COMPETITIVE AND SUSTAINABLE GROWTH

(GROWTH)

PROGRAMME

Contract for Shared-cost RTD

Final Report

Contract number:	G6RD-CT-2002-00856
Project acronym:	SPOTS
Project full title:	Standardisation Project for Optical Techniques of Strain Measurement
Duration:	36 months
Project Co-ordinator:	Professor Eann Patterson University of Sheffield

Contractors:

University of Sheffield	(USFD)
Optical Metrology Innovations	(OMI)
Dantec Dynamics AG	(ET)
European Commission	(EC-JRC-IHCP)
NPL Management Ltd	(NPL)
SNECMA Moteurs	(SNECMA)
Honlet Optical Systems GMBH	(HOS)
Politechnika Warszawska	(PW)
CRF Societa Consortile per Azioni	(CRF)
Eidgenössische Materialprüfungs-und Forschungsanstalt	(EMPA)
Airbus	(AIRBUS)

Date of Issue: January 2006

TABLE OF CONTENTS

2. EXECUTIVE PUBLISHABLE SUMMARY

SPOTS was a prenormative project for optical techniques of strain measurement. Optical methods of strain measurement are a generic technology, which support life cycle performance, safety and reliability assessments, and design optimisation of products, components and machines varying in scale from micro-machines to ships. These methods form a powerful set of tools for use in defining the performance, reliability and safety of primary structures. However, the quality of the data generated is strongly dependent on the procedures employed and set-up of the instrumentation. So, there is a significant need to provide standards both for procedures and instrumentation in order to provide traceability, to prevent technical barriers to trade, and to promote the compatibility of systems. The objectives of the project addressed these issues and the outputs will help to provide opportunities to both enhance the competitiveness of European suppliers of optical instrumentation and, simultaneously, to improve the competitiveness of end-users through contributions to design optimisation leading to improvements in strategic products ranging from mobile phones to aerospace components.

The objectives of the project were:

- The investigation and development of candidates for both physical and virtual reference materials that allow traceability, validation and transparent comparability of full-field optical methods of strain measurement;
- The optimisation of methodologies for full-field optical techniques for strain measurement;
- A contribution to standardisation activity for full-field optical methods for strain measurement.

The major innovation of the project was the provision of a unified reference system for optical techniques of strain measurement. The project was organised into three technical work packages with additional packages for co-ordination and for dissemination. Each of the technical work packages had an emphasis on a different stage of the innovation process with 'Development of Reference Materials' focused on research laboratories; 'Optimisation of Methodologies' focused on technique and instrumentation suppliers; and 'Verification and Implementation' focused on end-users and concerned with checking and applying the outcomes in order to provide a high level of confidence in them. The project has been completed on schedule and all the deliverables have been achieved. The main outputs from the project were:

- A recommended data format for full-field optical strain data;
- Draft standard guides on ESPI, geometric moiré, grating interferometry, image correlation, photoelasticity, and thermoelasticity;
- Completion of two round robins and a set of industrial case studies as part of the verification process;
- Project internet (www.opticalstrain.org) and intranet established;
- Reports on routes for traceability and on feasibility of full-field data comparisons.
- A SPOTS standard for the calibration and assessment of optical strain measurements including the design and methodology for use of a reference material and a set of standardised test materials. This document will be submitted as a proposed ISO TTA via VAMAS.

3. OBJECTIVES OF THE PROJECT

The strategic objectives of the SPOTS project are given above in the 'Executive Summary', in more detail the scientific and technical objectives were:

1. The development of a physical reference material, reference geometry, and reference loading condition for speckle techniques, image correlation, moiré, moiré interferometry, photoelasticity, and thermoelasticity.
2. The design and construction of simulated, virtual reference materials. For each technique, the virtual reference material will include: simulated data, synthesised fringe patterns with and without random or systematic noise.
3. Definition of recommended data formats for image data, numerical data, and processed data for full-field optical techniques of strain measurement.
4. Optimisation of methodologies for the use of unified reference materials and for the practical application of speckle techniques, image correlation, moiré including moiré interferometry, photoelasticity and thermoelasticity.
5. Liaison with international bodies associated with optical methods of strain measurements, in order to ensure recognition of the measurement procedures and reference materials developed; and simultaneous dissemination to EU industrial base.
6. Identification of routes for traceability for calibration of systems.

It should be noted that image correlation has replaced shearography in the list of primary techniques being considered by the consortium. This decision was taken by the Project Steering Committee in the light of a rapid increase in popularity and use of image correlation both within the consortium but also in the wider technical community. By contrast, shearography has not grown in popularity at the rate expected at the time of preparation of the proposal in late 2001.

4. SCIENTIFIC AND TECHNICAL DESCRIPTION OF THE RESULTS

4.1 Introduction

Optical methods of strain measurement provide data on the behaviour of a component or structure subject to external, applied loading or stresses arising from assembly or manufacturing processes. This data is invaluable to engineers in assessing the 'fitness for purpose', or reliability of the structure or component. In turn, these more effective assessments can alleviate uncertainty and lead to less conservative and more efficient designs with lower failure rates and lower production and operating costs, in both environmental and financial terms, all of which contribute to quality of life for society and the competitiveness of industry. Since optical strain measurement is a generic activity associated with products, components, and machines varying in scale from micro-machines to ships, greater standardisation will lead to more widespread use and hence greater competitiveness and efficiency through better designs in many European industrial sectors. The substantial move towards standardisation represented by the project will also assist European manufacturers of equipment for optical strain measurement by providing a unified and larger European market and a strong basis from which to tackle international markets. This market is dominated by SMEs (Small & Medium sized Enterprises) who are represented within the project, whilst the supply chains of the major end-users represented in project, namely aerospace and automotive are also dominated by SMES, so that the project is likely to have significant impact on the competitiveness of this sector in Europe.

The consortium includes representatives from seven states and includes partners operating at all stages of the innovation process from fundamental research to end-users, including manufacturers and suppliers, and national laboratories.

The objectives of the project are ambitious particularly in terms of the development of a unified system of virtual and physical reference materials. The strategy for the first half of the project was to assimilate the existing material in the field, to use a rational decision making model to identify candidate reference materials and their attributes, design a physical reference material and to establish a framework for communicating the outputs. This was achieved and in itself represented a substantial scientific and technical achievement that was communicated to the scientific community at the International Conference on Experimental Mechanics in September 2004 in Bari, Italy where a special session on the project was heavily over-subscribed.

In the second half of the project: a set of standardised test materials were developed for the evaluation, as opposed to the calibration, of optical system for strain measurement; methodologies for the use of both the reference material and standardised test materials were prepared and both the designs and methodologies incorporated in a SPOTS standard that will be submitted for publication as an ISO TTA (Technology Trend Assessment) via VAMAS. A series of industrial case studies and a second round robin were used to verify the designs and methodologies in the SPOTS standard, and reports were prepared on routes for traceability of strain measurement and the feasibility of full-field comparison of strain data. Dissemination and communication with the technical community has been a strong component of the project and, in addition to a number of articles and presentations, a second special session dedicated to SPOTS was organised at the 4th International Conference on Advances in Experimental Mechanics held in Southampton, UK during September 2005.

The approach taken and results achieved are described for each work package in the following sections. Detailed reports produced as deliverables are either in the Appendices or on the project intranet site*.

4.2 Work Package 1: Project Coordination

This work package contained three tasks: technical coordination, financial coordination and technology implementation plan. Since there was no scientific content, no description is included here and the coordination aspects are described elsewhere in the report (section 7).

4.3 Work Package 2: Optimisation of methodologies

Objectives:

a) Definition of recommended data formats for image data, numerical data, and processed data for full-field optical techniques of strain measurement. (**M6** & **D3**)†

b) Optimisation of a unified methodology for the use of reference materials with each class of optical technique.

c) Optimisation of methodologies of use in engineering practice for each class of optical technique. (**M11** & **D4**)

Task 2.1 – Definition of data formats

The range of optical techniques available for assessing strain and stress is broad and the techniques are diverse in nature. Since neither stress nor strain are quantities that can be measured directly all techniques are based on measurements of deformations and, or displacement or other properties of materials subject to stress and strain. Approaches to experimental analysis tend to be derived from concepts of displacement or deformation and to consider stress or strain, so that a plethora of formats result for presenting data, which makes comparisons difficult or impossible. The purpose of this task was to generate a set of recommended data formats for image data, numerical data and processed data. This has been completed and the resultant data format has been published on the SPOTS web page (www.opticalstrain.org) (**D3**). It is also reproduced in Appendix 1. It provides a framework for reporting and exchanging image and processed data maps as ASCII files. A small software program has also been prepared to assist users in preparing and reading data in the recommended format. The software can be downloaded from the project website for no charge.

The recommended data format was initially defined prior to the first round robin and subsequently refined following experience during the round robin. It was used in the industrial case studies undertaken in task 4.2 and in the second round robin. The format was publicised to the wider technical community at the 12th International Conference on Experimental Mechanics being hosted in Bari during August & September 2004[1].

Task 2.2 – Incorporation/evaluation of existing technical notes/guidelines

For some optical techniques, there already existed a set of technical notes for their implementation. These technical notes and guidelines were identified, their suitability

* www.sheffield.ac.uk/spots/members/ username: SPOTS and for the password contact the coordinator at e.a.patterson@sheffield.ac.uk

† Bold letters and numbers in parentheses refer to project deliverable and milestones.

for adoption as standard methodologies assessed and recommendations brought forward concerning their amendment as appropriate.

The majority of these technical notes relate to photoelasticity and moiré, and are available at http://new.vishay.com/brands/measurements_group/pubs/tnotes.htm.

Three German standards are available for shearography[2,3,4] and there is an ASTM (American Society for the Testing of Materials) standard for calibration of an interferometric system for tyre inspection[5] and a draft standard guide on optical strain instruments[6]. An internet search was conducted for other sources of technical notes and guidelines using the following keywords: applications notes, technical notes, guidelines, guides, image correlation, moiré, geometric moiré, moiré interferometry, grating interferometry, grid methods, photoelasticity, ESPI, shearography and thermoelasticity. Almost no further information was obtained, although one site offered the prospect of technical notes in the future and another provided some high quality outline descriptions of techniques.

This scarcity of information led to the consideration of three generic publications[7,8,9] in order to widen the field being evaluated and to provide some comparators.

The publications identified above were reviewed in order to assess their suitability for incorporation into a standard on optical techniques of strain measurement. It was concluded that the existing standards for shearography need not be supplemented at this stage and that the existing material in photoelasticity, geometric moiré and grating interferometry could be incorporated into standard guides. For the remaining techniques no existing technical notes or guidelines were identified. Draft standard guides for photoelasticity, geometric moiré and grating interferometry have been completed and published on the website (www.opticalstrain.org) (**D4**).

The objectives of this task have been achieved. In addition to the proposals in the original work package, these standard guides have been reviewed and edited into a single volume together with those from task 2.4. The collection of standard guides forms part III of the SPOTS standard which is being proposed as an ISO TTA (Technology Trend Assessment) through VAMAS.

Task 2.3 - Methodologies for use of reference materials

The design of the physical reference material was completed in task 3.1 and a number of specimens were manufactured separately by partners at several different scales. Strain measurements on these reference materials have been made using four optical techniques and have confirmed the effectiveness of the design. A detailed finite element study was also performed to assist in understanding the performance of the reference material and to support refinement of the design. An overview of these results were included in a paper presented at the 4th International Conference on Advances in Experimental Mechanics and is reproduced in Appendix 2[10]. The experience gained in performing these experiments and processing the results was used to develop the methodology for the use of the reference materials. A number of brain-storming sessions were also held to discuss the concepts of uncertainty in the measurements and the approach to be used to characterise uncertainty in full-field measurements which is distinctly different from most measurands that are essentially one-dimensional. The methodology has been incorporated into Part 1 of the SPOTS Standard for the Calibration and Assessment of Optical Strain Measurement which is available on the project website: www.opticalstrain.org (**D11**).

