machine or pressure equipment, rubbing between grips and test specimen, etc., shall be suppressed prior to the test. If this is not possible, correctly identified noise signals can be removed from data during post-analysis using data filter or location procedures.

6.6 Application of load

The application of load depends on the aim of the test, the test object, the pressurization fluid when applicable, and operation safety requirements.

The loading profile shall define the maximum test load, loading rate, level and duration of load holds, and if necessary, unloading/reloading steps to determine the Felicity ratio.

In cases where the test load is not sufficiently higher than the previous maximum in-service load, a longer period off-load prior to the test might be required.

The application of load shall specify the load level for starting the AE data acquisition.

Loading rate shall consider the inherent high AE activity of FRP and potential for hit overlapping leading to continuous emission.

The loading rate and times for hold periods shall be adapted for each application. Care shall be taken with very low strain rates and very long hold periods which can lead to creep (relaxation) effects.

6.7 Graphs for real-time monitoring

Real-time monitoring should comprise the following steps:

a) evaluating AE activity, e.g. the rate or cumulative number of selected AE hits or located events and noting their correlation with time or applied load;

b) evaluating AE intensity, e.g. the burst signal peak amplitude, burst signal energy, continuous signal parameters and their behaviour with load;

c) AE source location.

Graphs for real-time observation and analysis of the AE behaviour depend on the type of application.

7 Specific methodology

7.1 Size of component

There are differences and specific problems with testing of small specimens or large components and structures.

Account shall be taken of the dispersion and attenuation effects in FRP as described in 5.2.

7.2 Testing of specimens

FRP specimens are tested for material characterization and design optimization of critical structural parts of composites.

The aim of AE monitoring is detection and characterization of initial failure by inter-fibre fracture mode (fibre/matrix debonding and matrix cracking) and stages of ultimate macro-failure by fibre fracture and/or unstable delamination.

The advantages of AT of specimens from FRP structures are low wave attenuation due to short distances between AE sources and sensors and associated higher accuracy of AE source location.

A problem of specimens is that wave reflections from the side edges superimpose waves that directly propagate to the sensors and, hence, influence the AE signal.

Because of approximately one-dimensional wave propagation, a linear location setup is sufficient to locate AE sources in longitudinal direction of the specimen.

By attachment of at least two sensors to the specimen (one to each clamp or support) and performing linear location, AE background noise (hydraulic, friction or electrical) can be removed by filtering.

7.3 Testing of components and structures

7.3.1 Preliminary information

Prior to the test, the following information shall be available:

a) explicit statement of the purpose of the test and limitations if any;

b) type and dimensions of test object;

c) material (composition and mechanical properties);

d) design load, in-service temperature;

e) conditions of use or operation;

f) history of the object (maximum in-service load, temperature, etc.), if available;

g) particular zones to be monitored (damage zones or zones with high stress level)

h) test conditions (type and sequence of loading);

i) environmental conditions at the test site and safety regulations to be observed;

j) potential sources of interference noise (mechanical, electrical, process noise, etc.);

k) the results of previous tests, if applicable;

l) type, size, and position of identified discontinuities, if available.

Interpretation of results shall usually require reference to a relevant experimental database. For uncommon structural materials, of which the AE response characteristics are unknown, a qualitative analysis shall be made under controlled test conditions using test specimens of the same material, fabricated in the same way and simulating, as near as possible, the original causes of the discontinuity and service stress conditions.

7.3.2 Test preparation

All safety requirements concerning the test location and test personnel shall be met. Precautions shall be taken to provide protection against the consequences of unexpected catastrophic failure of the structure or the release of safety installations, structural parts, or potentially hazardous fluids.

Usually for pressure vessels, hydraulic tests are recommended. Special safety requirements shall be taken when pneumatic testing is required, e.g. if normal service loads include either a superposed gas pressure or gas pressure only.

Due to the Felicity effect, when the test load is not sufficiently higher than the previous maximum in-service load, the operating conditions for structures that have been stressed previously shall be reduced prior to AT. The time for conditioning at reduced load (generally between 12 h for 90 % or more and 7 days for 40 % reduction of operating load) should ensure a sufficient stress relaxation and a clear determination of the Felicity ratio.

