

Project MMS1

**Review of Composites
Standardisation Activities,
April 2002 – March 2003**

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October 2003

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ABSTRACT

This report reviews progress on standardisation of test methods, material specifications and product standards for polymeric matrix composites containing “long” fibres during the period April 2002 to March 2003. Long fibre composites are defined by NPL in ISO standards “as those containing fibres with a length greater than 7.5 mm in the starting material or compound”. Several standardisation “levels”, see below, of increasing complexity exist that contribute to the testing and traceability of any final composite product. Good progress was made at several levels with new documents published that were influenced by NPL research and standards work (i.e. relevant levels indicated below by asterisks). Several new composite final product standards were published in 2001/2002 that are important for the progress of the industry.

- Constituent material specifications and test methods*
- Compound specification and test methods*
- Coupon level test methods*
- Composite material database standards
- Structural element test methods
- Sub-component specifications*
- Product approval standards*

This review is produced as part of Project MMS1 on “implementation of UK work under the materials measurement programmes as international standards”. The outputs suitable from standardisation have arisen from the prior Performance of Adhesive Joints (PAJ) and Composites Performance and Design (CPD) programmes, and will be followed by output from the current Measurement for Materials Systems (MMS) programme. The MMS1 project includes round-robin validation of test methods developed in CPD and PAJ, convenorship of two CEN working groups and the project leadership of several “UK owned” international standards, as detailed on the NPL Composites Group web site [www.npl.co.uk/cog/index.html]. Enquiries can be sent to coil@npl.co.uk.

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Approved on behalf of Managing Director, NPL, by Dr C L Lea,
Head of NPL Materials Centre

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	ABBREVIATIONS	

AECMA	European Aerospace Trade Federation
AFNOR	Association Francaise de Normalisation
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
BSI	British Standards Institution
CD	Committee Draft ballot stage
CEN	Comité European de Normalisation
DIN	Deutsches Institut für Normung
DIS	Draft International Standard ballot stage
EN	European Standard
EN Aerospace	Aerospace Series of CEN standards prepared by AECMA, (n.b. EN 6000 series based on Airbus Industries Test Methods (AITMs)).
FDIS	Formal Draft International Standard ballot stage
ISO	International Standards Organisations
JIS	Japanese Industrial Standards
prEN	Preliminary enquiry vote for EN standard
SC	Sub-committee
TC	Technical Committee
VAMAS	Versailles Project on Advanced Materials and Standards
WD	Working Draft (within Working group)
WG	Working Group

1. INTRODUCTION

This report reviews progress on standardisation of test methods, material specifications and final products standards during the period April 2002 to March 2003. The report only considers those materials containing “long” fibres (i.e. those containing fibres with a length greater than 7.5 mm in the starting material or compound).

In the previous report [1], several levels of standards and specifications were identified as listed below. These are shown diagrammatically in figure 1 highlighting the alternating dependence of specification and test methods standards at each level. There has not been active work at all levels in the past year. Hence, only levels where there has been activity are reported here. The introductory aspects covered previously [1], such as, standards organisations and standards ballot approval procedures are not repeated in this report.

Standardisation levels for composite materials.

- Constituent material specifications and test methods
- Compound specification and test methods
- Coupon level test methods
- Composite material database standards
- Structural element test methods
- Sub-component specifications
- Product approval standards
- Non-destructive evaluation standards

This review is produced as part of Project MMS1 on “implementation of UK work under the materials measurement programmes as international standards”. The outputs suitable from standardisation have arisen from the prior Performance of Adhesive Joints (PAJ) and Composites Performance and Design (CPD) programmes; and will be followed by outputs from the current Measurements for Materials Systems (MMS) programme.

The MMS1 project includes round-robin validation of test methods developed in CPD and PAJ, convenorship of two CEN working groups and the project leadership of several “UK owned” international standards, as detailed in the NPL Composites Group web site [www.npl.co.uk/cog/index.html]. Detailed enquiries on composite materials standardisation can be sent to coil@npl.co.uk.

2. STANDARDISATION INFRASTRUCTURE

The main bodies responsible for standardisation in this field are ISO, CEN (General), CEN Aerospace, ASTM, JIS and other national bodies. The activities are identified via the lead body, although most test method standards in ISO are eventually published as triple numbered BS EN ISO standards. All CEN standards are automatically published as British Standards.