Task 2.4 - Methodologies for measurements

It was decided to extend the concept of draft standard guides developed in task 2.2 to include those techniques within the remit of the project but for which there were no existing guidelines. Standard guides for ESPI, image correlation and thermoelasticity have been prepared. The standard guides were used in the second round robin in Task 4.1 and the industrial case studies in Task 4.2. As mentioned under task 2.2, this work has been taken beyond the original work package and the standard guides have been reviewed and edited into a single volume together with those from task 2.2. The collection of standard guides forms part III of the SPOTS Standard which is being proposed as an ISO TTA (Technology Trend Assessment) through VAMAS and is available on the project website: www.opticalstrain.org (**D14**).

A single source of information on the use of optical techniques in practical situations does not appear to exist at the moment and so these guides will be a valuable contribution to the industrial and scientific communities.

4.4 Work Package 3: Development of Reference Materials

Objectives:

a) Development of physical reference materials to allow calibration and comparison of techniques and instrumentation for optical methods of strain evaluation. (**M7**, **M12** & **D7**)

b) Development of virtual reference materials to allow validation and comparison of algorithms associated with optical techniques for measuring stress and strain. (**M8** & **M13**)

Task 3.1 – Physical reference materials for data acquisition stage

The rational decision making model was used to guide the development of the physical reference materials[11,12]. This model involves a number of steps that can be briefly described as: identification of essential attributes, identification and weighting of desirable attributes, development of candidate designs, evaluation of candidate designs, selection and embodiment of preferred design or designs. The design of the physical reference material consists of a monolithic four-point bending beam shown in figure 1. A detailed description of the design is included in Part 1 of the SPOTS Standard which is being proposed as an ISO TTA (Technology Trend Assessment) through VAMAS and is available on the project website: www.opticalstrain.org (**D7**).

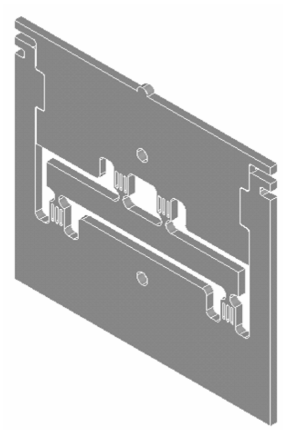


Figure 1 – Three-dimensional view of the physical reference material (*EU Community Design Registration 000213467*) which is scalable to any size and can be manufactured in any material.

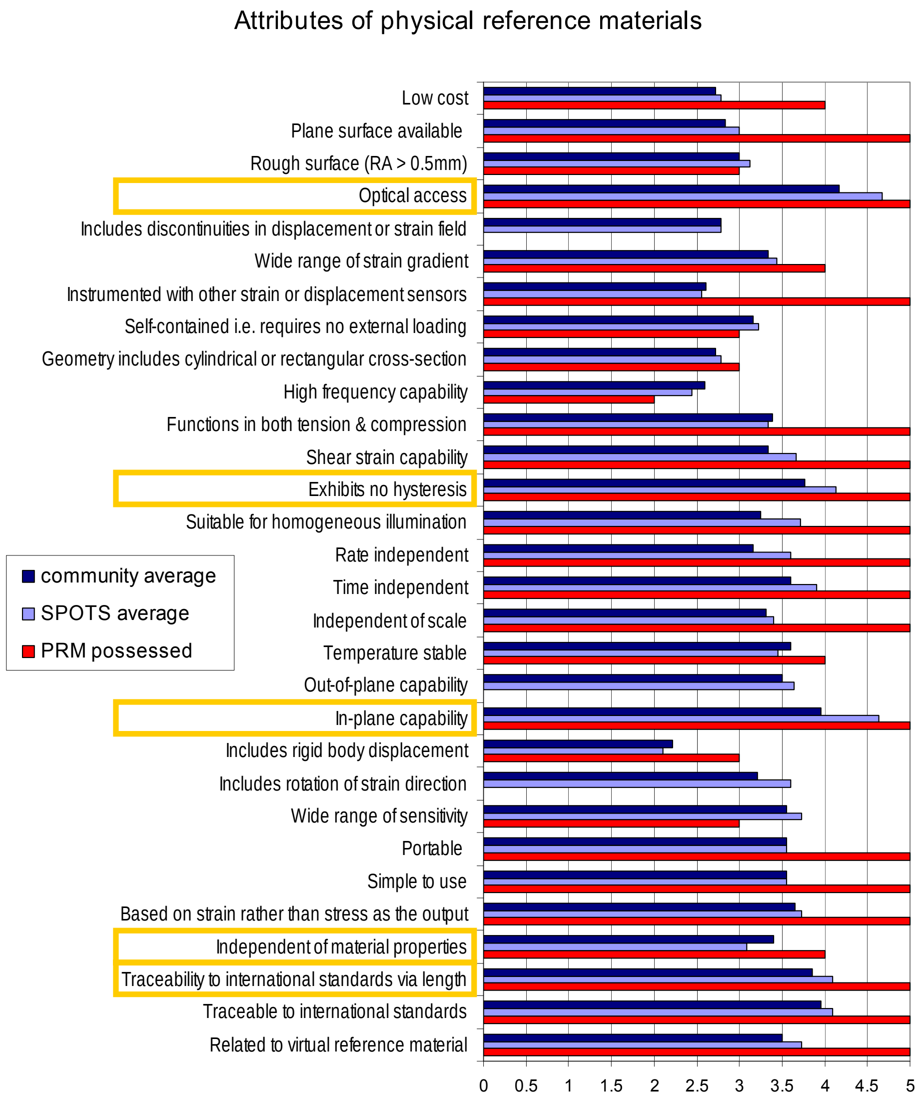


Figure 2 – Attributes and their weightings for the physical reference materials (PRM) together with the extent to which they are possessed by the selected PRM. The weightings (1 - unimportant, 2 - preferred, 3 - important, 4 - highly desirable, or 5 – essential) assigned by individual partners in the project were averaged and the same exercise repeated for the wider community including the SPOTS partners. Essential attributes were identified as those having an average weighting from the whole community greater than the mean plus a standard deviation of the weightings and are highlighted above. The extent to which an attribute was possessed by the new PRM were assessed as 5 – completely possessed, 4 – to a large degree, 3 – to some degree, 2 – to a limited degree or in some circumstances, 1 – not possessed but could be arranged, 0 – not possessed at all.

A list of attributes for the reference materials were arrived at through discussion, by email, between project partners during which all viable suggestions for attributes were included on the list. Subsequently the list of attributes was circulated to all partners who were asked to weight each attribute according its perceived importance. The results were reviewed and discussed at the six-month meeting, and subsequently individual partners were given the opportunity to revise their weighting of the attributes. In addition the views in the wider community were sought in both the USA and Japan. The results from these weightings of the attributes are shown in figure 2. It can be seen that the differences between the SPOTS partners and the wider community is very small. The essential attributes were identified as those with an average weighting from the whole community of greater than the mean plus a standard deviation of the average weightings. These attributes are high-lighted in figure 2. The extent to which the selected design possesses these attributes has also been assessed and is included in figure 2. The new design scores 80% in terms of its possession of the weighted attributes and possesses all the essential attributes.

The design was conceived during a number of brain-storming sessions and involved a sub-set of partners with regular reporting to the consortium through the intranet and at six-monthly meetings. The brain-storming sessions were structured around the rational decision making model with both the virtual and physical reference materials being considered.

The monolithic design ensures alignment through the specimen geometry and traceability to the length standard is provided by closure of defined gap in the structure upon loading. The design is constrained to be two-dimensional so that it can be manufactured by a very wide range of techniques and at a range of scales from the micro to macro. The four-point bending of a beam became the favoured candidate in part because the basic geometry has been used in existing standards for optical measurements[13,14]. The design was successfully evaluated at a number of scales using a variety of optical techniques as well as finite element analysis. An overview of these results is provided in Appendix 2 in the form of a paper presented at the 4th International Conference on Advances in Experimental Mechanics in Southampton, UK during September 2005[10].

The development of a single unified physical reference material for all techniques of optical strain measurement was identified in the work description as one of the major risks in the execution of the project. The rational decision making model was identified as a method of providing a framework for directing and focussing the creativity needed to achieve the ambitious outcome. This has worked effectively and the result is an innovative and effective design which initial assessments indicate meets all the criteria.

Task 3.2 – Virtual reference materials for data processing stage

Initial work on the virtual reference materials focussed on defining their function and position in the measurement process, which led to the development of a process map and a process flow chart. The map and flowchart represent the first attempt to formulise in a unified framework the processes associated with measurements of strain and, or displacement using full-field optical techniques. In particular, they have allowed the need for and nature of a series of virtual reference materials to be identified. These developments were presented at the 12th International Conference on Experimental Mechanics in Bari, Italy in August 2004[15].

Subsequently, the rational decision making model was employed to guide the development of the virtual reference materials. The attributes for the virtual reference materials were identified and weighted. Consideration of these attributes during the identification of the candidate materials, led to the conclusion that the reference materials should consist of simple strain distributions that allow calibration of optical systems via traceability to the primary standard for length. In addition, standardised tests were also required that would include more sophisticated features in their strain distributions and which would allow assessment of fitness for purpose. The design of standardised tests goes beyond the work description for the project but, with the agreement of the consortium, was incorporated into the work programme.

The virtual reference material is a simple analytical description of the strain field in the gauge section of the physical reference material. The gauge section is the central portion of the beam subjected to four-point bending so that simple theory of elasticity can be used to describe the strain field. The monolithic frame produces some constraint that would not be present in a classical four-point bend specimen that usually would be mounted on knife-edges. Consequently a simple correction is included to allow for the effect of the constraint. A complete description of the virtual reference material and its use is included in Part 1 of the SPOTS Standard which is being proposed as an ISO TTA (Technology Trend Assessment) through VAMAS and is available on the project website: www.opticalstrain.org (**D9**).

Standardised test materials were designed to allow sophisticated optical instruments and their sub-systems to be evaluated and their 'fitness for purpose' assessed. This is relevant to system developers when designing an instrument and its algorithms, to manufacturers concerned with quality assurance, to instrument purchasers wishing to compare the capabilities of systems, and to end-users for setting up and maintaining the system and training staff in its use. The standardised test materials are intended to provide a set of strain fields which are challenging to analyse and to allow each stage in the determination of strain to be evaluated. The strain fields were chosen after consultation[16] with the experimental mechanics community and include a strain concentration, variation in strain direction, reversal of the sign of strain, discontinuity in the strain distribution, and a physical boundary.

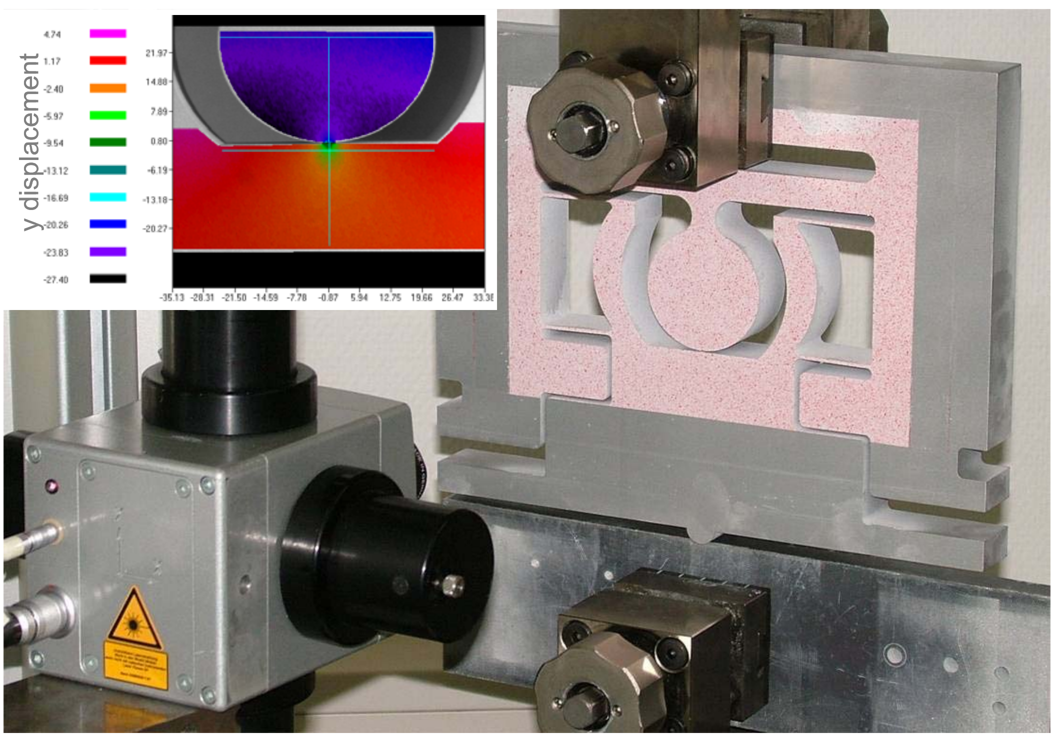


Figure 3 – A physical standardised test material (PSTM1) manufactured from aluminium with a disc diameter of 50mm under test with a ESPI system (Dantec Dynamics Q300). Typical results are shown in the inset. (*EU Community Design Registration 000299094*).