7.3.3 Load profiles

Loading procedure depends on application and aim of AE test. The loading shall be performed with a minimum extraneous noise. Hold periods during loading are a key aspect for evaluation of AE results. An initial period at starting load is monitored to check the increase of the background noise based on the loading procedure.

The strain rate and times for hold periods shall be adapted for each application. Care shall be taken with very low strain rates and very long hold periods which can lead to creep effects. A typical load hold time for composites is about 4 min to 10 min. For determination of the Felicity ratio at specific load levels, unload-rest-reload steps shall be designed. The existence of damages is also indicated by friction-based AE sources during unloading. Common loading profile examples are given in Figures 1 and 2.

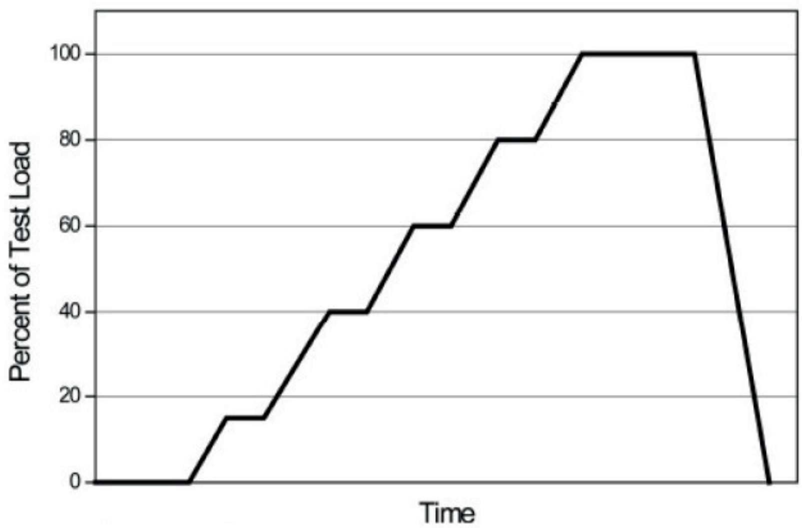

Figure 1 — Load schedule with steps

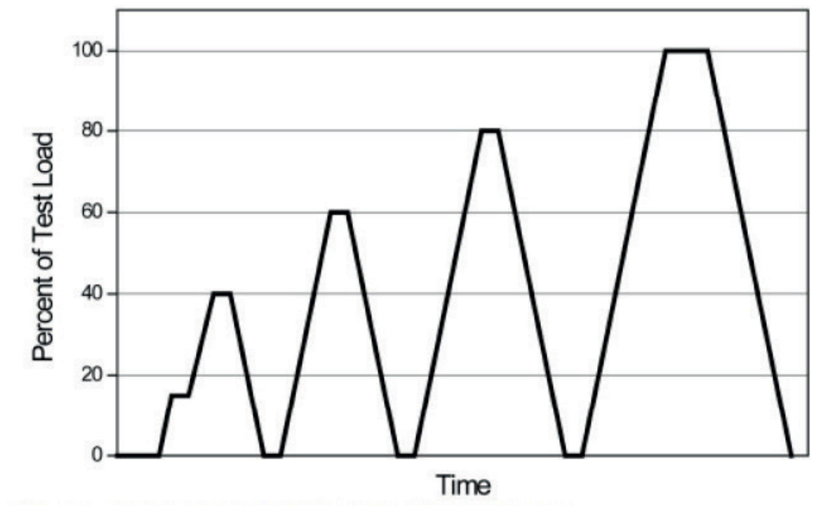

Figure 2 — Load schedule with a loading-holding-unloading

As examples, load schedules for fibre reinforced tanks, vacuum, and pressure vessels are given in Figures 3 to 5.

EXAMPLE Fibre reinforced tanks and vessels should be pressurized with a maximum strain rate of 0,005 % of principal strains per minute. Intermediate load holds at specific load levels shall be 4 min and the final load hold shall be 30 min.

