Project MMS1

Review of Composites Standardisation Activities, April 2002 – March 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 standardisation 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.

The report was prepared as part of the research undertaken at NPL for the Department of Trade and Industry’s Measurements for Material Systems programme.
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ABBREVIATIONS

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

**Figure 1. Chain of validation for composites products**

- **APPROVED REPAIR PROCEDURES**
- **NDE INSPECTION METHODS**
- **FINAL PRODUCT APPROVAL**
- **FULL SCALE TEST METHODS**
- **SUB-COMPONENT APPROVAL**
- **STRUCTURAL ELEMENT TEST METHODS**
- **COMPOSITE SPECIFICATION**
- **LAMINATE TEST METHODS**
- **MOULDING AND PREPREG SPECIFICATIONS**
- **MATERIAL AND PROCESS TEST METHODS**
- **FIBRE AND MATRIX SPECIFICATIONS**
- **FIBRE AND MATRIX TEST METHODS**
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

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

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

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

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 reintroducing the topic as a new work item (NWI).

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

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

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**

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

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**

<table>
<thead>
<tr>
<th>Property</th>
<th>International Standard</th>
<th>ASTM/CRAG Methods</th>
<th>Review Year</th>
<th>Confirm to date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension - “Isotropic” (nominally)</td>
<td>BS EN ISO 527-4</td>
<td>D 3930/300</td>
<td>2002</td>
<td>Yes</td>
</tr>
<tr>
<td>Tension - Unidirectional (anisotropic)</td>
<td>BS EN ISO 527-5</td>
<td>D 3930/300</td>
<td>2002</td>
<td>Yes</td>
</tr>
<tr>
<td>Flexure</td>
<td>BS EN ISO 14125</td>
<td>D 695/200</td>
<td>2003</td>
<td></td>
</tr>
<tr>
<td>Compression</td>
<td>BS EN ISO 14126</td>
<td>D 3410/400</td>
<td>2004</td>
<td></td>
</tr>
<tr>
<td>Shear - ± 45° Tension</td>
<td>BS EN ISO 14129</td>
<td>D 3815/101</td>
<td>2003</td>
<td></td>
</tr>
<tr>
<td>Shear - interlaminar by short beam flexure</td>
<td>BS EN ISO 14130</td>
<td>D 2344/100</td>
<td>2003</td>
<td></td>
</tr>
</tbody>
</table>

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 (e.g. 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].
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

<table>
<thead>
<tr>
<th>Material</th>
<th>Repeatability Conditions</th>
<th>Reproducibility Conditions</th>
<th>Mean $\sigma_y$ (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$S_r$</td>
<td>$r$</td>
<td>$S_n$</td>
</tr>
<tr>
<td>1</td>
<td>30.8</td>
<td>86.2</td>
<td>57.1</td>
</tr>
<tr>
<td>2</td>
<td>15.1</td>
<td>42.2</td>
<td>40.0</td>
</tr>
<tr>
<td>3</td>
<td>15.0</td>
<td>42.1</td>
<td>44.9</td>
</tr>
<tr>
<td>4</td>
<td>21.2</td>
<td>59.3</td>
<td>33.1</td>
</tr>
</tbody>
</table>

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

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

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

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
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 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.

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.
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


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


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

Fibre reinforced plastics (or polymer matrix composites)


Laminated materials – Mechanical property tests


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 ±45° 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 Gic 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 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 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 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 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


EN 13706: Fibre reinforced plastics – Specification for pultruded profiles

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


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