Two geometries have been used to create standardised test materials. A disc in contact with an elastic half-space and subject to diametral compression has been used as the focus of both a physical standardised test material (PSTM1) (see figure 3) and a virtual standardised test material (VSTM1). This geometry contains a strain concentration, a variation of strain direction, a reversal of the sign of the strain and physical boundaries. The second geometry is the interference fit between two cylinders or rings which introduces a discontinuity in the strain field and is dealt with only as a virtual standardised test material (VSTM2). These cases are both planar or two-dimensional which was intentional since most measurements follow this form and it was decided to address the challenge of a unified approach for all planar techniques before addressing out-of-plane or three-dimensional strain systems.

The design and methodology for use of the standardised test materials were presented at the 4th International Conference on Advances in Experimental Mechanics[17] and are described in Part II of the SPOTS Standard which is being proposed as an ISO TTA (Technology Trend Assessment) through VAMAS and is available on the project website: www.opticalstrain.org.

Task 3.3 – Routes for traceability

The terminology on traceability, calibration chain and reference materials was clarified early in the project in order to allow the development of reference materials to proceed. These activities also forced an early discussion and decision on traceability for strain measurements being related to the unit of length, i.e. the metre and an overview of the issues is included in Part I of the SPOTS Standard and were presented at the 4th International Conference on Advances in Experimental Mechanics[18]. Subsequently a detailed report on traceability and the options that had been considered was prepared and is available on the project intranet site[‡]. An extract from the report is reproduced in Appendix III and is available on the project website: www.opticalstrain.org (**D15**).

4.5 Work Package 4: Verification and implementation

Objectives:

a) Identification of foci for work on optimisation of methodologies. (**M1**, **M14** & **D5**)

b) Verification of effectiveness of unified methodologies for use of reference materials and for measurement of stress and strain in engineering practice.

Task 4.1 – Round robins using classical problems

The goal was to conduct an initial round robin, in order to establish the sources and levels of variability in results arising from a lack of standardisation and unified methodologies. This was followed by a second round robin that was used to assess the effectiveness of the work performed in other work packages and to provide confidence in the outputs from the project.

A coupon (figure 4) was designed for the initial round robin which was intended to be simple in external form allowing it to be treated as a simple tensile test, but that had an intricate internal geometry so that the strain field could not be easily predicted thus creating a 'blind' test. Eighty percent of the partners completed the round robin and the results were published in a paper at the 12th International Conference on Experimental Mechanics held in Bari, Italy in August 2004[1] (**D5**).

A significant number of lessons were learnt from the exercise which assisted in the development of work in the other packages, particularly the development of reference materials. These lessons included:

[‡] www.sheffield.ac.uk/spots/members/ username: SPOTS and for the password contact the coordinator at e.a.patterson@sheffield.ac.uk

- the requirement for very simple geometries to allow effective comparisons. This outcome contributed to a recognition that standardised tests were required as well as reference materials.
- The difficulties associated with employing results from numerical modelling as the 'gold standard'. This conclusion has guided the design of virtual reference materials and standardised test towards strain fields for which there are an analytical descriptions.
- The difficulties associated with making effective comparisons between laboratories when the specimen has to be loaded via an independent machine or mechanism. This experience led directly to the concept of the monolithic physical reference material.

The first round robin would probably not be considered a success by all the participants since some large and unreconciled differences in results were observed between partners. However, the exercise certainly served its original purpose in highlighting the issues that needed to be addressed in the remaining work packages and from this perspective it was extremely successful.

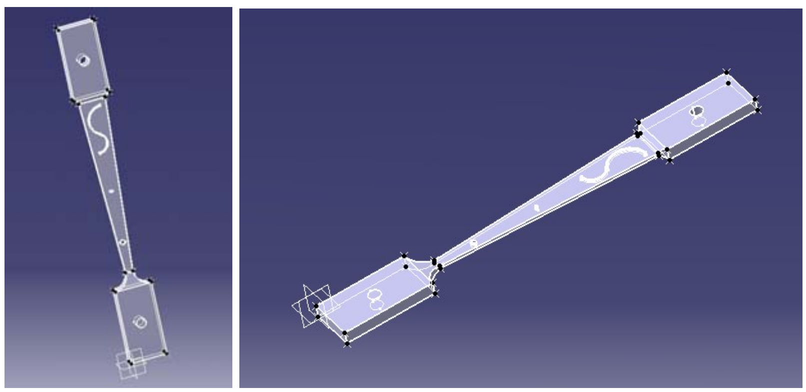


Figure 4 – Diagrams of the coupon used for the first round robin.

A second round robin was conducted in the second half of the project using the physical standardised test material shown in figure 3. ESPI, grating interferometry reflection and transmission photoelasticity, and thermoelasticity were applied. Specimens made of three materials (stainless steel, aluminium, and SLA polymer) with three different sizes of the disk (diameter of D=10, 50 and 100mm) were analysed. Once again 80% of partners participated and a wide range of results were obtained. The design philosophy of the standardised test material was based on the concept that it should provide challenges to the most advanced and sophisticated optical systems. This approach was taken so that the fitness for purpose of these systems could be assessed by designers, vendors and end-users. As a consequence its adoption for the second round robin presented an ambitious task for most techniques. Only reflection photoelasticity applied to the largest specimen generated good quality results in all the areas of analysis specified in the protocol and shown in figure 5. The other techniques utilised were not able to resolve the strain data in all of the areas. Whilst this decreased the value of the exercise as a round robin, it confirmed the usefulness of the physical standardised test material. A few minor modifications were made to the design following the completion of the second round robin and the methodology for use in Part II of the SPOTS Standard was refined. A report describing the complete results of the second round robin is available on the SPOTS intranet site[§] (**D16**) and is not reproduced here due its length.

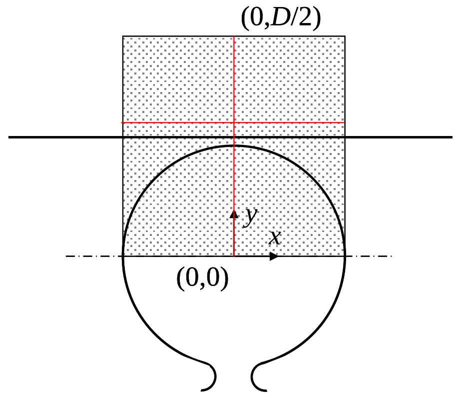


Figure 5 – Schematic of the gauge section of the standardised test material showing the data analysis area (grey shading) and the lines (red) along which strain data was compared.

Task 4.2 – Case studies on industrial problems

Three case studies from three industries were identified for study:

- A flip-chip to be supplied by OMI;
- A composite automotive component from CRF; and
- A friction stir weld joint from Airbus.

ESPI (ET), image correlation (OMI & ET), photoelasticity (SNECMA & USFD), and thermoelasticity (USFD & HOS) were selected for the strain analyses. Protocols for the tests were established and distributed together with the multiple samples by the partners who supplied the components. A complete report of these industrial studies has been prepared and is available on the project intranet site[§] (**D12**). It is planned to produce a paper for publication in the technical literature based on this report.

Task 4.3 - Feasibility study on data comparison with simulated results

The development of unified methodologies and standards gives rise to the opportunity for more rigorous validation of numerical results from simulations. This task involved a feasibility study on the development of a unified methodology for the comparison of results from experimental and numerical strain / stress analysis. This would be of significant benefit in assessing the viability of designs and could have a major impact on the acceptability of optical techniques in the design process. The task employed a literature study and a discussion session amongst interested partners to sketch out a unified methodology for the comparison of results from experimental and numerical strain analyses. It is believed that the recommended approach is feasible but it was beyond the scope of this project to demonstrate its efficacy. A full report is available on the project's intranet site[§] (**D17**).

4.6 Work Package 5: Dissemination activity

Objectives:

a) Adoption of outputs from project by international standard authorities. (**M9**)

[§] www.sheffield.ac.uk/spots/members/ username: SPOTS and for the password contact the coordinator at e.a.patterson@sheffield.ac.uk

b) Widespread use of outputs by EU industrial base and their trading partners. (**M15**)

c) Establishment and maintenance of a project web site. (**D1**, **M3** & **M4**)

Task 5.1 – Contribution to international standards

The SPOTS project has been registered as a project within VAMAS (Versailles Project on Advanced Materials And Standards) by TWA26 (Technical Working Area No. 26) and the production of a draft ISO TTA (Technology Trends Assessment) based on part I, II and III of the SPOTS Standard has been proposed. The SPOTS Standard has been independently reviewed by Professor Jim McKelvie of the University of Strathclyde in order to provide consistency across a document that has evolved through many revisions with contributions from multiple authors. After the completion of the SPOTS project, the documents will be forwarded to TWA26 which will arrange an international review and encourage participants in the review to conduct experiments with the reference material and standardised test materials. Following a successful review by TWA26 the revised documents will be passed to VAMAS for approval and submission to ISO. This process is likely to take twelve to eighteen months beyond the end of the SPOTS project (**D18**).

NPL has kept CEN and NIST (National Institute of Standards) informed of the likely outcomes of the project. The addition of Airbus UK to the consortium has allowed the chairman of TWA26 of VAMAS, Dr R.L. Burguete to formally join the PSC (Project Steering Committee). Through TWA26 contact with ASTM is being maintained and wider dissemination to the international standards community is being achieved. The co-ordinator has attended both ASTM and JSME (Japanese Society for Mechanical Engineering) meetings during the project and presented some of its results. During these meetings standards in the field of optical strain measurement were discussed and it is clear that the European activity is leading developments in this area.

Task 5.2 – Dissemination to EU industrial base

At the beginning of the project it was decided that in year 1 the consortium should focus on developing its philosophy, analysing the issues and developing a strategy for gaining acceptance of its solutions; that in year 2 the focus should be on educating the community about the standardisation processes and potential benefits and then to promulgate and promote the results in year 3. Following this approach, a programme of dissemination through publication in the literature and attendance at conferences and exhibitions was developed. A complete list of these activities is provided in Appendix 4 (**D19**).

The major activities were special SPOTS sessions organised at the 12th International Conference on Experimental Mechanics in Bari, Italy during August 2004 and the 4th International Conference on Advances in Experimental Mechanics in Southampton, UK in September 2005. At both conferences a booth was taken in the conference exhibition hall, and live demonstrations of the physical reference material and standardised test materials were performed. A special leaflet was printed and distributed at these conferences and others attended by SPOTS partners. Four papers were presented in Bari[1,16,17,19] and three in Southampton[11,18,19] and there were large audiences in both locations.

In addition, conference papers were presented at ASTM and SEM (Society for Experimental Mechanics)[20] meetings in the USA and at a number of European meetings in order to achieve a wide dissemination and, at this stage, acceptance of the need for standards and reference materials.

A set of archived journal papers are being planned based on the outputs from the project. The list is included in Appendix 4 and the manuscripts will be written in 2006.

It is anticipated that some of the industrial partners will adopt the SPOTS standard as an internal, company standard. Airbus and CRF have indicated their intention to initiate this process.