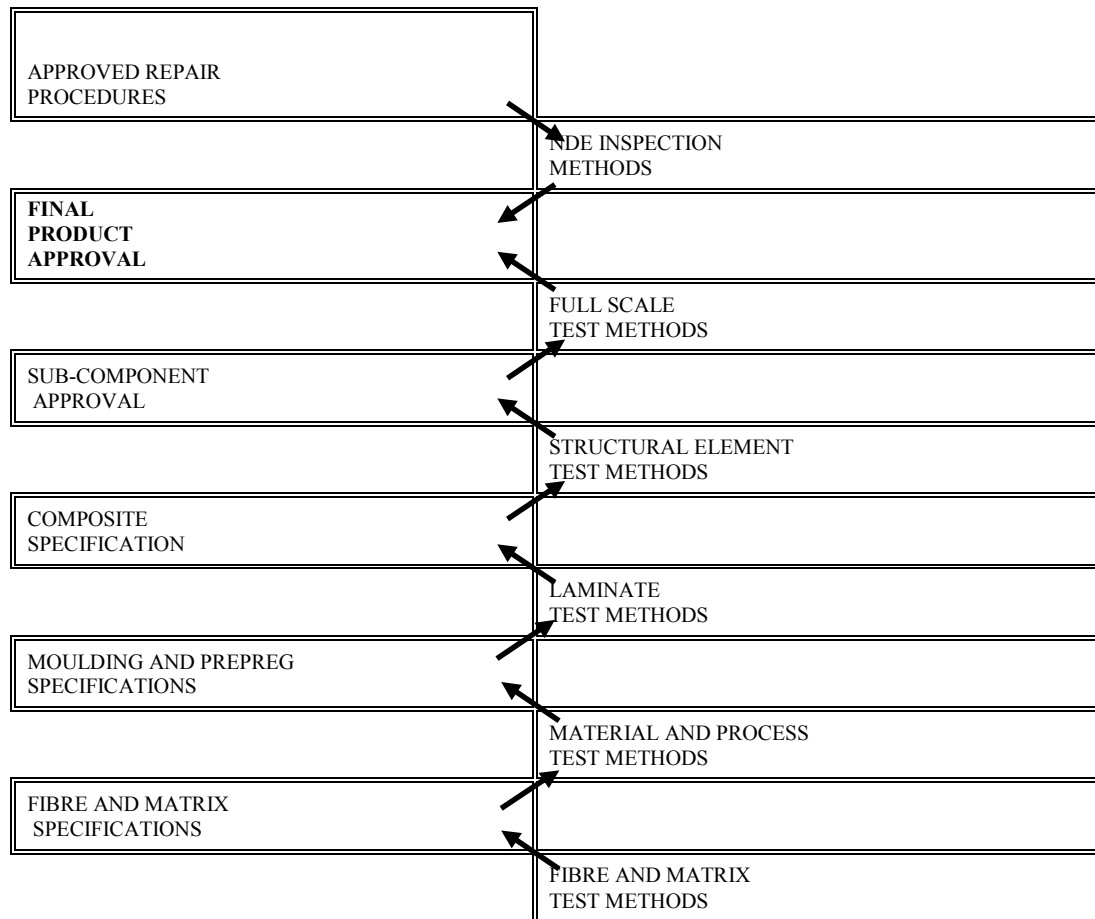


Figure 1. Chain of validation for composites products

In the previous review [1], a major issue discussed was the effect on standardisation work of the increased financial pressure on standardisation development organisations, such as AFNOR for composite material standards. This remains an issue with AFNOR still requiring funding to progress individual standards.

It should also be noted that the requirements to place a new item on the official work programme as an approved work item (AWI) are quite demanding in their own right. A new work item requires 12 countries to support, 5 countries to work (ie read documents carefully, participate in discussions, possibly participation in round-robin test on documents with nominated experts) and a qualifying score for the need and impact of proposed documents. The score is based on assessment on the following aspects.

3. PROGRESS IN STANDARDISATION

3.1 CONSTITUENT MATERIAL SPECIFICATIONS AND TEST METHODS

The work undertaken during the last year enabled the carbon fibre standards covering carbon – fibre density (ISO 10119) and size content (ISO 10549)) to be published. The revision of the standard for the tensile strength of carbon fibres (ISO 10618) continues. The proposed carbon fibre yarn specification standard (prEN 13002) has been withdrawn pending appointment of a new project leader. This type of specification standard is important for the supply industry as an illustration to potential end-users that fibres are available to a consistent specification, and from more than one supplier.

A further CEN specification for non-crimp fabrics (NCF) is now published as BS EN 13473 and will provide timely support for this increasingly important reinforcement format [2]. Stitched non-crimp fibre formats allow larger weights of material to be deposited with multiple fibre orientations, which is particularly suitable for resin transfer moulding (RTM) methods. The latest position on constituent material standards is given in table 1

Table 1: Constituent material specifications and test method standards

Standard Number	Brief Title	Status
ISO 10119	Carbon-fibre – Determination of density	Published 2002
ISO 1054: 2002	Carbon-fibre – Determination of size content	CEN UAP vote
ISO/CD 10618	Carbon-fibre – Determination of tensile properties	Minor revision to a published standard
ISO/DIS 9163	Textile glass rovings – Preparation of test specimens and determination of tensile strength of impregnated rovings.	Ballot to finish 29/10/03
prEN 13002 Parts 3	Specification for carbon fibre yarns. Part 3 Technical specification	Withdrawn pending new project leaders
BS EN 13417 Parts 1-3	Specification for woven fabrics	Published 2001
BS EN 13473 Parts 1-3	Specification for multi-axial multi-ply fabrics (NCFs)	Published 2001
BS EN 14020 Parts 1-3	Specification for textile glass rovings	Published 2002
BS EN 14118 Parts 1-3	Specification for textile glass mats	Published 2003

3.2 COMPOUND SPECIFICATION AND TEST METHODS

Good progress has been made with two more standards (i.e. EN 13677 and 13706) being published to give three recently published specification standards (see table 2). There is a format difference between BS EN 13706 for pultruded profiles, which includes mandated minimum levels of performance, and the other two standards (i.e. for GMTs and SMCs specification) that rely on establishing bounds for the mean properties agreed between supplier and moulder/user. This is to be expected in the latter cases as many “brews” or “recipes” exist. The standard defines the properties to be controlled and the limits, in percentage terms, while the customer/supplier agree the absolute level of the properties. For pultrusions, the CEN specification, written at NPL, is already increasing the application of these pultruded composites.