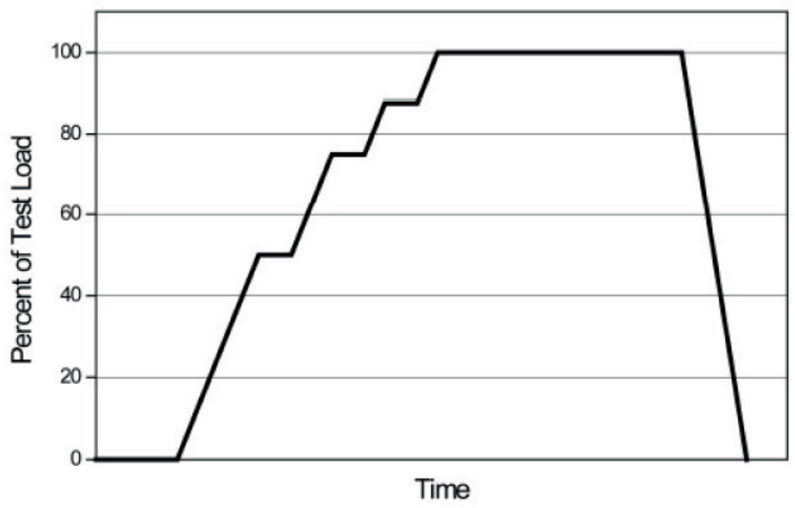

Figure 3 — Load schedule for tanks

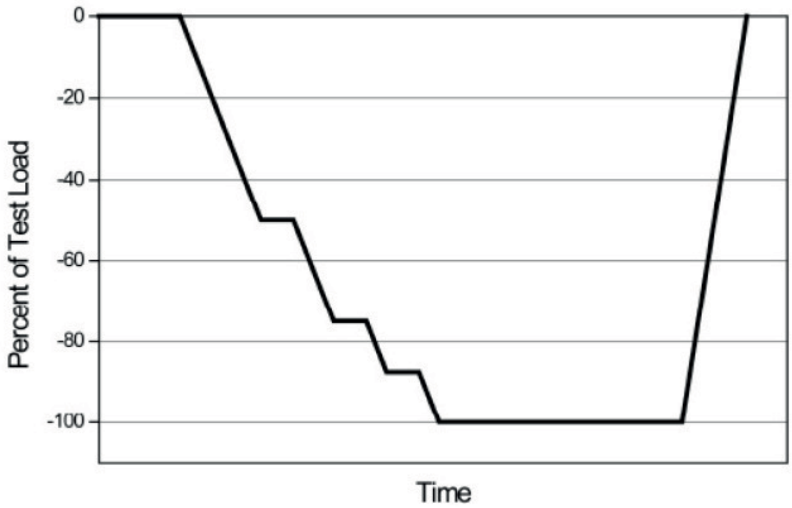

Figure 4 — Load schedule for vacuum vessels

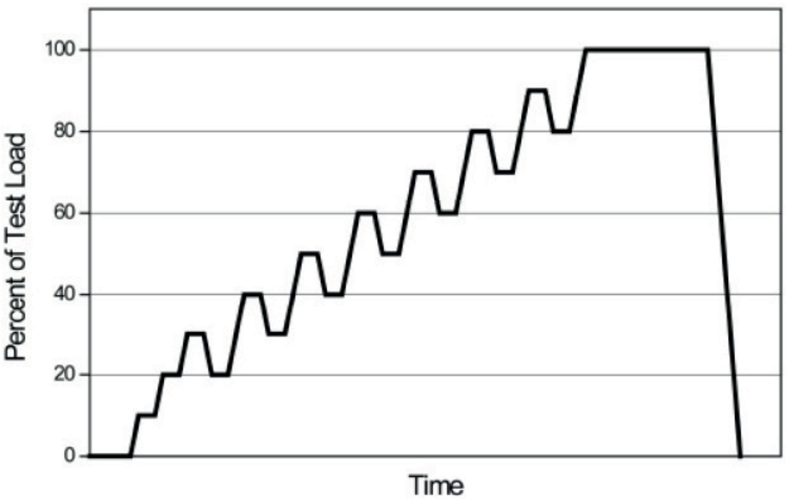

Figure 5 — Load schedule for pressure vessels

7.3.4 Written test procedure

The organization where the acoustic emission tests are being conducted shall provide a written test instruction, which shall include appropriate parts of preliminary information and the following:

a) sensor type, frequency, and manufacturer;

b) method of sensor attachment;

c) type of acoustic couplant used;

d) type of AT equipment used with the main characteristics;

e) energy measurement method to be used;

f) sensor location maps representing the structure or part of it;

g) description of equipment verification procedure;

h) description of the *in situ* verification (see EN 14584);

i) type and sequence of loading, temperature range of composite.