Task 5.3 Website management

An internet site was established for the project and the domain names www.opticalstrain.org and www.opticalstrain.com purchased for ten years from 2005 on behalf of the consortium. The site has been populated with the outputs from the project in accordance with the work description (**D1**). A secure intranet site was also established at www.sheffield.ac.uk/spots/members** where project documents and other relevant information have been lodged. This site will be maintained for at least twelve months after the end of the project. The contents of both websites are available on CD-ROM from the co-ordinator.

** The username is SPOTS and the password can be obtained from the project co-ordinator: e.a.patterson@sheffield.ac.uk

5. LIST OF DELIVERABLES

	Description	Due Month	Month Completed	Availability
D1	Project description on website	6	6	See www.opticalstrain.org
D2	Six month technical progress report	6	7	Management report attached as Annex IV to 12 month report (see D6)
D3	Recommendations for data formats published on website	8	8	See www.opticalstrain.org
D4	Recommendations for the adoption of pre-existing technical notes/guidelines as standard methodologies	11	11	Report in the form of standard guides attached as Annex II in 12 month report (see D6).
D5	Results of initial round robin on classical geometry and load	12	13	Report attached as Annex V to 12 month report (see D6)
D6	Twelve month technical progress report	12	13	Document submitted to EU and available on intranet[††]
D7	Specification of physical reference material on website	18	18	Design report attached as Annex II to mid-term report (see D8) also available in Part 1 of SPOTS Standard on www.opticalstrain.org.
D8	Mid-term report	18	19	Document submitted to EU and available on intranet[††].
D9	Specification of virtual reference materials published on website	24	24	Available in Part 1 of SPOTS Standard at www.opticalstrain.org.
D10	Six monthly technical progress report (end of yr 2)	24	25	Document submitted to EU and available on intranet[††].
D11	Draft methodologies for measurement published on website	25	25	Available as Part III of SPOTS Standard at www.opticalstrain.org.
D12	Results of case studies on industrial problems	30	30	Report attached as Appendix 4 to month 30 report (see D13) and available on project intranet[††].
D13	Six monthly technical progress report	30	31	Document submitted to EU and available on intranet[**].
D14	Draft methodologies for use of reference materials published on website	31	31	Available in Part 1 of SPOTS Standard at www.opticalstrain.org
D15	Possible routes for traceability for calibration of systems published on website	33	33	See www.opticalstrain.org for an extract and a full report available on project intranet[††].
D16	Results of second round robin	34	36	Report available on project intranet[††].
D17	Feasibility study on data comparison methodologies	34	34	Report available on project intranet[††].

[††] www.sheffield.ac.uk/spots/members/ username: SPOTS and for the password contact the coordinator at e.a.patterson@sheffield.ac.uk

D18	Information exchanged with VAMAS TWA26 members	36	37	SPOTS Standard Parts I, II & III submitted to TWA26 for reviewed & approval by VAMAS. Documents available at www.opticalstrain.org
D19	Publications on unified methodology in trade and professional literature	36	36	List of dissemination activities attached to this report as Appendix 4. List of publications available at: www.opticalstrain.org
D20	Outline project report on website	36	37	This report available on website at www.opticalstrain.org
D21	Final report	36	38	This document (note D20).

6. COMPARISON OF INITIALLY PLANNED ACTIVITIES AND WORK ACTUALLY ACCOMPLISHED

All the planned activities have been completed. In addition to the planned activities a set of standardised test materials have been designed and tested. This is a significant additional contribution and falls within the philosophy of the project objectives to provide the means to calibrate and evaluate optical systems for strain measurement. The outputs of the project have been disseminated in the usual way via conference presentations, the scientific literature and a website (www.opticalstrain.org) but in addition a proposed draft ISO TTA (Technology Trend Assessment) has been prepared because this was seen as the most effective way of achieving a significant and lasting impact on the technical community.

7. MANAGEMENT AND CO-ORDINATION ASPECTS

Seven meetings of the complete consortium have been held, i.e. a kick-off meeting in Sheffield UK, a mid-term meeting in Warsaw, Poland, a final meeting in Ispra, Italy and six-monthly progress meetings in: Ispra, Italy; Elchingen Germany; Cork, Eire; and Paris, France. In addition, seven brain-storming meetings on the development of reference materials and standardised tests involving Airbus, EMPA, ET, JRC and USFD have been held in: Bristol, UK; Brussels, Belgium; Dubendorf, Switzerland; Ispra & Bari, Italy; Greifensee, Switzerland; and Paris in July 2003, October 2003 and January 2004, August 2004, January 2005 and May 2005 respectively. Whenever possible these brain-storming meetings were appended to other meetings. To help ensure that the project finished in timely manner, an interim progress meeting was held during the last six months in Southampton during the 4th International Conference on Advances in Experimental Mechanics.

A secure intranet site (www.sheffield.ac.uk/spots/members) was established for the project and is the principal means of disseminating information within the consortium. The username is 'SPOTS' and a password can be obtained from the project coordinator.

All partners appear to have remained motivated to complete the project and achieve the objectives. The contributions of personnel at EMPA, JRC and ET are particularly noteworthy for their dedication to the development of the SPOTS standard. Some difficulties with the availability of instrumentation for strain analysis at CRF inhibited their contributions until the later stages of the project and led to the Project Steering Committee reallocating some funds assigned for CRF in the first round robin to USFD for reviewing of the SPOTS Standard. The lack of attendance by personnel from NPL at crucial meetings in Cork and Southampton created significant difficulties for the second round robin and undermined its potential impact. As consequence the second round robin ran slightly late but a draft report was available for discussion at the final meeting at the beginning of December 2005.

Table 1 (Appendix 5) provides the manpower allocation, both actual and scheduled for each task and partner. Three changes have been made with the approval of the project steering committee and with no cost implications for the EU. These are as follows:

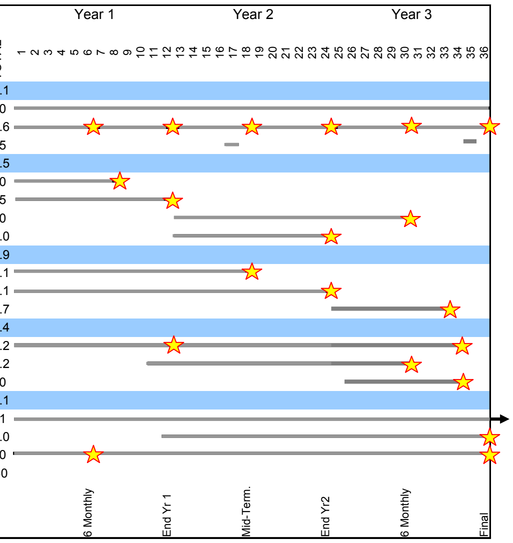
- Airbus UK joined the project with effect from the beginning of month 13 (1st January 2004) and made contributions to all work packages except WP2. They have not received any funding from the EU and their contribution is self-funded.

- For OMI 0.5 man-months has been moved from task 2.1 to 2.2 in order to allow image correlation to be considered as a core technique in task 2.2.
- EMPA's commitment was reduced from 13 to 10 man-months by Swiss authorities and included dropping out of the second round-robin and focussing on the feasibility study (task 4.3) and traceability (task 3.3). They have not received any funding from the EU and their contribution is self-funded.
- For CRF 2 man-months were removed from task 2.2 and reallocated to USFD to allow an independent review of the standard guides to be commissioned.

Table 2 shows the original and updated work plan. All tasks proceeded according to plan and all deliverables and milestones have been completed. Technical and financial reports have been delivered on time to the EU but there has been a considerable in the receipt of payments from the EU following the mid-term report.

Table 2: Original work plan updated to show man-month changes for CRF, EMPA OMI, USFD and the addition of AIRBUS. Completed deliverables are shown as gold centred stars and outstanding ones at 100% red. Grey lines indicated proportion of task completed and black lines proportion outstanding.

WP / Task Nr.	Task Title	Partner Man Months											
		USFD	OMI	ET	JRC	NPL	SNECMA	HOS	PW	CRF	EMPA	AIRBUS	TOTAL
1	**Project Coordination**	8.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.6	17.1
1.1	Financial coordination	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
1.2	Technical coordination	4.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.6	13.6
1.3	Technology Implementation	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
2	**Optim. of methodologies**	9.0	2.0	7.0	0.0	2.0	2.5	0.0	8.0	3.0	0.0	2.0	35.5
2.1	Definition of data formats	0.0	2.0	2.0	0.0	2.0	0.0	0.0	1.0	2.0	0.0	0.0	9.0
2.2	Inc. existing guidelines	2.0	0.0	1.0	0.0	0.0	0.5	0.0	4.0	0.0	0.0	0.0	7.5
2.3	Ref. materials methodologies	2.0	0.0	2.0	0.0	0.0	0.0	0.0	2.0	1.0	0.0	0.0	7.0
2.4	Measurement Methodologies	5.0	0.0	2.0	0.0	0.0	2.0	0.0	1.0	0.0	0.0	2.0	12.0
3	**Develop. of ref. maters.**	23.0	2.0	8.0	3.0	2.0	0.0	0.0	3.0	0.0	3.5	0.4	44.9
3.1	Physical reference materials	9.0	1.0	3.0	2.0	2.0	0.0	0.0	1.0	0.0	0.0	0.1	18.1
3.2	Virtual reference materials	9.0	0.0	3.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.1	14.1
3.3	Routes for traceability	5.0	1.0	2.0	0.0	0.0	0.0	0.0	1.0	0.0	3.5	0.2	12.7
4	**Verification & implem.**	3.0	3.0	7.0	3.0	2.0	4.0	2.0	3.0	11.0	5.0	0.4	43.4
4.1	Round robins	1.0	1.0	3.0	3.0	2.0	2.0	0.0	2.0	7.0	1.0	0.2	22.2
4.2	Case studies	1.0	2.0	3.0	0.0	0.0	2.0	2.0	1.0	4.0	0.0	0.2	15.2
4.3	Feasibilty study	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	6.0
5	**Dissemination activity**	3.0	1.0	1.0	1.0	1.0	0.5	7.0	1.0	2.0	1.0	0.6	19.1
5.1	Contribution to int. standards	1.0	0.0	0.0	0.5	0.0	0.0	1.0	0.0	1.0	0.0	0.6	4.1
5.2	Dissem. to EU industry	1.0	1.0	1.0	0.5	1.0	0.5	6.0	1.0	1.0	1.0	0.0	14.0
5.3	Website management	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
	TOTALS (man-months)	46.0	9.0	24.0	8.0	8.0	8.0	10.0	16.0	17.0	10.0	4.0	160
	Reports												



8. RESULTS AND CONCLUSIONS

All aspects of the project have been completed according to plan and two additional, unplanned contributions have been made: the design of standardised test materials and the preparation of a proposed ISO TTA (Technology Trend Assessment). One deviation from the work description was discussed and agreed by the consortium, namely the substitution of image correlation in place of shearography in the list of techniques being considered.

Airbus UK joined the consortium with effect from the beginning of month 13. They have made contributions to all work packages except WP2 as shown in the revised programme of work in table 2. Although the man-month contribution is relatively small, the technical contribution has been significant because Airbus is a major and innovative end-user of optical strain measurement techniques and represented a new sector for the consortium, namely airframes.

Three major factors contributed to the success of project:

- The blend of partners from across the spectrum of innovation from research laboratories including national labs, through instrument designers, manufacturers and vendors to end-users in the aerospace, automotive and electronics industries. It should be noted that the same blend was achieved in miniature for the brain-storming sessions which were a key part of the innovation process in the project.
- The use of the brain-storming sessions guided by the rational decision making process to guide the development of highly innovative designs for the reference materials and standardised test materials.
- The dedication and team spirit of the personnel from the partners.