Table 2: Compound specification and test methods

Standard Number	Title	Status
prEN 14598 Parts 1-3	SMC/DMC Specifications	Awaiting texts
prEN 13421	SMC/BMC – determination of anisotropy	Draft for public enquiry
BS EN 13677 Parts 1-3	GMT - Specifications	Published 2003
BS EN 13706	Pultruded Profiles - Specifications	Published 2002
prEN 14447.	GMT. Determination of flowability and solidification	Awaiting public comment

The first public composite road bridge designed by Mouchel (see figure 2) has been opened on the B4508 road in Oxfordshire [3]. Interestingly, the main structural load bearing units forming the cross-beams are based on plain pultruded GRP box sections, conforming to the E23 grade defined by BS EN 13706 standard, stiffened by carbon-fibre capping. An EU research project funded the development of the more complicated shaped pultrusions known as “Asset” units that are bonded together to form the road deck. There was considerable interest in this bridge application as shown by the 250 delegates attending a seminar, organised by Mouchel, on the bridge design and build held on the day previous to the official opening. The sight of a military tank crossing the bridge during the opening ceremony showed the builders’ confidence in the composite construction, although the author was not one of those fortunate enough to ride in the tank.

**Figure 2. On-site testing of Mouchel designed bridge following installation.**

3.3 COUPON LEVEL TEST METHODS

3.3.1 Test panel preparation

The revision of ISO 1268 as a multi-part standard is now almost complete as noted in table 3. As new processes outside the existing scopes are established, further parts will be added to the standard.

Airbus Industries (AI) have agreed to sponsor the ultrasonic C-scan documents [3-5] through the new AECMA system for developing EN Aerospace standards. AI have also asked for copies of the NPL documents in CEN format for use in developing new inter-company documents following the establishment of Airbus Industries as a separate company.

An important future standard at this level is ISO/DIS 14127 for the measurement of fibre volume fraction by several methods including the principle method of chemical dissolution. Unfortunately, the work is still in abeyance as its development exceeded the allowed 7-year period due to the additional time used for round-robin trials to obtain precision data. NPL participated in these trials. Japan, as project leaders, is re-introducing the topic as a new work item (NWI).

Table 3: Parts of (EN) ISO 1268 for test plate manufacture

No.	Title	Publication Date
1	General principles	2001
2	Contact and spray-up moulding	2001
3	Wet compression moulding	2000
4	Moulding of preimpregnates	
5	Filament moulding	2001
6	Pultrusion moulding	2002
7	Resin transfer moulding	2001
8	Moulding of SMC/BMC	
9	Moulding of GMT/STC	2003
10	Injection moulding of BMC/DMC	

3.3.2 Mechanical test methods

Laminate test methods are still principally defined in the ISO work programme as noted in table 4. The final draft of "Fatigue Testing of Composites – General Principles (ISO 13003)" is with ISO Central Secretariat in Geneva for publication later in 2003. The UK, through the author, has been heavily involved in drafting and editing this French lead project through the incorporation and exploitation of experiences from the VAMAS fatigue studies organised by NPL [6].

Table 4: Composite material test methods

Standard Number	Title	Status
ISO 3597 Part 1 - 4 (Revision)	Textile glass reinforced plastics – Determination of mechanical properties on rods made of roving reinforced resin. (Preparation of rods, flexure, tension and shear strengths)	Forwarded for publication
ISO 13003	Fatigue - General principles	Publication expected October 2003
ISO/DIS 14127, also N595 for NWI re-submission	Carbon-fibre laminates- Determination of resin, fibre and void content	Needs to be re-submitted as outside 7 year allowed for development
ISO NWI N565	Glass reinforced products – Determination of fibre length	Forwarded to CD stage
ISO NWI N617	Test method for compression-after-impact properties of carbon fibre reinforced plastics.	Japanese proposal

The six standards, shown in table 5, provide the basic coupon tests used for design (in-plane tension, shear and compression) and QA (i.e. interlaminar shear strength, flexure) testing. These ISO test methods were harmonised during the drafting work at NPL with CRAG and ASTM versions of the same test methods, with one standard (i.e. BS EN ISO 14129) based on the equivalent ASTM test. As a result of the work corresponding changes were made to ASTM test methods to improve harmonisation. These standards are being balloted under the automatic five-year review procedure for confirmation, revision or withdrawal.

Table 5: Harmonised BS EN ISO Test Methods

Property	International Standard	ASTM/ CRAG Methods	Review Year	Confirm to date
Tension - "Isotropic" (nominally)	BS EN ISO 527-4	D 3930/300	2002	Yes
Tension - Unidirectional (anisotropic)	BS EN ISO 527-5	D 3930/300	2002	Yes
Flexure	BS EN ISO 14125	D 695/200	2003	
Compression	BS EN ISO 14126	D 3410/400	2004	
Shear - $\pm 45^\circ$ Tension	BS EN ISO 14129	D 3815/101	2003	
Shear - interlaminar by short beam flexure	BS EN ISO 14130	D 2344/100	2003	

The first of these, the tensile test methods BS EN ISO 527 - 4 and – 5 were agreed for confirmation. However, the Japanese had requested a revision of ISO 527-5 to include tapered tabs as well as, or instead of, square ended tabs, and revised strain levels for modulus determinations (c.f. ASTM D3039 [7]). The first aspect was considered fully when the different standards were initially harmonised by NPL ten years ago. Indeed, it was Japanese round-robin data that was tabled at the annual ISO meeting that resulted in the choice of square ended-tabs as in the UK CRAG, EN Aerospace and existing (at that time) ISO 3268 tests for GRP. The Japanese work found that for two carbon-fibre systems tested in a round-robin exercise, one obtained a higher strength with a tapered tab, and the other with a square ended tab. Consequently, on a balance of technical aspects, but also considering the cost and time for tabbing the specimen, the Japanese recommended square tabs. ASTM subsequently, modified ASTM D3039 - the equivalent tensile standard - to allow tab angles up to 90° to obtain maintain harmonisation, while retaining a preference for 7° tapered tabs.

