# Uncertainty Quantification in Materials Testing

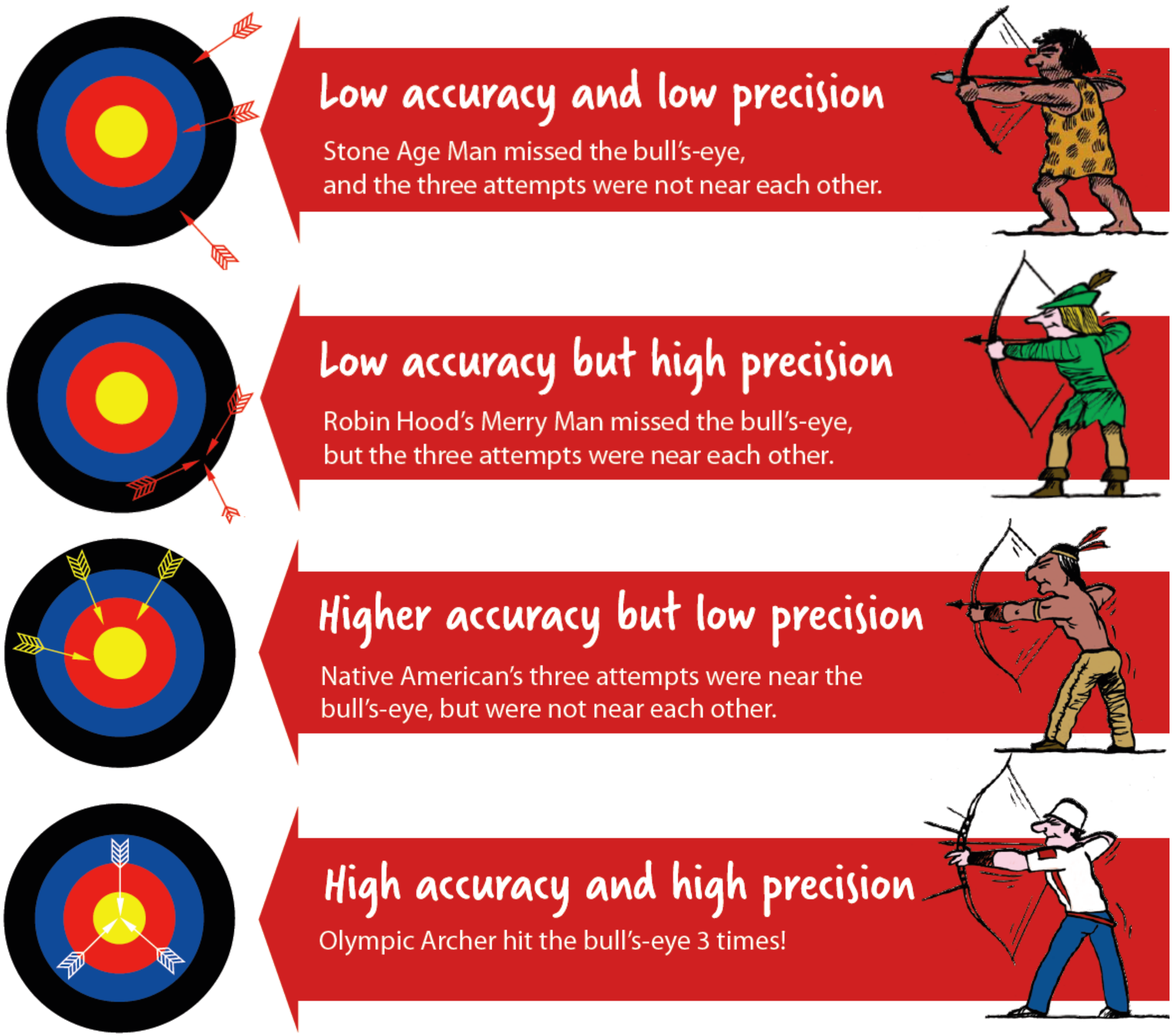
Dr Jerry Lord
BSSM
Materials Testing Consultant