The key results from the project are listed below:

- Recommendations for data formats (D3): A set of recommended data formats for image data, numerical data, and processed data have been developed. The range of optical techniques available for assessing strain and stress is broad and the techniques are diverse in nature. Since neither stress nor strain are quantities that can be measured directly all techniques are based on measurements of deformation and, or displacement of materials. Consequently, a plethora of formats have been introduced for presenting data, which makes comparisons difficult or impossible. The adoption of the recommended data formats is expected to facilitate data exchange and comparison between techniques and between organisations on a pan-European scale. The recommendation is published on the project website: www.opticalstrain.org.
- Optimised methodologies for measurement of strain (D4, D11): the diversity of optical techniques implies that the results can be dependent on the method used to acquire data. A set of draft standard guides have been generated for the following techniques: ESPI, grating interferometry, photoelasticity, image correlation, and thermoelasticity. The draft standard guides for photoelasticity and grating interferometry are based on existing guidelines and technical notes. The set of standard guides provide recommendations for best practice and optimised methodologies for the measurement of strain. They should lead to better quality of data being generated, so that engineering decisions are better informed. The target areas are all industries concerned with load-

bearing components, from turbine blades to oil rigs. The standard guides have been incorporated as part 3 of a proposed ISO TTA document (see www.opticalstrain.org).

- Round robin results (D5, D16): some of the results of the round robins are being published in the scientific and engineering literature. The results have had a significant impact on the directions taken in the design and development methodologies for the use of the reference materials and standardised test materials. Reports in the round robins are available on the project intranet site[‡‡].

- Specification of reference materials (D7, D9, D14): Physical and virtual reference materials for use in the calibration of optical systems for strain measurement have been designed and tested. The design details and methodologies for use of the reference materials have been incorporated as part 1 of a proposed ISO TTA document. In addition, two standardised test materials with associated standardised data sets have been developed for the evaluation of optical systems and their component hardware and algorithms. The design details and methodologies for use of the standardised test materials have been incorporated as part 2 of a proposed ISO TTA document (see www.opticalstrain.org).

- Industrial case studies (D12): the utility of the reference materials and standard guides have been demonstrated via a set of industrial case studies which are being disseminated through the technical and scientific literature. A report on these case studies is available on the project intranet site[‡‡] and a paper is being prepared for the scientific literature.

- Possible routes for traceability for calibration (D15): confidence in the reliability and accuracy of a measuring system is in part derived from the ability to demonstrate or calibrate its performance against norms or reference materials, which are themselves founded on reliable, calibrated sources. The route through which the calibration of the reference material can be traced is not straightforward for strain, which is a relative change in length, and hence is not measured but derived from some other measurement e.g. birefringence and optical path length. Possible routes for traceability for calibration of systems have been studied and a recommendation made to employ the standard metre as the primary standard for strain measurement. This recommendation is on the project website and has been promoted as internationally acceptable norm via international conferences. A section on the subject is included in the proposed ISO TTA document (part 1) (see www.opticalstrain.org).

- Feasibility study on data comparison methodologies (D17): This study makes a number of recommendations related to the comparison of detailed maps of data obtained from optical measurement systems and from computer-based numerical techniques. Good practice is highlighted and further work is identified to develop an acceptable approach that would be widely adopted in engineering applications. A report is available on the project intranet site[‡‡] and a paper is being prepared for the scientific literature.

[‡‡] www.sheffield.ac.uk/spots/members/ username: SPOTS and for the password contact the coordinator at e.a.patterson@sheffield.ac.uk.

Optical techniques provide a non-contacting approach to the assessment of the behaviour of components and structures under load including assembly and, or manufacturing stresses. Confronted by uncertainty about true loading conditions and by the demand for 'quality' – reliability, comfortable ride and safety – many engineers retain their conservative design factors for load bearing components and seek reductions or efficiencies elsewhere. Optical techniques can play a valuable role in evaluating in-service behaviour under load thus removing a level of uncertainty and allowing the creation of more efficient designs. The aerospace industry has been perhaps the most ardent supporter amongst end-users for research that has lead to recent advances in full-field optical techniques of strain measurement. The techniques are able to contribute to the critical technologies of design, manufacture, quality control, structures and materials application, and propulsion. Similar benefits will apply to all products and processes involving load-bearing components. The range is vast extending from art frescos to prosthetic heart valves, so that the subject of the project represented a 'cross-cutting generic materials technology' with multi-sectorial applications involving materials being used more efficiently.

9. ACKNOWLEDGEMENTS

The support of the project's first EU scientific officer, Mauro Facchini is gratefully acknowledged. His interest and faith in our approach was a significant benefit in the earlier stages of the project. The support of the conference organisers in Bari and Southampton, Carmine Pappalettere and Janice Dulieu-Barton respectively is also gratefully acknowledged. They enabled us to both hi-jack their conferences to hold special SPOTS sessions and to have a booth in prime positions in their exhibition halls. Funding for EMPA through the Swiss Federal Office for Science and Education is gratefully acknowledged

10 REFERENCES

1 Mendels, D. –A., Hack, E., Siegmann, P., Patterson, E.A, Salbut, L., Kujawinska, M., Schubach, H.R., Dugand, M., Kehoe, L., Stochmil, C., Brailly, P., Whelan. M,. 2004, 'Round robin exercise for optical strain measurement', *Proc. 12th Int. Conf. Exptl. Mechanics, Advances in Experimental Mechanics* edited by C. Pappalettere, McGraw-Hill, Milano, pp.695-6
2 DIN 54180-1 (Jan. 1997): Zerstörungsfreie Prüfung – Shearografie – Teil 1: Allgemeine Grundlagen *(Document "DIN 54180-Teil 1.pdf").*
3 DIN 54180-2 (Jan. 1997): Zerstörungsfreie Prüfung – Shearografie – Teil 2: Geräte *(Document "DIN 54180-Teil 2.pdf").*
4 DIN V 54180-3 (März 1997): Zerstörungsfreie Prüfung – Shearografie – Teil 3: Prüfungen von Rohrleitungen *(Document "DIN 54180-Teil 3.pdf").*
5 ASTM F 1364 – 92 (Reapproved 1997): Standard Practice for Use of a Calibration Device to Demonstrate the Inspection Capability of an Interferometric Laser Imaging Non-destructive Tire Inspection System *(Document "ASTM_F1364.pdf").* ASTM International, West Conshohocken, PA, USA.
6 ASTM E2208-02 (2002) *Standard Guide for evaluating non-contacting optical strain measurement systems*, ASTM International, West Conshohocken, PA, USA.
7 Patorski, K., *The Handbook of the Moiré Fringe Technique*. Elsevier Oxford, 1993.
8 Post, D., Han, B., Ifju, P., *High sensitivity moiré – experimental analysis for mechanics of materials*. Springer-Verlag, Berlin, 1994.

9 Doyle, J.F., Phillips, J.W., (eds) *Manual on experimental stress analysis*, 5th edition, SEM, Bethel, CT., 1989.

10 Whelan, M., Hack, E., , Siebert, T., Burguete, R.L., Patterson, E.A., Saleem, Q., 2005, 'On the calibration of optical full-field strain measurement systems' *Proc. BSSM Int. Conf. on Advanced Experimental Mechanics, Southampton*, UK, published as *Applied Mechanics & Materials*, vols.3-4, pp.397-402.

11 Cross, N., *Engineering Design Methods*, John Wiley & Sons, London, 1989.

12 Olden, E.J., Patterson, E.A., 'A rational decision making model for experimental mechanics', *Experimental Techniques*, 24(4): 26-32, 2000.

13 ASTM C770-98, *Standard test method for measurement of glass stress-optical coefficient*, ASTM International, West Conshohocken, PA, USA.

14 ASTM C1377-97, *Standard test method for calibration of surface/stress measuring devices*, ASTM International, West Conshohocken, PA, USA.

15 Burguete, R.L., Hack. E., Kujawinska, M., Patterson, E.A., 2004, 'Classification of operation and processes in optical strain measurement', *Proc. 12th Int. Conf. Exptl. Mechanics, Advances in Experimental Mechanics* edited by C. Pappalettere, McGraw-Hill, Milano, pp.697-8.

16 Burguete, R.L., Hack, E., Siebert, T., Patterson, E.A., Whelan,M., "Candidate reference materials for optical strain measurement", *Proc. 12th Int. Conf. Exptl. Mechanics, Advances in Experimental Mechanics* edited by C. Pappalettere, McGraw-Hill, Milano, pp. 699-700.

17 Burguete, R.L., Hack, E., Patterson, E.A., Saleem, Q., Siebert, T., Whelan, M., 2005, 'Design of reference materials & standardised tests for optical strain measurement**'**, *Proc. BSSM Int. Conf. on Advanced Experimental Mechanics*, Southampton, UK, published as *Applied Mechanics & Materials*, vols.3-4, pp.403-408.

18 Hack, E., Burguete, R.L., Patterson, E.A., 2005, 'Traceability of optical techniques for strain measurement', *Proc. BSSM Int. Conf. on Advanced Experimental* Mechanics, Southampton, UK, published as *Applied Mechanics & Materials*, vols.3-4, pp.391-396.

19 Hack, E., Simms, G., , Mendels, D., 2004, 'Traceability, reference materials and standardised tests in optical strain measurement', *Proc. 12th Int. Conf. Exptl. Mechanics, Advances in Experimental Mechanics* edited by C. Pappalettere, McGraw-Hill, Milano, pp.693-4.

20 Burguete, R.L., Hack, E., Kujawinska, M., Patterson, E.A., Siebert, T., Whelan, M., 2005, 'Design of reference materials and standardised tests for optical strain measurement', *Proc. SEM Annual Conf. on Experimental and Applied Mechanics*, Portland, Oregon, USA, paper no 295.

APPENDICES

APPENDIX 1 - Recommended data format: extract from website (D3)

Task 2.1 – Definition of data formats

The definition of data formats is important to facilitate data exchange at all stages of the strain measurement and stress analysis process. The SPOTS partners have agreed on the use of the format described below during the course of the project, with the intention of recommending it for use in an international standard in the subject.

The standard format will be ASCII for the exchange of all types of data. The format of the ASCII file is given below, with the format shown on the left and an example provided on the right. For visualisation purposes only, 8-bit BMP files may also be used exchanged. The use of a header should be compulsory, but that it should provide the minimum information required for data exchange. The primary concern of the user will be to read the file. In additional information required for validation and detailed interpretation could be included in a log file whose details would be given in the header.

To assist the user a pair of software tools are provided to build (SPOTSBuilder) and read (SPOTSReader) the standard data set. These are provided without instructions though their use should be intuitive especially to LabView users. The SPOTS partners accept no liability for the use or consequences arising from the use of SPOTSBuilder and SPOTSReader.

Standard File Format for Data Exchange

Description of line in file	Example of file content
File Descriptor	This is my excellent data
Measurand (e.g. intensity, phase, displacement, strain)	shear strain
units of measurand (AU-arbitrary units for intensity)	m/m
no. of pixels in each row	5
no. of pixels in each column	10
pixel pitch at sample plane in row (units: m)	±0.001E±00
pixel pitch at sample plane in column (units: m)	0±0.012E±00
transformation matrix for local to global axes	1 1 1 0
r_{11} r_{21} r_{31} t_1	
r_{12} r_{22} r_{32} t_2	1 1 1 0
r_{13} r_{23} r_{33} t_3	1 1 1 0
Fixed last line of transformation matrix	0 0 0 1
End Of Header	EOH
Data in rows with single space delimiters. Masks indicated by 'NAN'. Origin defined at bottom left corner.	±0.000E±00 ±0.000E±00 ±0.000E±00 ±0.000E±00 ±0.000E±00
	±0.000E±00 ±0.000E±00 ±0.000E±00 ±0.000E±00 ±0.000E±00
	±0.000E±00 ±0.000E±00 ±0.000E±00 ±0.000E±00 ±0.000E±00
	±0.000E±00 ±0.000E±00 ±0.000E±00 ±0.000E±00 ±0.000E±00
	±0.000E±00 ±0.000E±00 ±0.000E±00 ±0.000E±00 ±0.000E±00
	±0.000E±00 ±0.000E±00 NAN ±0.000E±00 ±0.000E±00
	±0.000E±00 ±0.000E±00 ±0.000E±00 ±0.000E±00 ±0.000E±00
	±0.000E±00 ±0.000E±00 ±0.000E±00 ±0.000E±00 ±0.000E±00
	±0.000E±00 ±0.000E±00 ±0.000E±00 ±0.000E±00 ±0.000E±00
	±0.000E±00 ±0.000E±00 ±0.000E±00 ±0.000E±00 ±0.000E±00
End Of File	EOF

home

APPENDIX 2 – Paper presented at 4th International Conference on Advances in Experimental Mechanics, 6th-8th September 2005 and published in Applied Mechanics and Materials, vols. 3 & 4, p.397-402.