The strain levels used for modulus measurement in ASTM D3039 (i.e. 0.1% to 0.3%) gives the same strain range of 0.2% as in the ISO standard based on a strain range of 0.05% to

0.25%. Whereas, the EN aerospace standard (EN 2561 [8]) is fundamentally different being based on the data between P/10 to P/2, where P = peak load. The ISO conditions were drawn from the previous standards (eg ISO 3268, ISO 527, ISO 178, ISO 604) that applied across all plastics (i.e. films, engineering plastics, moulding composites and composites) and test modes (i.e. tension, compression and flexure). Following discussion and consideration of the official revision ballot results, both Part 4 and 5 of ISO 527 were re-confirmed.

Work on “compression-after-impact”, is expected to progress as the Japanese delegation confirmed its intention to submit a new work proposal on this item. Crucially, Japan will also fund the French secretariat, AFNOR, to progress this work. This work area is of particular interest to the UK following studies in previous and current DTI programmes (e.g. MMS13) on “defect criticality” [9].

(c) Round-robin exercises undertaken in UK.

A round-robin (RR) validation has been undertaken for the double-notch shear test based on ASTM D3846 [10]. Three materials representing different classes of composites were used (i.e. unidirectional carbon-fibre/epoxy, glass-fibre/polyester pultrusion and woven glass-fibre/epoxy) [11]. The RR was undertaken by supplying participants with material to prepare specimens that were subsequently returned to NPL for testing. This approach was taken as the test is considered to be particularly sensitive to the quality of test specimen preparation. A similar approach was followed for a thick adherend test method using aluminium specimens for the RR exercise [12].

3.3.3 Thermal analysis test methods

During the year, NPL prepared, as the project leader, the CD ballot version of ISO 6721-11 on measurement of T_g (glass transition temperature) using dynamic mechanical analysis (DMA) methods. This will be followed by the preparation of Part 12 on calibration of DMA equipment. These drafts were based on the Measurement Good Practice Guide No 32 on thermal analysis methods [13], which included a first draft for ISO 6721-11. This test method was researched and precision data obtained in an NPL/industry studio project, and comparisons made with T_g measured by DSC (differential scanning calorimetry). The two techniques are routinely used for high performance pre-impregnated composites (prepregs), and are often interchanged or used in comparison, although not clear the relationship between two very different tests. Not all users can afford to have both techniques.

A typical set of RR data are shown in figure 2. Although, repeatability (within site) and reproducibility (between sites) were good for DSC (Differential Scanning Calorimetry), and repeatability was good for DMA (Dynamic Mechanical Analysis), poor reproducibility was obtained from DMA tests. The variability of DMA data was shown to be associated with temperature calibration errors in DMA equipment. Further details of the calibration work leading to Part 12 of ISO 6721 are given in [13].

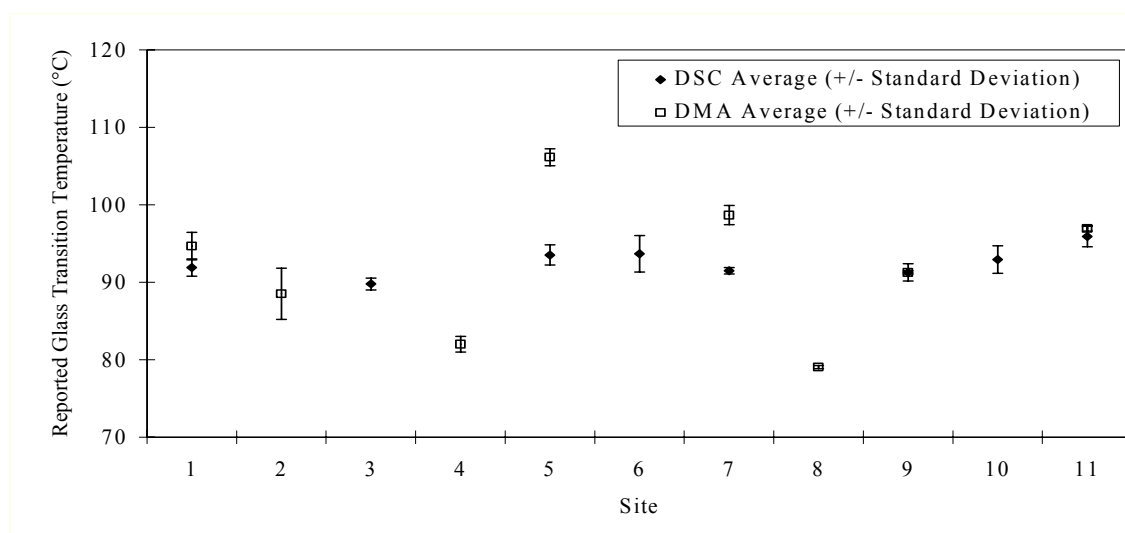


Figure 2. DSC and DMA results on unreinforced polyester [9]

NPL also acted as convenor for the annual meeting of ISO TC61/SC5/WG8 that is responsible for the DSC standard (ISO 11357-1). This Working Group is planning a series of test methods for thermal conductivity test methods for all plastics as listed in table 6. Work to be undertaken by the UK relates to use of temperature modulated DSC for thermal conductivity measurements, including a Part 1 General Principles document. These methods were studied in the second phase of the recent thermal analysis studio project, resulting in an updated version of the Measurement Good Practice Guide [14]. It will be necessary to launch official new work item ballots and obtain sufficient support, as noted in Section 2.