j) waveform acquisition and analysis, if necessary;

k) recorded data and recording method;

l) available online presentation of data;

m) real-time stop and evaluation criteria;

n) post-analysis procedure with adopted filtering technique if used;

o) final report requirements;

p) qualification/certification of the personnel.

The written test instruction shall be prepared in accordance with ISO 9712.

7.3.5 Evaluation criteria

Acoustic emission monitoring for structural applications frequently concentrates on assessing structural integrity using activity, intensity, Felicity ratio, and/or criteria for the location of AE sources (see Table 1).

Table 1 — Evaluation criteria for AT of FRP

Evaluation criteria	AE feature and information
a) Detection of significant AE	Continuous increase of both the hit rate and hit energy from onset or continuation of damage processes. At low stress levels, it normally indicates inter-fibre micro-failure, such as matrix cracking, fibre/matrix debonding, etc. During determination of Felicity ratios from severe damage states also fibre breakage and delamination growth can be associated to AE events.

Table 1 *(continued)*

Evaluation criteria	AE feature and information
b) AE activity and intensity	AE activity and intensity specified by number of hits, ring down counts, or signal energy as rate or cumulative function that show, e.g. — an exponential increase which can be described by a factor a depending on the composite, temperature, and strain-rate [Brunner et al. (1995)]: $AE_{cumulative} = k \cdot e^{\alpha \cdot t}$ $AE_{rate} = k \cdot \alpha \cdot e^{\alpha \cdot t}$ — an increase with a “knee” in the curve which is related to progressive damage due to inter-fibre failure and/or occurrence of new failure mechanisms, e.g. fibre breakage — values equal to or beyond statistically firmed mean values and standard deviations for “normal” AE behaviour — an increase during unloading indicating rubbing of damaged areas against each other, e.g. delaminated surfaces.
c) AE during load hold	Constant or increasing rate of AE activity or AE intensity parameter during hold periods — indicates extensive damage and achievement of unstable damage stages — is often associated with matrix cracking.
d) Burst signal peak amplitude or energy	NOTE 1 Cumulative distribution of burst signal peak amplitude or energy that: — can be characterized for the amplitude distribution by its b-value [Pollock (1981)] in the relationship $\log N = a - b \cdot A\left(dB_{AE}\right)$ calculated from the slopes of the lines through the data — is related to number and types of failure mechanisms — indicates the occurrence of new failure mechanisms such as breakage of fibre bundles or unstable delamination and/or critical damage stages if high amplitude or energy hits are recorded. NOTE 2 If all peak amplitudes are attenuated equally, the measured slope or b-value of the amplitude distribution will be independent of the source-sensor distance. This is not the case for FRP structures that show a distinct anisotropic attenuation characteristic. NOTE 3 Zone location of AE sources from FRP does not allow a distance correction of burst signal peak amplitudes and, hence, an evaluation based on specific peak amplitude values at source location.