On the Calibration of Optical Full-field Strain Measurement Systems

Maurice Whelan[1], Erwin Hack[2], Thorsten Siebert[3], Richard Burguete[4],
Eann Patterson[5], Qasim Saleem[5]

[1] Institute for Health and Consumer Protection, European Commission DG Joint Research Centre, 21021 Ispra (VA), Italy. maurice.whelan@jrc.it

[2] Laboratory of Electronics & Metrology, EMPA Duebendorf, Ueberlandstrasse 129, CH-8600 Duebendorf, Switzerland. erwin.hack@empa.ch

[3]Dantec Ettemeyer GmbH, Kaesbohrerstr. 18, D-89077 Ulm, Germany. thorsten.siebert@dantec-ettemeyer.com

[4] Airbus UK, New Filton House, Filton, Bristol, BS99 7AR, UK. richard.burguete@airbus.com

[5] Department of Mechanical Engineering, University of Sheffield, Mappin Street, Sheffield, UK. e.a.patterson@sheffield.ac.uk, q.saleem@sheffield.ac.uk

Keywords: calibration, optical, strain, measurement

Abstract. There are no standard reference materials suitable for the calibration of full-field optical strain measurement systems. This is hindering the uptake of the technology by industrial end-users since optical metrology instrumentation and procedures cannot be easily integrated into quality assurance systems. The EU-funded SPOTS project is developing a physical reference material (PRM) and measurement protocol that should provide the basis of a calibration standard for establishing the traceability of strain values obtained with optical devices. This paper describes a PRM based on a parametric design of monolithic four-point bend test that can reliably generate a known strain field over a range of specimen sizes. Measurements acquired from strain gauges and LVDTs compared well with data obtained from ESPI, digital image correlation, photoelasticity and thermoelasticity studies, demonstrating excellent repeatability and inter-laboratory reproducibility.

Introduction

Calibration is a fundamental requirement in metrology. The calibration process allows a measurement to be traced back to a primary standard and therefore must be considered if metrology instrumentation and procedures are to be integrated into certified quality assurance systems. In the field of optical strain measurement, however, there is a significant lack of standards and reference materials suitable for calibration purposes. To address this, the EU-funded SPOTS project [1] aims to develop reference materials and protocols that can be used to calibrate and characterise instruments during production and while in-service. Ultimately these reference materials and protocols should provide the basis of a calibration standard that establishes the traceability of strain values obtained with optical devices [2]. The objective is to produce calibration materials which are applicable to a number of optical techniques including ESPI, digital image correlation, moiré, grating interferometry, photoelasticity and thermoelasticity.

This paper describes the development of a physical reference material (PRM) that generates a known strain field in a defined gauge-zone as a function of an applied displacement. An iterative design process was adopted involving analytical, computational and experimental mechanics techniques in order to reduce possible sources of experimental uncertainty and to simplify the manufacturing process. Experiments conducted with the PRM involved both traditional electrical sensors (i.e. strain gauges and LVDTs) and four different full-field optical techniques.

Design of a Physical Reference Material for Calibration Purposes

A rational decision making approach was adopted to guide the definition and development of the reference material [3]. It involved a number of steps including the identification and weighting of desirable and essential attributes and the development and evaluation of candidate designs. After an extensive consultation with project partners and the wider experimental mechanics community [3], four essential attributes were identified for the PRM, namely, it should provide easy optical access, exhibit no hysterisis, produce an in-plane (2D) strain field and be traceable to international standards via length. These attributes formed the basis of a set of design constraints within which various design concepts were elaborated, leading to the specification of an initial design. The overall development route is illustrated in Fig. 1 and consisted of an iterative process involving analytical, experimental and computational mechanics (FEM) analyses.

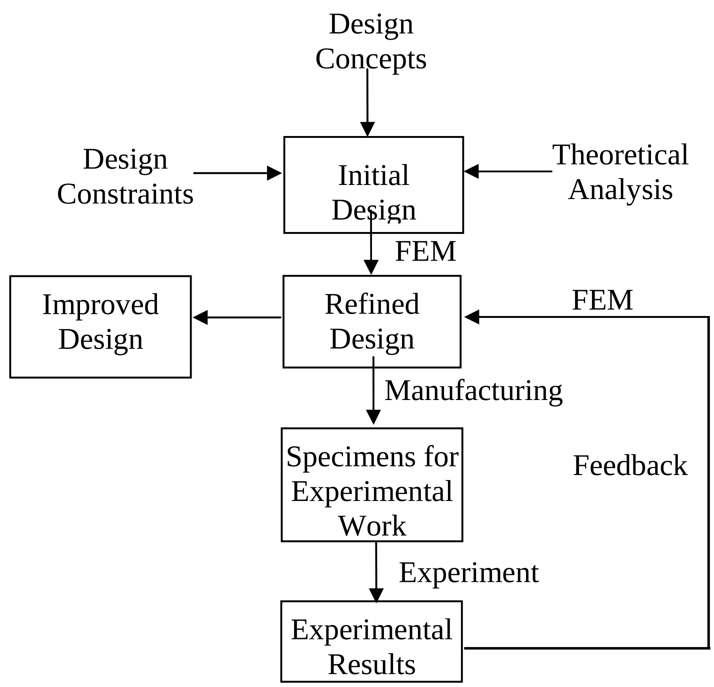


Fig. 1 Flowchart describing the development route for the physical reference material.

A number of designs were proposed during brainstorming sessions [3] which led to the selection of a four-point bending geometry, a modified Brazilian disk and a Hertzian contact-pair as the favoured candidate physical reference materials. The four-point bend test was preferred because the basic geometry of the specimen and the simple strain field it generates were considered more suitable for calibration purposes. Such a model has also been used in existing standards for optical measurements [4]. However, a major concern of the project partners was the lack of repeatability and reproducibility of the loading and constraint conditions often arising with even basic test setups. This led to the concept of a self-contained 2D monolithic design incorporating both a loading frame and the beam specimen in order to eliminate misalignment or positioning errors and to facilitate easy and precise fabrication. Schematic and solid-model drawings of the first version of the monolithic PRM are shown in Fig. 2. The design is parametric in that every key dimension is a function of the beam width, *W*. Varying *W* scales the model proportionately allowing specimens to be easily produced in a range of sizes, from the micro to macro. A detailed design drawing and explanatory notes are available on the SPOTS website [1].

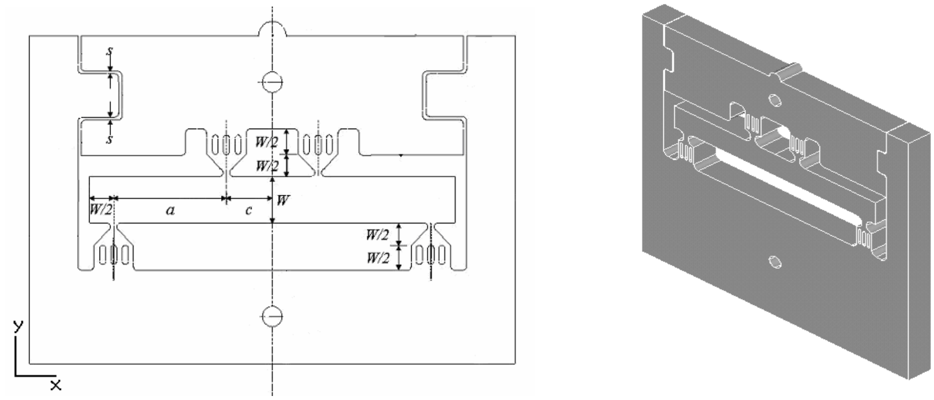


Fig. 2 Schematic and solid-model drawings of the monolithic PRM specimen. Certain important dimensional parameters and the chosen co-ordinate system are also shown.

The monolithic design ensures a high degree of alignment and eliminates any slip or friction phenomena. To achieve this, however, an alternative to knife-edges or rollers for loading and constraining the beam had to be devised. Whiffletrees were the chosen solution since although they allow the interface between the beam and frame to remain continuous, the rotational and lateral stiffness of a whiffletree joint can be minimised with careful design of its strut elements. A detailed FE analysis was carried out to minimise the generation of lateral forces and moments at the joints while avoiding any yielding or buckling.

The upper beam of the loading frame was designed to incorporate a simple interlock feature that serves to limit the maximum deflection of the beam in both tension and compression. The limit is reached when the applied displacement closes the gap *s* (Fig. 2). Consequentially, the maximum strain occurring in the beam can be limited, protecting it from overloading. The flat platen on the lower surface and a central half-cylinder on the otherwise flat upper surface facilitate easy alignment and a centrally applied load in compression. Two holes on the vertical axis of symmetry support tensile loading. The frame surrounding the beam has a high relative stiffness to resist bending deformations both in compression and tension.

The region of the reference material intended for use in a calibration procedure (gauge-zone) is located in the central section of the beam, between the two inner loading points. Simple beam theory can be used to derive expressions for the strain components and their gradients in this region, in terms of both applied load and displacement, as follows;

$$e_{xx} = \frac{-6\,a\,F\,y}{E\,B\,W^3} = \frac{-y\,d}{6W^2}, \qquad e_{yy} = \frac{-\nu\,y\,d}{6\,W^2}, \qquad e_{xy} = 0, \tag{1}$$

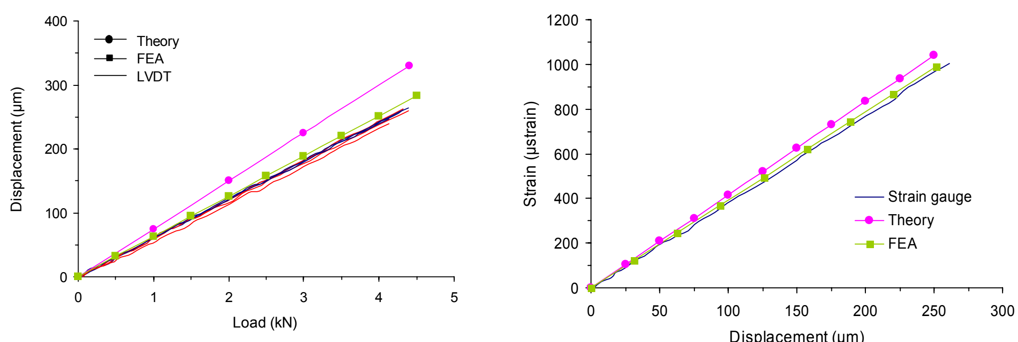
$$\frac{\partial e_{xx}}{\partial y} = \frac{-6aF}{EBW^3} = \frac{-d}{6W^2}, \quad \frac{\partial e_{yy}}{\partial y} = \frac{-\nu\,6\,a\,F}{EBW^3} = \frac{-\nu\,d}{6W^2}, \tag{2}$$

where *F* is the applied load, *d* is an applied displacement to the inner loading points, *E* is the Young's Modulus of the beam material, *v* is Poisson's ratio, *W* is the width of the beam, *B* is the thickness of the beam, and *a* is the distance between the inner and outer loading points. The co-ordinate system adopted is shown in Fig. 2 and the origin was chosen as the centre of the beam.

Experimental Investigation

Initial Design. Once the initial concept of the PRM (Fig. 2) had been refined using FE analysis, three specimens were produced from aluminium (E= 72 GPa, ν = 0.3). Two specimens had a beam width (*W*) of 20 mm while the third was produced with a beam width of 29 mm. Both had a thickness equal to their width (i.e, *B* = *W*). Each specimen was tested by a different partner using a variety of measurement techniques, both optical and non-optical. The results obtained were then compared with data from theoretical and FE analyses. The main objectives of this initial investigation were i) to determine how favourably measurements made by different partners on different specimens compared, and ii) to assess how similar the strain field generated in the gauge-zone was to the theoretical four-point bending beam solution.