Table 6: Proposed new series of test methods for thermal conductivity

Introduction
Introduction and presentation of the different techniques and their uses according to the plastic materials (H. LOBO, USA)
Hot Wire Techniques::
Hot Wire (S. HEYEZ, Belgium) (ISO 8894)
Line Source (H. LOBO, USA) (D 5930 ASTM)
Hot Disk (S. GUSTAFSSON, Sweden)
Wave and Pulse methods:
Temperature Wave Analysis (J. MORIKAWA, Japan)
Laser Flash (B. HAY, France) (ISO 18755)
Steady State methods:
Guarded Hot Plate (G. SIMS, UK) (ISO 8302)
Guarded Heat Flux (G. SIMS, UK) (ISO 8301/ ASTM E 1530)
Temperature Modulated DSC (new separate series) (G SIMS UK)

3.4 STRUCTURAL ELEMENT TEST METHODS

The round-robin validation [14] has been completed for the pin-bearing test within the MMS1 project. The pin-bearing test is used for this information for all types of composites not just aerospace materials. In fact, the first mandatory use of the pin-bearing test is in the specification standard for pultruded profiles (i.e. EN 13706) in recognition of the frequent use of bolting for assembly structures from these profiles (c.f. alternative of bonding). Four materials representing different classes of composites were used in the exercise. The materials were:

- a) unidirectional carbon-fibre/epoxy,
- b) woven glass-fibre/epoxy,
- c) chopped strand mat/polyester,
- d) glass-fibre/polyester pultrusion.

Abstracts from [14] are given in Figures 3-5 and Table 7. Please see reference [14] for full details. The precision data will be used to support a new work item proposal.

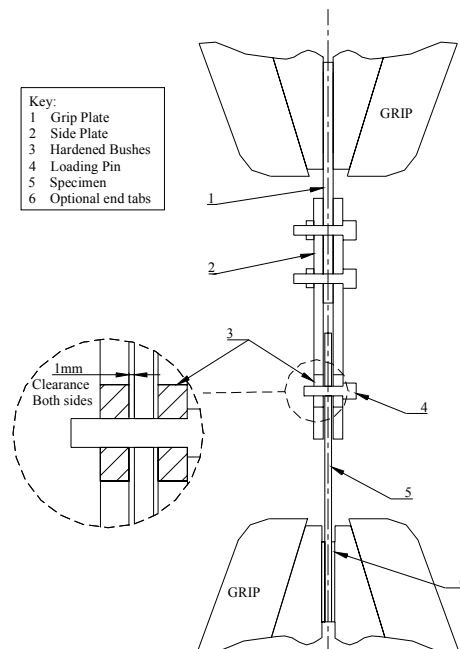


Figure 3. Pin-bearing test geometry

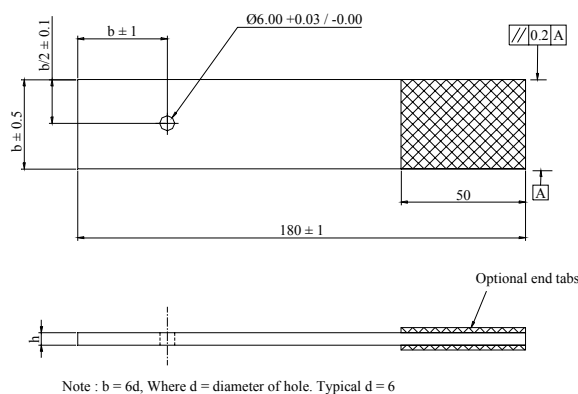


Figure 4. Pin-bearing specimen geometry

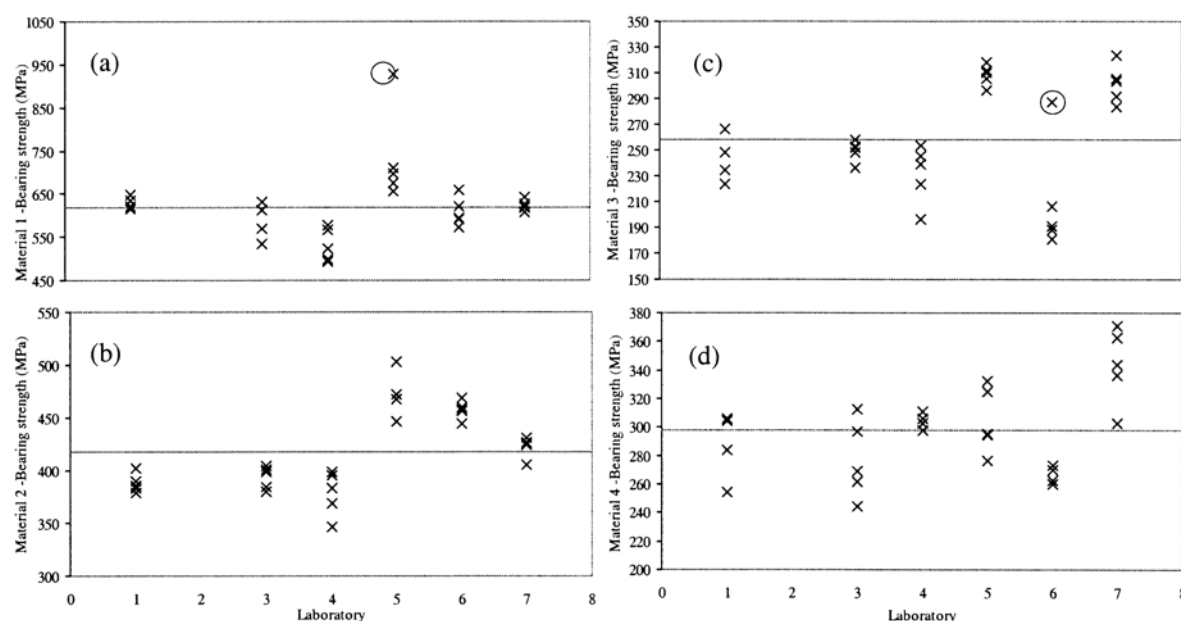


Figure 5 Data from pin bearing tests for materials (a) to (d)
(n.b. horizontal line represents overall mean, encircled points = outliers)

