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Oil and gas industries including lower carbon energy — Non-metallic materials in contact with media related to oil and gas production —

Part 4:
Fiber-reinforced composite materials

Industries du pétrole et du gaz y compris les énergies à faible teneur en carbone — Matériaux non métalliques en contact avec les fluides relatifs à la production de pétrole et de gaz —

Partie 4: Matériaux composites renforcés de fibres

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Foreword

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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 document 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).

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This document was prepared by Technical Committee ISO/TC 67, *Oil and gas industries including lower carbon energy*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 12, *Oil and gas industries including lower carbon energy*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

A list of all parts in the ISO 23936 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Non-metallic materials are used in the petroleum, petrochemical and natural gas industries for a wide range of components. The purpose of this document is to establish requirements and guidelines for systematic and effective planning, for non-metallic material selection to achieve cost effective technical solutions, taking into account possible constraints due to safety and/or environmental issues.

This document is of benefit to a broad industry group ranging from operators and suppliers to engineers and authorities. It covers relevant generic types of non-metallic material (e.g. thermoplastics, elastomers, thermosetting plastics) and includes the widest range of existing technical experience.

This information aids in material selection. It can be applied to help avoid costly degradation failures of the equipment itself, which can pose a risk to the health and safety of the public and personnel or the environment. This document complements the document for metallic materials in sour service (the ISO 15156 series). It differs in the form of guidance provided to the user related to the potential degradation of desired properties when used in equipment for oil and gas production environments. The ISO 15156 series provides application limits and qualification requirements for metallic materials in H_2S-containing environments which are related solely to relevant environmentally assisted cracking mechanisms.

Mechanical properties and the environmental stability of composite materials depend on the properties and environmental stability of matrix resins, fibres and fibre/resin bonding interfaces. This document focuses on the overall composite properties and their environmental stability. To permit this assessment this document utilizes flat plates and/or tubular shapes made specifically for these tests.

The document recognizes that a wider range of compounds and parameters influence the degradation of non-metallic materials and thus provides guidance to permit selection of materials for oil and gas exploration and production applications based upon stability in appropriate test conditions.

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Part 4:
Fiber-reinforced composite materials

CAUTION — Non-metallic materials selected using the ISO 23936 series are resistant to the given environments in the petroleum and natural gas industries, but not necessarily immune under all service conditions. This document allocates responsibility for suitability for the intended service in all cases to the equipment user.

1 Scope

This document provides general principles, requirements and recommendations for the assessment of stability of fibre-reinforced composite materials for service in equipment used in oil and gas production environments.

This document describes the procedures for comparative testing of composite materials consisting of polymers (thermoplastics and thermosets) and re-enforcing materials e.g. glass, carbon, aramid and metals as continuous fibres or woven fabric used in equipment for oil and gas production.

Testing and characterization of neat resins and fibre products are beyond the scope of this document.

The equipment considered includes, but is not limited to, non-metallic pipelines, piping, liners and downhole tool components.

Blistering by rapid gas decompression, coatings and compounded particulate- and short fibre-reinforced composites are excluded from the scope of this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

ISO 175, *Plastics — Methods of test for the determination of the effects of immersion in liquid chemicals*

ISO 527-4, *Plastics — Determination of tensile properties — Part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites*

ISO 527-5, *Plastics — Determination of tensile properties — Part 5: Test conditions for unidirectional fibre-reinforced plastic composites*

ISO 1172, *Textile-glass-reinforced plastics — Prepregs, moulding compounds and laminates — Determination of the textile-glass and mineral-filler content using calcination methods*

ISO 1183-1, *Plastics — Methods for determining the density of non-cellular plastics — Part 1: Immersion method, liquid pycnometer method and titration method*

ISO 1268-1, *Fibre-reinforced plastics — Methods of producing test plates — Part 1: General conditions*

ISO 1268-3, *Fibre-reinforced plastics — Methods of producing test plates — Part 3: Wet compression moulding*

ISO 1268-4, *Fibre-reinforced plastics — Methods of producing test plates — Part 4: Moulding of prepregs*

ISO 1268-5, *Fibre-reinforced plastics — Methods of producing test plates — Part 5: Filament winding*

ISO 1268-7, *Fibre-reinforced plastics — Methods of producing test plates — Part 7: Resin transfer moulding*

ISO 1268-9, *Fibre-reinforced plastics — Methods of producing test plates — Part 9: Moulding of GMT/STC*

ISO 2781, *Rubber, vulcanized or thermoplastic — Determination of density*

ISO 6721-11, *Plastics — Determination of dynamic mechanical properties — Part 11: Glass transition temperature*