For the first test specimen (*W* = 20 mm), a strain gauge rosette was bonded on the underside of the beam at the centre to measure strain in the longitudinal direction (e_{xx}). Two displacement transducers (type LVDT) were also mounted on the upper section of the specimen frame to accurately measure applied displacement (*y* direction). The specimen was placed on a mechanical testing machine and loaded in compression. The test was repeated three times, the specimen being removed, replaced and realigned each time. The results obtained are shown in Fig 3. The measurements made were very repeatable and both the load-displacement and displacement-strain relationships exhibited a high degree of linearity. The experimental data compare very well with the FEA but less so with theory. The results indicated that the stiffness of the beam constrained within its monolithic frame was higher than that predicted by simple four-point bending theory.



(a) (b)

Fig. 3 Load-displacement (a) and displacement-strain (b) responses obtained for the specimen instrumented with a strain gauge rosette and LVDTs.

The second specimen (*W* = 20 mm) was also tested in compression but in this case Electronic Speckle Pattern Interferometry (ESPI) and Digital Image Correlation (DIC) were used to measure the complete strain field in the gauge-zone. Gradients of longitudinal strain in the vertical direction ($\partial e_{xx}/\partial y$) were then calculated from the optical strain data (Eq. 2), for various loading levels, and compared with theoretical and FE predictions. The results obtained are given in Fig. 4 and showed a good correspondence between the different measurement techniques used. The excellent comparison between ESPI and strain gauge data is particularly interesting since as mentioned above, these measurements were carried out in different partner laboratories on different specimens. The relationship between applied load and strain gradient (Fig. 4a) given by the experimental data did not follow the relationship predicted by theory but was closer to that calculated by the FEA. However, the experimental data compared very favourably with both theory and FEA in the case of the relationship between applied displacement and strain-gradient (Fig. 4b).

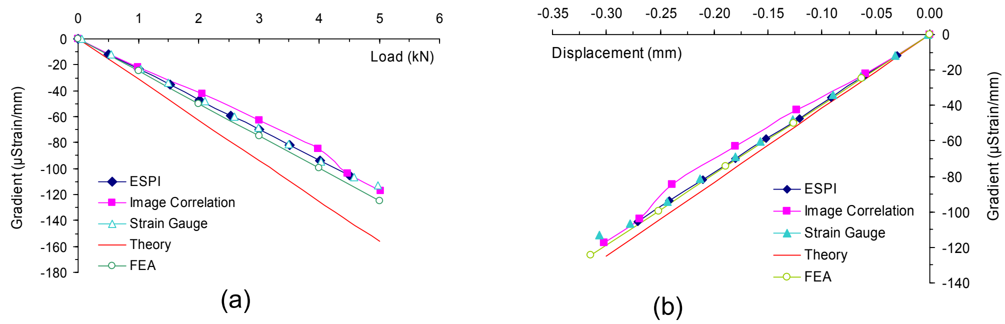


Fig. 4 Comparison of experimental (ESPI, DIC, strain gauge) and predicted (theory, FEA) values for applied load versus strain-gradient (a) and applied displacement verse strain-gradient (b).

The third specimen (*W, B* = 29 mm) was tested by a third partner but in this case Thermoelastic Stress Analysis (TSA) and Reflection Photoelasticity (RPE) were used to analyse the stress-strain field in the gauge-zone. For the TSA experiment, the specimen was cyclically loaded in tension between 0.3 and 8 kN at a frequency of 12Hz and the measurand considered was the sum of the principal stresses (SPS). In the RPE experiment, the specimen was loaded to maximum (i.e. closure of gap *s*) and the difference of the principal stresses was measured over the gauge-zone. In both cases the variation of the measurand in the vertical direction, along the beam centreline, was determined and compared with theoretical and FEA calculations, as shown in Fig. 5. As with the results presented for the first two specimens, the experimental data compared very well with the FEA but less so with theory.

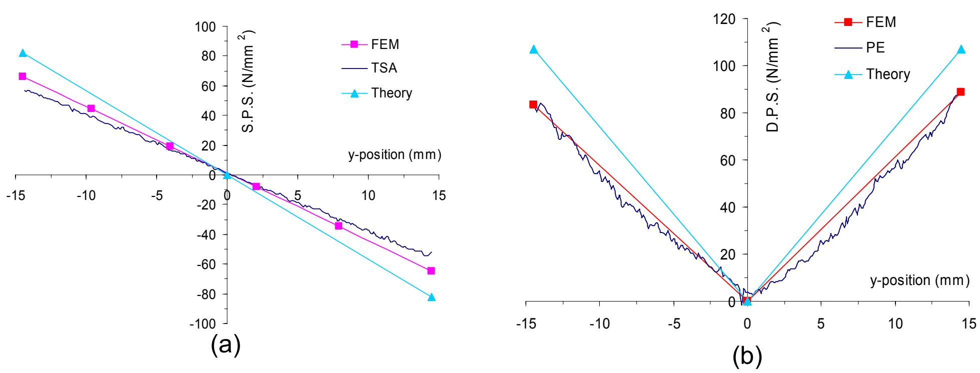
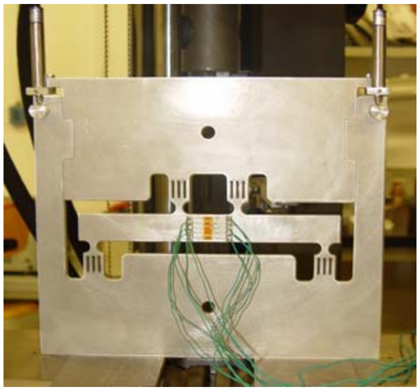


Fig. 5 Comparison of TSA data (a) - sum of the principal stresses, and PE data (b) – difference in principal stresses, with FEA and theory (*W, B* = 29 mm).

Refined Design. Encouraged by the promising results obtained for the initial PRM design, further refinements were proposed to bring the behaviour of the specimen closer to that of a theoretical four-point bend test. It was suspected that the beam was over-constrained and therefore the dimensions of the whiffletrees were altered to reduce their lateral and rotational stiffness. The thickness of the PRM was also reduced from *W* to *W/4*. This resulted is a 75 percent decrease in the load required to achieve the same strain levels as before and thus made it more practical to test large specimens on testing rigs of modest capacity. Finally, minor modifications were made to the upper section of the PRM to facilitate easier and more reliable attachment of displacement transducers.

After manufacture, the refined PRM was instrumented with five single-element strain gauges in the gauge-zone to measure longitudinal strain (e_{xx}) along the vertical axis (*y*). An image of the specimen is given in Fig. 6 (a) which shows the location of the strain gauges and the two LVDTs that were used to measure applied displacement. A simple compression test was performed to measure strain and applied displacement as a function of load. The test was repeated three times, the specimen being removed, replaced and realigned each time. Results obtained for displacement versus load are shown in Fig. 6 (b).



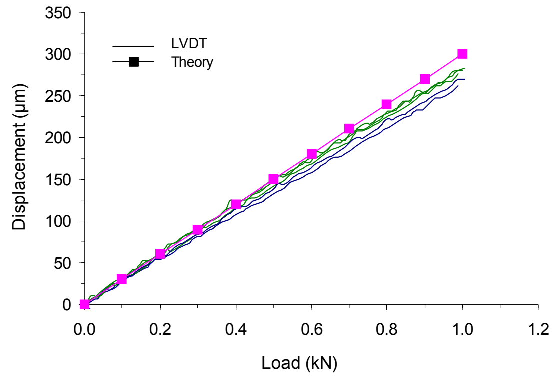


Fig. 6 Image of the refined PRM specimen (a) showing location of strain gauges and LVDTs. Results obtained for applied displacement versus load for three repeat tests (b).

Although the measurements were closer to the theoretically predicted response when compared with the earlier design, the scatter in the data acquired during the three repeat runs was significantly increased. This was attributed to the reduction in specimen thickness from 20 mm (*B* = *W*) to 5 mm (*B* = *W/4*) which had two undesirable effects, i) the specimen became more difficult to vertically align within the compression platens and ii) the specimen exhibited out-of-plane deflection when the alignment was not exact. The intention is to test the specimens in tension since these problems should not arise. The compression tests were postponed until a new specimen could be manufactured, this time with a thickness of 10 mm (*B* = *W/2*).

Conclusions

A design of monolithic four-point bend test has been proposed as a PRM for the calibration of optical strain measurement systems. Initial measurement from strain gauges, LVDTs and four different full-field optical methods compared very well and demonstrated excellent repeatability and inter-laboratory reproducibility. Minor refinements should deliver a PRM capable of reproducing a theoretically predictable strain field, thus simplifying the calibration process and allowing the production of calibration specimens at a range of sizes from the same parametric design.

References

[1] Standardised Project for Optical Techniques of Strain measurement (SPOTS), EU contract no. G6RD-CT-2002-00856, see www.opticalstrain.org.

[2] E. Hack, R.L. Burguete, E.A. Patterson, "Traceability of optical techniques for strain measurement", paper 61, Proc. Int. Conf. Adv. in Exp. Mech., Southampton, UK, September 2005.

[3] R.L. Burguete, E. Hack, T. Siebert, E.A. Patterson, M.P. Whelan, "Candidate reference materials for optical strain measurement", paper 145, Proceedings ICEM, Bari, Italy, 2004.

[4] ASTM C1377-97, Standard test method for calibration of surface/stress measuring devices, ASTM International, West Conshohocken, PA, USA.

APPENDIX 3 – Extract from project website describing possible routes for traceability of strain measurements (D15).

Possible routes for traceability of strain measurement.

Strain is related to deformation. Therefore, in order to realize a strain reference material, an instrument must be devised to deform a piece of material in a reproducible manner by applying a load. Any effect that causes a material deformation can be envisaged to provide a viable route for traceability. And because strain is a derived quantity, it must be connected to the value of load control by a simple mathematical relation, as exemplified by the accepted method for traceability of strain values in tensile testing. Here, strain is approximated by the average unit elongation in the direction of measurement, determined from total elongation ΔL of a selected gauge length L_0 by

$$\varepsilon = \frac{\Delta L}{L_0} \qquad \text{(a)}$$

In this simple one-dimensional, two-point case traceability is established by calibrating the devices for measuring elongation (e.g. extensometer calibration rig) and for measuring gauge length against a reference standard for the unit of length such as a laser interferometer or a gauge block, respectively. Mechanical deformation and tracing back strain measurement values to a length standard by using traceable gauge length and displacement values seems a natural choice.

However, less obvious traceability chains can be devised. Electrostrictive materials could be used to trace back strain values to the Volt using the voltage-strain relation; thermal expansion of a calibration body would allow tracing back strain values to the temperature scale. Table 1 compiles possible routes for traceability of strain values and indicates a simplified version of the mathematical description of the effect.

Table 1: Possible routes for traceability of strain values

Primary standard	Possible realizations, generation of strain field	Relevant equation
voltage	generate a strain field by electric field controlled deformation of an electrostrictive or piezoelectric material	$\varepsilon = Q \cdot E^2$
current	generate a strain field by current controlled magnetic field induced deformation of a magnetostrictive material	$\varepsilon = L \cdot H$
temperature	generate an in-plane displacement field by temperature controlled expansion of a body with linear CTE.	$\varepsilon = \alpha_{CTE} \cdot T$
angle	generate a strain field by angle controlled deformation of an elastic material (torsion rod).	$\varepsilon = \kappa \cdot \alpha$
length	generate a strain field by displacement controlled deformation of an elastic material (bending beam, tensile test specimen).	$\varepsilon = \kappa \cdot d$

Traceability to the unit of length

An important issue is acceptance of the traceability procedure. Traceability cannot just be claimed by a party; it must be accepted, either by virtue of the fact that an accepted standard agency sustains the calibration chain, or that the technique is accepted as traceable by virtue of its principle of operation. Accordingly, hooking strain values to the traceability chain of dimension would have a high acceptance.