Table 7 Repeatability and reproducibility limits and standard deviations

Material	Repeatability Conditions		Reproducibility Conditions		Mean σ_p (MPa)
	S_r	r	S_R	R	
1	30.8	86.2	57.1	160.0	606.0
2	15.1	42.2	40.0	111.9	418.0
3	15.0	42.1	44.9	125.6	257.3
4	21.2	59.3	33.1	92.7	297.7

3.5 PRODUCT APPROVAL STANDARDS

The main progress was the publication of several final product standards. For example, ISO 14692 covering the use of GRP pipework in off-shore applications. This standard is likely to have a significant impact on use of composites in other applications; as the comprehensive coverage and procedures are applied more widely. The increasing use of fibre wrapped or fully composite cylinders for liquid petroleum gas (LPG) storage and rescue pack applications is well represented by the number of new linked EN and ISO standards in this area. These standards are in two application areas that are safety critical.

Equally, EN 40-7 is an important standard as it covers a routine civil construction applications and contains design rules for GRP light-columns alongside other parts of the standard dealing with steel, aluminium and concrete light columns. NPL first worked on the design modifications required for anisotropic materials (i.e. composites) some 15 years ago for the then Department of Transport.

Table 6: Composite material product standards

Product	Standard Number	Comments
GRP pressure vessels	prEN 13121 (c.f BSI 4994)	Expected 2003
GRP piping offshore	ISO 14692	Published 2002
GRP Water piping	EN 1115-1 (c.f. BS 7159/6464)	Published 2001
GRP Water tanks	BS EN 13280 ((replaces BS 7491 3 parts)	Published 2001
FRP Lighting Columns	EN 40-7	Published 2002
Wrapped Gas Cylinders	EN 12445/N12447/ISO 11119 (3 parts)	Published 2001/2002

Progress continues on several other documents, which are replacing BS documents particularly in the piping and pressure vessels applications areas with publication already achieved in the case of pipework. It should be noted that the many cross references in these product standards to test method standards drafted by NPL were reviewed in [16].

4. CONCLUDING COMMENTS

4.1 FUTURE REQUIREMENTS

From testwork enquiries, it is noted that there is an increased interest in the compression testing of thick carbon-fibre systems (i.e. thickness > 4 mm). Equally, for other projects the wide range of data needed has been high-lighted (e.g. mechanical properties, degree of cure, water absorption, fatigue, creep, impact).

4.2 STANDARDISATION INPUTS FROM UK COMPANIES

As the UK primary delegate to ISO and CEN, with membership and links to ASTM and JIS, NPL is keen to hear from UK companies and research establishments on new requirements, revisions of existing standards or proposals for deleting obsolete standards. Inputs are requested on the standards listed in table 5, at their 5-year review points and on the preferred methods and industrial need for measuring thermal conductivity.

4.3 ROUND-ROBIN ACTIVITIES

Several test methods were developed in prior programmes require experimental validation via round-robin exercises to generate precision data (i.e. repeatability and reproducibility) prior to submission as new work item proposals for international standardisation. Three round-robins have been completed in the current MMS project as noted below.

- through-thickness shear [11],
- thick adherend adhesive test [12],
- pin-bearing (repeat with modified jig) [15],

The through-thickness compression test method is being researched further before the RR is launched. The additional work is aimed at making it easier to load and to reduce the specimen size necessary (i.e. thickness). NPL is keen to involve other establishments in validation exercises through material supply, plate and or specimen manufacture and through testing. Further details of these round-robins and other standardisation issues are available from Dr. Graham D Sims [graham.sims@npl.co.uk] or via the NPL Composites Group web site [www.npl.co.uk/cog/index.html].

REFERENCES

1. Sims G D, "Annual Review of composites Standardisation Activities, April 2002 – March 2003", NPL Report MATC (A) 110 (2003).
2. Sims G D and Bishop G, " UK Polymer Composites Sector, Competitiveness Analysis and Foresight Study", NPL Report MATC (A) 81, (2002).
3. Broughton W R, Sims G D, and Lodeiro M J, "Overview of DTI – Funded programme on Standardised procedures for ultrasonic inspection of polymer matrix composites" *Insight*, 40, 1, (1998).
4. Broughton W R, Lodeiro M J and Sims G D, "Validation of procedures for ultrasonic C-scan inspection of PMCs: UK round-robin", (1999).
5. Broughton W R, Lodeiro M J and Sims G D, "Validation of procedures for ultrasonic C-Scan inspection of PMCs: International round-robin",
6. Sims G D, "Standardisation Issues for Fatigue Testing", 1st International Conference on Polymer Matrix Composites Fatigue, Paris, (2000).
7. ASTM D3039, "Standard test method for tensile properties of polymer matrix composite materials",
8. EN 2561 (Aerospace series), "Carbon thermosetting resin unidirectional laminates. Tensile test parallel to the fibre direction",
9. MMS 13 - Assessment and Criticality of Defects and Damage in Material Systems (For further details)see <http://www.npl.co.uk/npl/cmmt/cog/mms13/mms13intro.html>
10. ASTM D3846-94, Standard test method for in-plane shear strength of reinforced plastics.
11. Shaw R M and Sims G D, "Round-robin validation exercise for the determination of through-thickness shear strength in compression", NPL Measurement Note (MN) 48, (2003).
12. Mera R D and Sims G D, "Round-robin validation exercise for the thick adherend shear test in compression", NPL Measurement Note (MN) 46, (2003).
13. Mulligan D R, Gnaniyah S J P and Sims G D, "Thermal Analysis Techniques for Composites and Adhesives", NPL Measurement Good Practice Guide No. 32, (2000).
14. Mulligan D R, Gnaniyah S J P and Sims G D, "Thermal Analysis Techniques for Composites and Adhesives – 2nd Edition", NPL Measurement Good Practice Guide No. 62, (2003).
15. R M Shaw and G D Sims, "Round-robin validation exercise for the determination of pin bearing strength", NPL Measurement Note (MN) 50, (2003).
16. Sims G D "Traceability and Qualification in Design with Composite Materials", NPL Report MATC (A) 81 (2002).