Table 1 *(continued)*

Evaluation criteria	AE feature and information
e) Felicity ratio — FR $$FR = \frac{L_{reload}^{AE}}{L_{\max}}$$	Felicity ratio [Fowler (1977); Downs, Hamstad (1986, 1992, 1995, 1998); Summerscales (1986); Whittaker et al. (1990)] — describes the ratio between the applied load at which significant AE reappears during the next application of loading (L_{reload}^{AE}) and the previous maximum applied load ($L_{\max}$) provides a measure of the severity of previously induced damage; the lower the value the greater the severity; — gives ultimate failure warning. NOTE 1 FR analysis can be based upon a combination of cumulative sums of number and energy from first hits of events or most active regions determined by zone, linear, or planar location mode. NOTE 2 FR values are affected by several variables, e.g. temperature, loading and unloading rates, applied load relative to the ultimate strength (stress ratio), time for load holds, time delay (period for stress relaxation of the polymer matrix) between test cycles from which the values are obtained, FRP relaxation and friction properties, etc. NOTE 3 Due to the different wave propagation behaviour for pneumatic pressurization compared to hydraulic (alternative wave propagation within the liquid), the FR values obtained from hydraulic tests can be lower, overestimating the severity.
f) Historic Index — H(t) $$H(t) = \frac{N}{N-K} \frac{\sum_{i=K+1}^{i=N} S_{0i}}{\sum_{i=1}^{i=N} S_{0i}}$$ where H(t) is the historic index at time t. N is the number of hits (ordered by time) up to and including time t. S_{0i} is the signal strength of the ith hit. K is an empirically derived factor that varies with the number of hits.	The historic index [Fowler et al. (1992, 1995)] is — a form of trend analysis that requires a statistical significance of data — a sensitive method of detecting a change in slope in the cumulative burst signal energy versus time curve characterized by the “knee” in the curve — valuable for determining the onset of new damage mechanisms — essential independent of test object size.

Table 1 *(continued)*

Evaluation criteria	AE feature and information
g) Severity — Sr $$S_r = \frac{1}{J}\sum_{m=1}^{m=J} S_{0m}$$ where S_{0m} is the signal strength of the mth hit. J is an empirical derived constant that depends on the material of structure.	The severity value [Fowler et al. (1992, 1995)] is: — the average of a specified number (J) of the largest burst signal strength values — a measure of structural damage. An increase in severity will often correspond to new structural damage of the type detected by a Felicity ratio measurement.
h) Intensity diagram	The intensity diagram of logarithmic severity vs. logarithmic historic index for each channel showing different intensity zones corresponding to different degrees of damage.
i) AE location clusters	Criteria based on AE location cluster data. High AE activity and/or intensity within a certain area indicate damage. The preferred location technique for FRP structures is zone location. Analysis of the AE intensity from zone location provides information for the assessment of damage severity. If applicable, linear or planar location allows correction of AE signal amplitudes for attenuation between source and sensor position and the determination of size, shape, and growth direction of AE areas caused by, e.g. weak areas of the structure, delamination propagation, impact damage, flaws, etc.

7.3.6 Stop criteria

Stop criteria to prevent unexpected structural failure can be

— progressive increase of the rate of AE activity or AE intensity as a function of loading,

— constant or increasing rate of AE activity or AE intensity parameter during hold periods, and

— Felicity ratio lower than a critical value FRC specific for the structure material.

Stop criteria shall be channel based, zone location, and if possible, cluster (linear or planar location) based.

If one of the stop criteria is exceeded, the loading shall be stopped and the test object shall be unloaded to a safe load level immediately.

Before the loading is continued, areas with high AE activity and AE intensity shall be investigated and appropriate NDT measurements made.

The method for calculating AE activity, AE intensity, Felicity ratio, and the stop criteria shall be defined within the written test instruction by the organization where the AE is being conducted.

The stop criteria values for specific types of loading, temperature ranges of the composite, and test objects/structures will differ.

7.3.7 Health monitoring

Periodic or continuous health monitoring is applicable for detection of fatigue and environmental degradation mechanisms, sudden impact damage, etc.

The methodology and evaluation criteria are based on the above, but require correlation with process and environmental parameters for damage assessment.

8 Interpretation of acoustic emission test results/source mechanisms

Acoustic emission source identification and the separation of different damage mechanisms from extraneous noise sources is an important objective of the interpretation of AT results.

The following tools are used for AE analysis:

a) Correlation plots of waveform features [CARP Recommended Practice (1999)]

1) Correlation of logarithmic burst signal duration (or counts) vs. burst signal peak amplitude. Stable delamination growth in small specimens involving micro-fracture events will produce medium or high amplitude and short duration bursts. Signals from effects such as unstable splicing or major delamination produce high amplitude and long duration bursts. Low amplitude, long duration bursts might indicate sliding or rubbing. Other sources such as leaks, electromagnetic interference (EMI), and radio frequency interference (RFI) are characterized by extremely short duration burst signals.