The result of a query suggests that traceability to the unit of length is advisable and most likely to be accepted by the experimental mechanics community. This is both because strain is by definition intimately related to length (deformation) and because users are well-experienced in length- and deformation measurement. As soon as traceability is established SPOTS RM can be certified. An uncertainty budget relaxes the need of having the highest accuracy such as in a primary standard.

Mechanical deformation is favoured over thermal or electrical deformation as it allows to directly relate deformation to the length scale. The introduction of deformation is displacement controlled in order not to be influenced by force measurement. The PRM thus fulfills the requirement to "*reproduce, in a permanent manner during its use, one or more values of strain*". In addition, traceability to length is a natural choice for optical techniques that measure displacement from which strain is deduced.

APPENDIX 4 – SPOTS Dissemination Activities 2003-2005 (D19)

- DISSEMINATION through PUBLICATIONS in literature
- ATTENDENCE at CONFERENCES and EXHIBITIONS
- PLANS for 2006

Responsible Author : Michel Honlet, Honlet Optical Systems GmbH (= HOS)

Dissemination activities in 2003

CONFERENCE PRESENTATIONS (without publication of a paper) :

Date, Place : 17-18 September 2003 , ENPC Champs-sur-Marne (F)
Event : GAMAC Extensometry days 2003,
(GAMAC = French group for strain analysis methods)
Title : La photoélasticimétrie en temps réel: une ancienne méthode devenue moderne et dynamique. *(in French. TRANSLATED: Real-time photoelasticity), M. Honlet*

Typically, on such an occasion, HOS presented briefly in his presentation the existence of SPOTS, its target headlines, the consortium list and the project URL.

CONFERENCE PRESENTATIONS (with publication of a paper) :

Date, Place : 17.-21. November 2003, Belfort (F)
Event : CMOI (Club des Méthodes Optiques pour l'Industrie) 2003 *(annual conference)*
Title : SPOTS - Projet Européen de Prénormalisation pour la Mesure de Contraintes par Méthodes Optiques, held within session about Standardization and Quality.
(in French. TRANSLATED: European project for pre-standardization for strain and stress analysis with optical methods), Michel Honlet.

Dissemination activities in 2004

PUBLICATIONS IN LITERATURE OR MAGAZINES :

In **April 2004**, in the Special Issue "Optical and Thermal Methods" of INSIGHT, the monthly Magazine published by the British Institute of NDT, in the introductory comment written by *Michel Honlet of HOS*, the **existence and importance of SPOTS** was mentioned.

CONFERENCE PRESENTATIONS (without publication of a paper) :

Date, Place : 18-19. March 2004, Dresden (D)
Event : GESA (German Society for Experimental Analysis), subdivision of Photoelasticity
Title : SPOTS - EU-Projekt zur Vorbereitung von Normen für die Dehnungs- und Spannungsanalyse mit optischen Verfahren, *(in German. TRANSLATED: European project for pre-standardization for strain and stress analysis with optical methods), Michel Honlet.*

Date, Place : 4-6. May 2004, Albi (F)
Event : PHOTOMECANIQUE 2004-Bi-Annual Conference on Analysis in Experimental
Mechanics exclusively with Optical Methods
Title : SPOTS : EU project for standardization preparation for strain and stress Measurement (*in English*), *Michel Honlet.*
Booth: In parallel, a small booth was organized, in order to inform personally about SPOTS, both to conference attendees and equipment manufacturers and to distribute SPOTS leaflets.

Date, Place : 13-14. October 2004, Ulm (D)
Event : Dantec Ettemeyer International User Meeting 2004
Title 1: SPOTS - European Standardisation Project for Strain and Stress Analysis with Optical Techniques, *M. Honlet.*
Title 2: Physical Reference Materials for Standardisation of Optical Strain Measurements
Th. Siebert, M. Whelan, R. Burguete, E. Hack Q. Saleem, E. Patterson

---

Dissemination activities in 2004

CONFERENCE PRESENTATIONS (with publication of a paper) :

Date, Place : May 2004, Salt Lake City, Utah
Event : ASTM Symposium on Full-Field Optical Deformation Measurement: Applications and User Experience
Title 1: PHASE DERIVATIVE QUALITY GUIDED UNWRAPPING FOR PHOTOELASTIC ANALYSIS.
Philip Siegmann and Eann Patterson (University of Sheffield).
Title 2: PROCESS MAPS FOR OPTICAL STRAIN MEASUREMENT
Richard Burguete, Erwin Hack, Eann Patterson

Date, Place : 17-19. May 2004, Salzburg (A)
Event : Annual Conference of the German & Austrian & Swiss Societies for Non-Destructive Testing (=NDT)
Title : SPOTS: EU-Projekt zur Vorbereitung von Normen für die Dehnungs- und Spannungsanalyse mit optischen Verfahren. *(in german. TRANSLATED: European project for pre-standardization for strain and stress analysis with optical methods), Michel Honlet.*
Booth: In parallel, a small booth was organized, in order to inform personally about SPOTS, both to conference attendees and equipment manufacturers and to distribute SPOTS leaflets.

Date, Place : 29 August to 2 September 2004, Bari (I)
Event : 12th International Conference on Experimental Mechanics
Session on : Standardisation Project for Optical Techniques of Strain Measurement (SPOTS)
Title 1: Traceability, reference materials and standardised tests in optical strain Measurement, *Erwin Hack (EMPA) , G. Sims, D. Mendels*
Title 2: Classification of common operations and processes within techniques of optical strain measurement
Richard Burguete (Airbus UK), Erwin Hack (EMPA), Malgorzata Kujawinska (Warsaw University) and Eann Patterson (University of Sheffield).
Title 3: Candidate reference materials for optical strain measurement
Richard Burguete (Airbus UK), Erwin Hack (EMPA), Eann Patterson (University of Sheffield), Siebert Thorsten (Dantec Ettemeyer), Maurice Whelan (JRC Ispra).
Title 4: Results from SPOTS round robin on a tensile specimen with a complex hole Geometry, *David Mendels (NPL)*

Dissemination activities in 2004

(continued)

Booth: In parallel, a large booth was organized, in order to inform personally about SPOTS to conference and SPOTS session attendees and to distribute SPOTS leaflets. Live demonstrations on the developed physical reference materials were performed.

Date, Place : Aug. 2004,
Event : Interferometry XII, Applications, ed. By W.Osten, E.Novak. Proc. SPIE vol. 5532, 268-277, 2004

Title : Development of standard measurement chain for full-field optical strain measurement methods, *Leszek Salbut, Malgorzata Kujawinska, Eann Patterson, Erwin Hack, Richard Burguete, Maurice Whelan, David Mendels*

Date, Place : 13-16 October, 2004, Jachranka, Poland, 2004
Event : 21st Symposium on Experimental Mechanics of Solid

Title : Standarization project for optical techniques of strain measurement *Eann Patterson, Malgorzata Kujawinska, Erwin Hack, Richard Burguete, David Mendels, Graham Sims, Maurice Whelan, Thorsten Siebert*

Date, Place : 15-19. November 2004, Saint-Etienne (F)
Event : CMOI (Club des Méthodes Optiques pour l'Industrie) 2004
Title 1: Progrès Technique dans le projet européen SPOTS visant la normalisation pour la mesure de contraintes par méthodes optiques, held within session about Standardization and Quality, *(in French. TRANSLATED: Technical progress in SPOTS, a European project aiming for pre-standardization for strain and stress analysis with optical methods), Michel Honlet.*
Booth: In parallel, a small booth was organized, in order to inform personally about SPOTS, both to conference attendees and equipment manufacturers and to distribute SPOTS leaflets.

Dissemination activities in 2005

CONFERENCE PRESENTATIONS (without publication of a paper) :

Date, Place : 2-3. May 2005, Bologna (I)
Event : StressPhotonics European User Meeting 2005 "Thermoelasticity and Industrial Applications"
Title : CRF applications within the EU Project "SPOTS", *M.M. Dugand (CRF)*

Date, Place : 1 June 2005, Orbassano (Torino, I)
Event : Club Specialistico Metrologia Ottica *(Optical Specialists Metrology Club)*
Title : Optical method for strain measurement within the Fiat Group, *M.M. Dugand (CRF)*

CONFERENCE PRESENTATIONS (with publication of a paper) :

Date, Place : May 2005 in Nuremberg (D)
Event : TEST 2005 Conference
Title : SPOTS – Standardization project for optical techniques of strain measurement: Traceability and reference materials, *Erwin Hack, Eann Patterson, Richard Burguete, Thorsten Siebert, Maurice Whelan, David Mendels*

Date, Place : 12-17 June 2005, Munich (D)
Event : 17th International Conference on Photonics in Europe, Optical Metrology, Optical Measurement Systems for Industrial Inspection IV
Title : Recent issues on development of reference materials and standardized tests of optical methods of strain measurement *Richard Burguete, Erwin Hack, Malgorzata Kujawinska, Eann Patterson, Leszek Salbut, Qasim Saleem, Thorsten Siebert, Maurice Whelan*

Date, Place : 6-8. September 2005, University of Southampton (UK)
Event : British Society Strain Measurement (BSSM)- EMex - Exhibition of experimental mechanics
Session on : Standardization Project for Optical Techniques of Strain Measurement
Title 1: Traceability of Optical Techniques for Strain Measurement
E. Hack (Switzerland), R. Burguete (UK), E. A. Patterson (UK)
Title 2: On the Calibration of Optical Full-field Strain Measurement Systems
M. Whelan (Italy). E. Hack (Switzerland), T. Siebert (Germany),R. Burguete (UK), E. A. Patterson (UK), Q. Saleem (UK)
Title 3. Standard Test for the Evaluation of Optical Strain Measurement Systems
E. A. Patterson, M. Whelan, E. Hack, T. Siebert, R. Burguete, Q. Saleem
Booth: In parallel, a large booth was organized. Live demonstrations on multiple physical reference materials developed within the SPOTS project were performed both at the booth and during a special demonstrations session.

Date, Place : September 2005, Parma (I)
Event : 22nd DANUBIA-ADRIA-SYMPOSIUM on Experimental Methods in Solid Mechanics
Title : Physical Reference Materials for Standardisation of Optical Strain Measurements
Thorsten Siebert, Maurice Whelan, Richard Burguete, Erwin Hack, Qasim Saleem, Eann Patterson

Dissemination activities planned for 2006

PUBLICATIONS IN LITERATURE OR MAGAZINES :

RR1:	N
RR2:	Y (see below)
Case studies:	Y: Combined paper in Experimental Techniques (Thorsten Siebert), Note: Best practice paper
Traceability:	Y: in STRAIN (Erwin Hack)
Feasibility data comparison:	Y: Journal to be chosen by Erwin
PRM:	Y: Details in STRAIN (calibration, by Maurice Whelan), Overview in special issue of Optics and Lasers in Engineering (Eann Patterson)
STM: (David)	Y: including results from RR2 in Experimental Mechanics
Overview:	Contrôles, Essais, Mesures (Translation of paper2 from Maurice, by Michel)

CONFERENCE PRESENTATIONS (with publication of a paper) :

Date, Place : January 2006, St Louis (USA)

Event : IMAC Conference

Title 1: Standards Project for Optical Techniques of Strain Measurement: Final Report
Eann Patterson Department of Mechanical Engineering, (University of Sheffield)

Date, Place : June 4 - 7, 2006 St. Louis, Missouri (USA)

Event : SEM Conference 2006

Title 1: Developing standards for optical methods of strain measurement
Richard Burguete, Erwin Hack, Malgorzata Kujawinska, Eann Patterson, Qasim Saleem, Thorsten Siebert, Maurice Whelan

Title 2: Contact stress analysis between flat plate and cylinder by thermoelasticity.
M.M. Dugand (CRF), R. Marsili, M. Moretti, J. Pirisinu, G. L. Rossi (University of Perugia)

Event: Photomechanics 2006 Keynote presentation about SPOTS by co-ordinator

March 2006: BSSM keynote, R.Burguete

End of Dissemination list
Date: 1.12.2005

APPENDIX 5 – Table 1: Man Power Table

(*to be inserted below*)