ISO 7822, *Textile glass reinforced plastics — Determination of void content — Loss on ignition, mechanical disintegration and statistical counting methods*

ISO 11357-2, *Plastics — Differential scanning calorimetry (DSC) — Part 2: Determination of glass transition temperature and step height*

ISO 14126, *Fibre-reinforced plastic composites — Determination of compressive properties in the in-plane direction*

ISO 14127, *Carbon-fibre-reinforced composites — Determination of the resin, fibre and void contents*

ISO 14129, *Fibre-reinforced plastic composites — Determination of the in-plane shear stress/shear strain response, including the in-plane shear modulus and strength, by the plus or minus 45 degree tension test method*

ISO 14130, *Fibre-reinforced plastic composites — Determination of apparent interlaminar shear strength by short-beam method*

ISO 15024, *Fibre-reinforced plastic composites — Determination of mode I interlaminar fracture toughness, G_{IC}, for unidirectionally reinforced materials*

ISO 15114, *Fibre-reinforced plastic composites — Determination of the mode II fracture resistance for unidirectionally reinforced materials using the calibrated end-loaded split (C-ELS) test and an effective crack length approach*

EN 2564, *Aerospace series – Carbon fibre laminates – Determination of the fibre, resin and void contents*

ASTM D792, *Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement*

ASTM E1131, *Standard Test Method for Compositional Analysis by Thermogravimetry*

ASTM D2290, *Standard Test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe*

ASTM D2344, *Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates*

ASTM D2412, *Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading*

ASTM D3039, *Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials*

ASTM D3171, *Standard Test Methods for Constituent Content of Composite Materials*

ASTM D3410, *Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading*

ASTM D3418, *Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry*

ASTM D3518, *Standard Test Method for In-Plane Shear Response of Polymer Matrix Composite Materials by Tensile Test of a ±45° Laminate*

ASTM D5229, *Standard Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials*

ASTM D5379, *Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method*

ASTM D5448, *Standard Test Method for Inplane Shear Properties of Hoop Wound Polymer Matrix Composite Cylinders*

ASTM D5449, *Standard Test Method for Transverse Compressive Properties of Hoop Wound Polymer Matrix Composite Cylinders*

ASTM D5450, *Standard Test Method for Transverse Tensile Properties of Hoop Wound Polymer Matrix Composite Cylinders*

ASTM D5528, *Standard Test Method for Mode I Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites*

ASTM D6641, *Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture*

ASTM D7028, *Standard Test Method for Glass Transition Temperature (DMA Tg) of Polymer Matrix Composites by Dynamic Mechanical Analysis (DMA)*

ASTM D7078, *Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method*

ASTM D7905, *Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method Standard Test Method for Determination of the Mode II Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites*

NPL (2020) Measurement Good Practice Guide No. 38, *Fibre Reinforced Plastic Composites – Machining of Composites and Specimen Preparation; National Physical Laboratory (UK)*[1)]

3 Terms and definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1.1
composite material
fibre-reinforced material system consisting of thermoplastic or thermoset polymers and reinforcing materials in the form of long and continuous glass, carbon and/or aramid fibres or woven fabric

3.1.2
fabricator
producer of test plates and specimens

1) Available at www.npl.co.uk.

3.1.3
glass transition temperature
T_g
characteristic value of the temperature range over which the glass transition takes place and at which the *composite material's* (3.1.1) mechanical properties change from elastic (glassy) state to viscous (rubbery) state

Note 1 to entry: The assigned glass transition temperature (T_g) may vary, depending on the specific property and on the method and conditions selected to measure it [for instance, by differential scanning calorimetry (DSC) or by dynamic mechanical analysis (DMA)].

3.1.4
lamina
ply
thin, single sheet of long and continuous reinforcing fibres sharing the same orientation in a polymeric resin matrix built up into a flat or curved arrangement

3.1.5
laminate
combination of *laminas* (3.1.4)

3.1.6
manufacturer
producer of the materials used for creation of semi-finished and/or finished products

3.1.7
sizing
optional treatments usually applied to yarn by *manufactures* (3.1.6) for reasons that can include increasing fibre-matrix compatibility, as well as facilitating handling during manufacture

3.1.8
wet T_g
glass transition temperature (3.1.3) of the fluid saturated material