APPENDIX A. ISO and EN STANDARDS FOR FIBRE REINFORCED PLASTICS

Reinforcing fibres and fibre products - Test methods and specifications

ISO 1887: Glass fibre – Determination of combustible matter content (size)

ISO 1888: Textile glass – Staple fibres or filaments - Determination of average diameter

ISO 1889: Reinforcement yarns – Determination of density

ISO 1890: Reinforcement yarns – Determination of twist

ISO 2078: Textile glass - Yarns -Designation

ISO 3341: Textile glass – Yarns - Determination of breaking force and breaking elongation

ISO 9291. Textile glass reinforced plastics – rovings – preparation of unidirectional plats by winding. (being replaced by ISO 1268)

ISO 10119: Carbon fibre – Determination of density

ISO 10548: Carbon fibre – Determination of size content

ISO 11566: Carbon fibre – Determination of tensile properties of single filament specimens

ISO 11567: Carbon fibre – Determination of filament diameter and cross-sectional area

ISO 10618: Carbon fibre – Determination of tensile properties of resin-impregnated yarn

ISO 13002: Carbon fibre – Designation system for filament yarns.

BS 4045:1966. Specification for epoxide resin pre-impregnated glass fibre fabrics.

BS ISO 10371:1993. Fibre reinforced plastics. Braided tapes for composite materials reinforcement. Basis for a specification.

BS EN 13003:1999. Para-aramid fibre filament yarns.

ISO/DIS 15039. Textile glass rovings – determination of solubility of sizing.

ISO/DIS 15100. Plastics – reinforcement fibres – chopped strands – determination of bulk density.

Moulding compound / pre-impregnates – test methods and specifications

prEN 14598: Reinforced plastics composites – Specifications for thermoset moulding compounds (SMC, BMC, DMC)

prEN 2833. Aerospace: Reinforced Plastics – Glass fibre pre-impregnates

prEN 14447. Fibre reinforced plastics. Glass mat reinforced thermoplastics (GMT). Determination of flowability and solidification

ISO 9782. Plastics; reinforced moulding compounds and prepregs; Determination of apparent volatile matter content.

ISO 10352. Fibre reinforced plastics – Moulding compounds and prepregs – Determination of mass per unit area.

ISO 11667. Fibre reinforced plastics – moulding compounds and prepregs – Determination of resin, reinforced fibre and mineral filler content – Dissolution methods.

BS EN ISO 12115. Fibre reinforced plastics – thermosetting moulding compounds and prepregs – determination of flowability, maturation and shelf life.

ISO 12114 – Fibre reinforced plastics – thermosetting moulding compounds and prepregs – determination of cure characteristics

BS EN 12575:1998. Plastics. Thermosetting moulding compounds. Determination of the degree of fibre wet out in SMC.

prEN 13677: Reinforced Plastics Composites – specifications for thermoplastic moulding compounds (GMT)

ISO 15034: Composites - Prepregs – Determination of resin flow

ISO 15040: Composites - Prepregs – Determination of gel time

Resin systems

BS 3532:1990. Specification for unsaturated polyester resin systems for low pressure fibre reinforced plastics.

Many other standards for unreinforced thermoplastic and thermoset resins applicable (www.bsi-global.com)

Fibre reinforced plastics (or polymer matrix composites)

BS 6564-3:1990. Polytetrafluoroethylene (PTFE) materials and products. Specification for E-glass fibre filled PTFE.

Laminated materials – Mechanical property tests

BS EN ISO 75-3:1996. Plastics. Determination of temperature of deflection under load. High-strength thermosetting laminates and long-fibre-reinforced plastics

BS EN ISO 527 – Part 1: Plastics – Determination of tensile properties – General principles

BS EN ISO 527 – Part 4: Determination of tensile properties – Test conditions for isotropic and orthotropic fibre-reinforced plastic composites

BS EN ISO 527-5: Plastics. Determination of tensile properties. 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 - Calcination methods (determination of loss on ignition)

ISO 1268: Fibre reinforced plastics – test plate manufacturing methods

ISO 2818: Plastics – Preparation of specimens by machining

ISO 3597. Textile glass reinforced plastics; Determination of mechanical properties on rods made of roving reinforced resin (Parts 1-4)

ISO 4899 Textile glass reinforced thermosetting plastics; properties and test methods.

ISO 10350-2: Plastics – acquisition and presentation of *comparable single-point data* – Part 2: *long fibre reinforced plastics*

ISO/FDIS 13003: Fibre reinforced plastic composites – determination of fatigue properties under cyclic loading

BS EN ISO 14125: Fibre-reinforced plastics composites – determination of flexural properties

BS EN ISO 14126: Fibre reinforced plastic composites – determination of the in-plane compression strength

ISO/DIS 14127. Composites – determination of resin, fibre and void content of composites reinforced with carbon fibre

BS EN ISO 14129: Fibre reinforced plastic composites – determination of the in-plane shear stress/shear strain, including the in-plane shear modulus and strength by the $\pm 45^\circ$ tension test method

BS EN ISO 14130: Fibre reinforced plastic composites – determination of apparent interlaminar shear strength by short-beam method

ISO 15024: standard test method for Mode I Interlaminar fracture toughness G_{IC} of unidirectional fibre reinforced polymer matrix composites

ISO 15310: Fibre reinforced plastic composites – determination of in-plane shear modulus by plate twist

Thermal analysis test methods

ISO 6721: Plastics – Determination of dynamic mechanical properties

ISO 11357: Plastics - Differential scanning calorimetry

Final Products –Test method and Product Standards

BS EN 40-7:2002 Lighting columns. Requirements for fibre reinforced polymer composite lighting columns.