NOTE A characteristic of EMI and RFI is also an instantaneous arrival time for all channels.

2) Cumulative distribution of burst signal peak amplitude: Different slopes of the peak amplitude distribution might indicate different mechanisms. The b-values characterize the slopes of the lines which can be drawn in specific intervals.

b) Post-test filters

Post-test filters, e.g. for time, channel, amplitude, or energy filtering are used to remove extraneous noise data such as wind noise, mechanical sliding, impact, leak, and noise from operating valves.

9 Report

The AT report shall include the following:

a) identification of the site of test and the customer;

b) identification of the component under test;

c) written test procedure;

d) any deviation from the test procedure;

e) reference to relevant procedural documents including the aims and objectives of the test;

f) description of the test equipment in particular instrumentation and frequency and sensitivity of the sensors used;

g) site operational conditions;

h) results of on-site verification of sensor sensitivity;

i) loading sequence;

j) type of analysis carried out;

k) test results;

l) interpretation of results, including the location and relative severity of all AE sources, where appropriate, on drawings of the component under test;

m) place, date, and time of the test;

n) name, qualifications, and signature of inspector.

The final report should be in accordance with ISO/IEC 17025:2005.

Bibliography

[1] ISO 472, *Plastics — Vocabulary*

[2] ISO 1043, *Plastics — Symbols*

[3] ISO 3673, *Plastics — Epoxy resins*

[4] EN 12654, *Textile glass — Yarns — Part 1 to 3*

[5] EN 12971, *Reinforcements — Specification for textile glass chopped strands — Part 1 to 3*

[6] EN 13002-2, *Carbon fibre yarns — Part 2: Test methods and general specifications*

[7] EN 13003, *Para-aramide fibre filament yarns — Part 1 to 3*

[8] EN 13417, *Reinforcement — Specifications for woven fabrics — Part 1 to 3*

[9] EN 13473, *Reinforcement — Specifications for multi-axial multi-ply fabrics — Part 1 to 3*

[10] EN 13677, *Reinforced thermoplastic moulding compounds — Specification for GMT — Part 1 to 3*

[11] EN 14020, *Reinforcements — Specification for textile glass rovings — Part 1 to 3*

[12] EN 14118, *Reinforcement — Specifications for textile glass mats (chopped strand and continuous filament mats) — Part 1 to 3*

[13] ASTM D3039/D3039-M, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, American Society for Testing and Materials International 15.03 (2006)

[14] ASTM E1067, Standard Practice for Acoustic Emission Examination of Fibreglass Reinforced Plastic Resin (FRP) Tanks/Vessels, American Society for Testing and Materials International 03.03 (2007)

[15] ASTM E1888/E1888M, Standard Test Method for Acoustic Emission Examination of Pressurized Containers Made of Fiberglass Reinforced Plastic with Balsa Wood Cores, American Society for Testing and Materials International 03.03 (2002)

[16] ASTM E2076, Standard Test Method for Examination of Fiberglass Reinforced Plastic Fan Blades Using Acoustic Emission. American Society for Testing and Materials International 03.03 (2005)

[17] ASTM E2191, Standard Test Method for Examination of Gas-Filled Filament-Wound Composite Pressure Vessels Using Acoustic Emission. American Society for testing and Materials, International 03.03 (2002)

[18] ASTM Subcommittee ASTM standard E 2661/E 2661M, ASTM standard E 2661/E 2661M ‗Standard Practice for Non-Waveform Based Acoustic Emission Examination of Plate-like and Flat Panel Composite Structures Used in Aerospace Applications

[19] ASNT. Acoustic Emission Testing' in Miller R K, v K Hill E, Moore P O, ASNT Handbook of Nondestructive Testing, Vol. 6 (3rd ed.) American Society for Nondestructive Testing (2005)

[20] Application of Fracture Mechanics to Polymers, Adhesives and Composites, European Structural Integrity Society, 33, Edit. D. Moore, Elsevier, Dec-2003