3.2 Abbreviated terms

ATM	accelerated testing method
CA	autoclave cured
CH	hot-press cured
CNC	computerized numerical control
CO	oven cured
COA	certificate of analysis
COC	certificate of conformity
COV	coefficient of variation
CU	UV cured
DMA	dynamic mechanical analysis
DSC	differential scanning calorimetry
GFRP	glass fibre reinforced polymer
GMT	glass fibre mat reinforced thermoplastic

HDT	heat deflection temperature
HPHT	high-pressure high-temperature
IPS	in plane shear
LF	filament winding lamination
LP	prepreg lamination
LR	vacuum-assisted resin-transfer moulding
LW	wet layup lamination
MOL	material operational limit
NDT	non-destructive testing
PA	Polyamide
ppm (vol)	volume parts per million volume parts
QC	quality control
QD	quality documentation
SEM	scanning electron microscopy
STC	sheet thermoplastic composite
TA	autoclave consolidation
TI	isothermal consolidation
TP	hot pressing
TGA	thermogravimetric analysis
UD	unidirectional
UV	ultraviolet light

4 Technical requirements

4.1 General requirements

Composite selection depends upon material property characteristics and fluid ageing behaviour. This document establishes four levels of testing for the purpose of comparing the properties of various composite materials. The testing methods at the material level shall focus upon the laminate and specimen geometry and do not represent a functional application test which is beyond the scope of this document. The specimen layup described is to provide a consistent, common basis for generating comparable data for different composite materials. Specific testing shall be required for the actual layup for samples representative of the final product form. Material property data are generated at the four levels to allow consistent comparison of the subject materials. Generic data shall be derived per Level 1 and Level 2 including threshold criteria, solely for the purpose of producing information for preselection. Where the user requires accelerated ageing material stability data in a multi-phase H_2S containing fluid, Level 3 shall apply. Where the user requires the material stability data beyond 56 days and an attempted long-term life estimation, Level 4 shall apply.

NOTE Ageing of composites faces combined challenges. Polymer or thermoset ageing alone deals in most cases with quasi-isotropic material properties. Composites of any configuration furthermore deal with polymeric challenges as well as with highly anisotropic properties resulting from fibre and interface properties, which can age very differently than the matrix material. All effects can overlay and become apparent in different failure modes or shifts thereof over the ageing period.

Ageing experiments can be designed in the following way to extract meaningful information, especially with regards to establishing lifetime models with these complex effects in mind:

a) identify possible ageing mechanisms for matrix material;

b) identify possible ageing mechanisms for fibre material;

c) identify possible ageing mechanisms for interface;

d) differentiate between physical and chemical ageing;

e) differentiate between reversible and irreversible ageing;

f) identify probabilities for the above-mentioned mechanisms to occur simultaneously during test periods;

g) rank mechanisms for severity;

h) rank for material characterization or application related testing;

i) exclude any unwanted ageing mechanism by physical/chemical exclusion of other ageing influences (monitored and protocolled), choosing variations in layup to promote specific failure, or some combination of both.

Level 1 conformity consists of the characterization and documentation of material properties in a material data report. It includes a COC for batch quality control testing. See 5.1 and Table 2 for a list of the required material properties to be documented. Physical and mechanical properties shall be characterized on materials in their unaged condition. These standard properties assist with the selection of materials that meet a design specification. Some property tests are also used for quality assurance and control. Level 1 testing establishes a baseline for higher level testing.

Level 2 conformity pertains to material stability (ageing) behaviour and shall be accompanied by a report. Clause 6 provides requirements for Level 2 conformity. The effect of the first three fluids listed in 6.2.4 on material properties shall be investigated with real time ageing studies. A material's resistance to chemical/physical/mechanical change is determined.

Level 3 conformity pertains to material stability (accelerated ageing) behaviour and shall be accompanied by a report. Clause 7 provides requirements for Level 3 conformity. The effects on material properties of three temperature aging evaluations shall be investigated. The intent of Level 3 evaluations is to accelerate material property changes specifically in multi-phase H_2S-fluids.

Level 4 conformity pertains to a material stability (long-term) assessment of 180 days or longer. Level 4 attempts life estimation and shall be accompanied by a report. Clause 8 provides requirements for Level 4 conformity. The intent of Level 4 assessment is to predict the material's progressive degradation; hence conformity threshold recommendations are offered for life estimation purposes. The report shall include a thorough account of data analysis, extrapolation, life estimation, and statistical confidence. Users shall evaluate the threshold criteria, life estimation results and all methodology to determine the suitability of materials for application.

All reports shall detail the testing and analysis that was performed as well as the edition of this document utilized at time of testing.