BS EN 1013-2:1999 Light transmitting profiled plastics sheeting for single skin roofing. Specific requirements and test methods for sheets of glass fibre reinforced polyester resin (GRP).

BS EN 1115 Plastics piping systems for underground drainage and sewerage under pressure. Glass-reinforced thermosetting plastics (GRP) based on unsaturated polyester resin (UP). General

BS EN 12445 Transportable gas cylinders. Fully wrapped composite cylinders

BS EN 12457 Transportable gas cylinders. Seamless, hoop-wrapped composite cylinders

BS EN 13280:2001 Specification for glass fibre reinforced cisterns of one-piece and sectional construction, for the storage, above ground, of cold water (replaces BS 7491 3 parts)

BS 4154:1985. Corrugated plastics translucent sheets from thermo-setting polyester resin (glass fibre reinforced).

BS 5480:1990. Specification for glass fibre reinforced plastics (GRP) pipes and fittings for water supply or sewerage.

ISO 7370. Glass fibre reinforced thermosetting plastics (GRP) pipes and fittings; nominal diameters, specified diameters and standard lengths.

ISO/FDIS 7432 Glass reinforced thermosetting plastics (GRP) pipes and fittings-test methods to prove the design of locked socket and spigot joints

BS 7491. Glass fibre reinforced plastics cisterns for cold water storage

ISO/DIS 7509 Plastics piping systems – glass reinforced thermosetting plastics (GRP) pipes – determination of time to failure under sustained internal pressure

ISO 7510. Plastics piping systems- glass reinforced plastics (GRP) components

ISO 7511. Plastics piping systems – glass reinforced thermosetting plastics (GRP) pipes and fittings – test methods to prove the leak tightness of the wall under short-term internal pressure.

ISO 7684. Plastics piping systems – glass reinforced thermosetting plastics (GRP) pipes – determination of the creep factor under dry conditions.

ISO 7685. Plastics piping systems - glass reinforced thermosetting plastics (GRP) pipes – determination of initial specific ring stiffness.

ISO/DIS 8483 Glass reinforced thermosetting plastics (GRP) pipes and fittings – test methods to prove the design of bolted flange joints.

ISO/DIS 8513. Plastics piping systems - glass reinforced thermosetting plastics (GRP) pipes – determination of initial longitudinal tensile properties.

ISO 8521 Plastics piping systems - glass reinforced thermosetting plastics (GRP) pipes – determination of the apparent initial circumferential tensile strength.

ISO/DIS 8533. glass reinforced thermosetting plastics (GRP) pipes and fittings – test methods to prove the design of cemented or wrapped joints.

ISO/DIS 8639. Glass reinforced thermosetting plastics (GRP) – test methods for leaktightness and resistance to damage of flexible and reduced-articulation joints.

ISO 10466. Plastics piping systems - glass reinforced thermosetting plastics (GRP) pipes – test method to prove the resistance to initial ring deflection.

ISO/DIS 10467. Plastics piping systems for pressure and non-pressure sewerage – glass reinforced thermosetting plastics (GRP) based on unsaturated polyester (UP) resin.

ISO/DIS 10468 plastics piping systems - glass reinforced thermosetting plastics (GRP) pipes – determination of the long-term specific creep stiffness under wet conditions and calculation of the wet creep factor.

ISO/DIS 10471. Plastics piping systems - glass reinforced thermosetting plastics (GRP) pipes – determination of the long-term ultimate bending strain and the long-term ultimate relative ring deflection under wet conditions.

ISO/DIS 10639. Plastics piping systems for water supply with or without pressure – glass reinforced plastics (GRP) based on unsaturated polyester (UP) resin.

ISO 10928. Plastics piping systems - glass reinforced thermosetting plastics (GRP) pipes and fittings – methods for regression analysis and their use.

ISO 10952. Plastics piping systems - glass reinforced thermosetting plastics (GRP) pipes and fittings – determination of the resistance to chemical attack from the inside of a section in a deflected condition

ISO 11119-1:2002. Gas cylinders of composite construction -- Specification and test methods -- Part 1: Hoop wrapped composite gas cylinders (available in English only)

ISO 11119-2:2002 Gas cylinders of composite construction -- Specification and test methods -- Part 2: Fully wrapped fibre reinforced composite gas cylinders with load-sharing metal liners (available in English only)

ISO 11119-3:2002 Gas cylinders of composite construction -- Specification and test methods -- Part 3: Fully wrapped fibre reinforced composite gas cylinders with non-load-sharing metallic or non-metallic liners

EN 13706: Fibre reinforced plastics – Specification for pultruded profiles

prEN 13923. Filament-wound GRP pressure vessels. Materials, design, manufacture and testing

ISO 14692:2002. Petroleum and natural gas industries - GRP piping (4 Parts)

ISO/DIS 14828. Plastics piping systems - glass reinforced thermosetting plastics (GRP) pipes – determination of the long-term specific ring relaxation stiffness under wet conditioned and calculation of the wet relaxation factor

Further information available from

www.npl.co.uk/cog/index.html
www.bsi-global.com

www.materialssolutions.info
www.iso.ch