[21] CARP Reports (1993), Guidance for Development of AE Applications on Composites. Committee on Acoustic Emission from Reinforced Plastics (CARP), Aerospace/Advanced Composites Subcommittee. J. Acoustic Emission. 1993, **11** (3) pp. C1–C24

[22] CARP Reports (1999), Recommended Practice For Acoustic Emission Evaluation Of Fiber Reinforced Plastic (FRP) Tanks And Pressure Vessels. Committee on Acoustic Emission from

Reinforced Plastics (CARP), a Division of the Technical Council of The American Society for Nondestructive Testing, Inc., Columbus, Ohio, Draft I, October 1999

[23] Brunner A.J., Nordstrom R., Flüeler P. A Study of Acoustic Emission-Rate Behavior in Glass Fiber-Reinforced Plastics. J. Acoustic Emission. 1995, **13** (3-4) pp. 67–77

[24] Downs K.S., & Hamstad M.A. Correlation of Acoustic Emission Felicity Ratios and Hold-Based Movement and Burst Strength. J. Acoustic Emission. 1995, **13** (3-4) pp. 45–55

[25] Downs K.S., & Hamstad M.A. Acoustic Emission from Depressurization to Detect/Evaluate Significance of Impact Damage to Graphite/Epoxy Pressure Vessels. J. Composite Materials. 1998, **32** (3) pp. 258–307

[26] Fowler T.J. 1977): "Acoustic Emission Testing of Fiber Reinforced Plastics", Preprint 3092, ASCE Fall Convention and Exhibit, San Francisco, California, American Society of Civil Engineers, Oct. 17-21, 1977

[27] Fowler T.J., Blessing J.A., Strauser F.E. (1992): — Intensity Analysis. Proc. Fourth Intern. Symposium on Acoustic Emission From Composite Material — AECM-4, Seattle 1992, American Society for Nondestructive Testing, Columbia, Ohio 1992: 237-246

[28] Fowler T.J. (1995): —Revisions to the CARP Recommended Practice for Tanks and Vessels. Proc. Fifth Intern. Symposium on Acoustic Emission From Composite Material — AECM-5, Sundsvall 1995, American Society for Nondestructive Testing, Columbia, Ohio 1995: 263-271

[29] Gorman M.R. —Plate wave acoustic emission. J. Acoust. Soc. Am. 1991, **90** (1) pp. 358–364

[30] Gorman M.R., & Ziola S.M. —Plate waves produced by transverse matrix cracking. Ultrasonics. 1991, **29** pp. 245–251

[31] Gorman M.R., & Prosser W.H. —AE Source Orientation by Plate Wave Analysis. J. Acoustic Emission. 1991, **9** pp. 283–288

[32] Gorman M.R. (1996): —Modal AE: A New Understanding of Acoustic Emission. Technical Publication DWC 96-002

[33] Hamstad M.A. —A Discussion of the Basic Understanding of the Felicity Effect in Fiber Composites. J. Acoustic Emission. 1986, **5** (2) pp. 95–102

[34] Hamstad M.A. (1992): —An examination of acoustic emission evaluation criteria for aerospace type fiber/polymer composites, Proc. Fourth Intern. Symposium on Acoustic Emission from Composite Materials, AECM-4, Seattle 1992, American Society for Nondestructive Testing, Columbia, Ohio 1992:436-49

[35] Mal A. —Elastic waves from localized sources in composite laminates. Int. J. Solids Struct. 2002, **39** pp. 5481–5494

[36] Pollock A.A. (1981): "Acoustic Emission Amplitude Distributions". International Advances in Nondestructive Testing (Editor: Warren J. McGonnagle), Volume 7, pp. 215-240, May 1981. Reprinted as Technical Report DE 79-1O, Dunegan/Endevco, San Juan Capistrano, California. Redistributed as PAC TR-103-91-5/89

[37] Prosser W.H., Jackson K.E., Kellas S., Smith B.T., McKeon J., Friedman A. —Advanced Waveform-Based Acoustic Emission Detection of Matrix Cracking in Composites. Mater. Eval. 1995, **53** p. 1052

[38] Prosser W.H. —Advanced AE Techniques in Composite Materials Research. J. Acoustic Emission. 1996, **14** pp. S1–S11