Laboratory studies using standard test conditions may not derive data that can be used for design purposes. The user may require fit-for-purpose testing or alternative testing to simulate production conditions to allow materials selection for final application. Component functional testing is not detailed in this document.

If there is scientific evidence on resistance of the material to the chemicals at the intended pressure and temperatures then such material may be exempt from Level 3 and Level 4.

4.2 Cautionary remarks

Designers should not assume that properties provided in a material data report as defined in Clause 5 accurately represent those properties found in finished product geometries. The method of conversion is known to have an impact on these properties and that impact should be accounted for during design.

Life estimation usefulness and certainty can increase when longer term data are used to establish the degradation trend. Level 3 testing at durations up to 56 days are most useful for shorter term (up to 1 year) life estimations and can have reduced certainty for long-term (greater than 1 year) life estimations. Level 4 testing requires up to 180 day or longer data in an effort to create higher certainty in long-term life estimation.

In some cases, progressive degradation of composites over long periods of time at temperatures well above the target service temperature is not observed. The data and the attempted life estimation are still valuable because they demonstrate material stability in that test environment.

4.3 Traceability

For a final component to maintain its ISO 23936-4 material conformity, it shall be made from a composite material that conforms with this document. The entire compound manufacturing process shall be fully traceable. conformity records shall state the edition of this document used in the assessment. Reference to conformity with the ISO 23936 series shall include the part and edition (year) of the standard used e.g. ISO 23936-4:2024.

Each component and accompanying COC shall be traceable back to the compound manufacturer. Each company that participates in the manufacture of a compound that conforms with this document shall maintain traceability records for a minimum of 10 years that include its own manufacturing procedures, locations, and dates.

Further requirements on conformity and traceability over the supply chain can be found in relevant product standards and agreed between interested parties.

4.4 Test specimen identification

The specimen fabrication details shall be reported using the following identification code system. If the type of fibre or resin is a new class not covered below, the full designation shall be added in the datasheet.

a) Material system:

A.1 Type of reinforcement fibre (e.g. carbon: CF, E-glass: EG, ECR-glass: ECR, S-glass: SG, aramid: AR, information regarding sizing and any additives, fibre modulus and precursor, bundle type, linear weight, tow size and type of weave, whenever applicable) and its grade should be included if made available. Designations for carbon, glass and aramid fibres can be provided according to ISO 13002, ASTM D578/D578M-23 and the EN 13003 series, respectively.

NOTE Discontinuous (short) fibre reinforced composites like veils composites are covered in ISO 23936-1.

A.2 Type of resin (e.g. epoxy: EP, Phenolic: PH, Vinyl ester: VE, unsaturated polyester: UP, Polyethylene: PE, bismaleimide: BMI, PEEK: PK, Polyphenylen sulfide: PPS, polyamide: PA, polyvinylidene fluoride: PVDF, polypropylene: PP) and its grade.

A.3 Type of fabric arrangement [e.g. woven roving: WR, stitch-bonded: SB, unidirectional (prepreg): UD, filament roving: FR, Braiding: BR].

b) Laminate lamina orientation and stacking sequence in test specimen preparation:

B.1 Cross-lamina laminate 0/90 orientation, $[0/90]_{ns,}$ where *n* represents the number of repeats and s stands for symmetrical stacking;

B.2 UD laminate $[0]_n$;

B.99 other cross winded orientations like + α /- α.

c) Lamination method:

C.1 Prepreg lamination (LP);

C.2 Vacuum-assisted resin transfer moulding (LR);

C.3 Wet layup lamination (LW);

C.4 Filament winding lamination (LF);

C.5 Tape placement welding (LT);

C.99 New lamination technology (method name).

d) Consolidation method for thermoplastic composites:

D.1 Hot pressing (TP);

D.2 Isothermal consolidation (TI);

D.3 Autoclave consolidation (TA);

D.99 New consolidation technology (method name).

e) Curing method for thermoset composites:

E.1 Oven cured (CO);

E.2 Hot-press cured (CH);

E.3 Autoclave cured (CA);

E.4 UV cured (CU);

E.99 New curing technology (method name).

f) Specimen extraction orientation from $[0/90]_{ns}$ and $[0]_n$ laminate or arbitrary pipe layup:

F.1 Longitudinal (OL);

F.2 Transversal (OT);

F.3 In ±45° direction (OD);

F.4 Perpendicular (hoop) to pipe axis (OP);

F.5 Along pipe axis (OA).

g) Extraction method:

G.1 Sawing (ES);

G.2 Milling/Turning (EM);

G.3 Water jet (EW);

G.4 Laser (EL);

G.99 New extraction technology (method name).