[39] Prosser W.H., Seale M.D., Smith B.T. —Time-frequency analysis of the dispersion of Lamb modes. J. Acoust. Soc. Am. 1999, **105** (5) pp. 2669–2676

[40] Summerscales J. (1986): —The Felicity Effect in Acoustic Emission from Composites. Proc. Intern. Symposium Composite Materials and Structures, Beijing, 1986, pp. 978-982

[41] Suzuki H., Takemoto M., Ono K. —A Study of Fracture Dynamics in a Model Composite by Acoustic Emission Signal Processing. J. Acoustic Emission. 1993, **11** (3) pp. 117–128

[42] Whittaker J.W., Brosey W.D., Hamstad M.A. —Felicity Ratio of Pneumatically and Hydraulically Loaded Spherical Composite Test Specimens. J. Acoustic Emission. 1990, **9** (2) pp. 75–83

[43] Whittaker J.W., Brosey W.D., Hamstad M.A. —Correlation of Felicity Ratio and Strength Behavior of Impact-Damaged Spherical Composite Test Specimens. J. Acoustic Emission. 1990, **9** (2) pp. 84–90

[44] ISO/TR 13115:2011, *Non-destructive testing — Methods for absolute calibration of acoustic emission transducers by the reciprocity technique*

[45] EN 13554:2011, *Non-destructive testing — Acoustic emission — General principles*

ICS 19.100

Price based on 20 pages

This page deliberately left blank

British Standards Institution (BSI)

BSI is the national body responsible for preparing British Standards and other standards-related publications, information and services.

BSI is incorporated by Royal Charter. British Standards and other standardization products are published by BSI Standards Limited.

About us

We bring together business, industry, government, consumers, innovators and others to shape their combined experience and expertise into standards -based solutions.

The knowledge embodied in our standards has been carefully assembled in a dependable format and refined through our open consultation process. Organizations of all sizes and across all sectors choose standards to help them achieve their goals.

Information on standards

We can provide you with the knowledge that your organization needs to succeed. Find out more about British Standards by visiting our website at bsigroup.com/standards or contacting our Customer Services team or Knowledge Centre.

Buying standards

You can buy and download PDF versions of BSI publications, including British and adopted European and international standards, through our website at bsigroup.com/shop, where hard copies can also be purchased.

If you need international and foreign standards from other Standards Development Organizations, hard copies can be ordered from our Customer Services team.

Subscriptions

Our range of subscription services are designed to make using standards easier for you. For further information on our subscription products go to bsigroup.com/subscriptions.

With **British Standards Online (BSOL)** you'll have instant access to over 55,000 British and adopted European and international standards from your desktop. It's available 24/7 and is refreshed daily so you'll always be up to date.

You can keep in touch with standards developments and receive substantial discounts on the purchase price of standards, both in single copy and subscription format, by becoming a **BSI Subscribing Member**.

PLUS is an updating service exclusive to BSI Subscribing Members. You will automatically receive the latest hard copy of your standards when they're revised or replaced.

To find out more about becoming a BSI Subscribing Member and the benefits of membership, please visit bsigroup.com/shop.

With a **Multi-User Network Licence (MUNL)** you are able to host standards publications on your intranet. Licences can cover as few or as many users as you wish. With updates supplied as soon as they're available, you can be sure your documentation is current. For further information, email bsmusales@bsigroup.com.

Revisions

Our British Standards and other publications are updated by amendment or revision.

We continually improve the quality of our products and services to benefit your business. If you find an inaccuracy or ambiguity within a British Standard or other BSI publication please inform the Knowledge Centre.

Copyright

Useful Contacts:

Customer Services
Tel: +44 845 086 9001
Email (orders): orders@bsigroup.com
Email (enquiries): cservices@bsigroup.com

Subscriptions
Tel: +44 845 086 9001
Email: subscriptions@bsigroup.com

Knowledge Centre
Tel: +44 20 8996 7004
Email: knowledgecentre@bsigroup.com

Copyright & Licensing
Tel: +44 20 8996 7070
Email: copyright@bsigroup.com

BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK

bsi.

...making excellence a habit.™