# Breakdown of Presentation

- Brief introduction to Uncertainties
- Uncertainties in Materials Testing
  - UNCERT procedures
  - Specific modulus example

- Potential issues contributing to DIC uncertainty
  - NPL tests
  - Recent iSTRESS project

- Some useful links
- Summary


Low accuracy and low precision
Stone Age Man missed the bull's-eye, and the three attempts were not near each other.
Low accuracy but high precision
Robin Hood's Merry Man missed the bull's-eye, but the three attempts were near each other.
Higher accuracy but low precision
Native American's three attempts were near the bull's-eye, but were not near each other.
High accuracy and high precision
Olympic Archer hit the bull's-eye 3 times!

# There is uncertainty in everything we measure !

## Where do uncertainties come from ?

- The test setup and measuring instrument
  - Equipment calibration, measurement resolution, misalignment, software calculations …
- The item being tested or measured
  - Homogeneity, stability, specimen size …
- Operator expertise and skill
- The test environment
  - Temperature, noise, vibration ……

## Why are uncertainties important ?

- To quantify the quality of a measured value
- To compare different measured values
  - e.g. Benchmarking of different systems/laboratories
- To compare a measured value with theory
- To compare a measured value with a permitted tolerance
  - e.g. instrument classifications, conformity assessment ….

# Uncertainty versus Error

- "Uncertainty" is an attempt to quantify measurement accuracy without knowledge of the true value

- An uncertainty provides bounds around the measured value within which it is believed that the true value lies, with a specified level of confidence

- It is only possible to state the probability that the value lies within a given interval

- Probabilistic basis for uncertainty evaluation

- "Error" is typically defined as:

  *error = measured value – true value*

- This implies a knowledge of the true value (not usually known)

# Uncertainty Classification

- Sources of uncertainty are classified as Type A or Type B depending on the way their influence is quantified.

- If the uncertainty is evaluated by statistical means (from a number of repeated observations) it is classified Type A, if it is evaluated by any other means it should be classified Type B

- The values associated with Type B uncertainties can be obtained from a number of sources including calibration certificates, manufacturer's specifications, data from reference handbooks, results of similar measurements carried out, or an expert's estimation.

- For Type B uncertainties, it is necessary for the users to estimate the most appropriate probability distribution for each source.

- It should be noted that, in some cases, an uncertainty could be classified as either Type A or Type B depending on how it is estimated.

# Uncertainties in Materials Testing (UNCERT)

NPL

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## Uncertainties in Mechanical Testing (UNCERT)

The Codes of Practice listed below were developed within UNCERT, a project partly funded by the EC's Standards, Measurement and Testing programme. Its aim was to simplify the way in which uncertainties for 17 mechanical tests on metallic materials are evaluated. These are intended for all those interested in measurement and testing and particularly for practicing engineers, technicians, and managers in the manufacturing and service sectors.

The UNCERT manual comprises six sections:

- Section 1: Introduction to the evaluation of uncertainty
- Section 2: Glossary of definitions and symbols
- Section 3: Typical sources of uncertainty in materials testing
- Section 4: Guidelines for the estimation of uncertainty for a series of tests
- Section 5: Guidelines for reporting uncertainty
- Section 6: Individual Codes of Practice:
    - CoP 1: High cycle fatigue testing
    - CoP 2: Low cycle fatigue testing
    - Cop 3: Plane strain fracture toughness (K1C) testing
    - CoP 4: Crack tip opening displacement (CTOD) testing
    - CoP 5: Fatigue crack growth measurement
    - CoP 6: Charpy impact testing
    - CoP 7: Tensile testing
    - CoP 8: Compression testing
    - CoP 9: Bend testing
    - CoP 10: Creep testing
    - CoP 11: Notched-bar creep rupture testing
    - CoP 12: Double shear testing
    - CoP 13: Dynamic Young's modulus measurement
    - CoP 14: Hardness measurement
    - CoP 15: Residual stress measurement (hole drilling technique)
    - CoP 16: Poisson's ratio measurement (from tensile tests)
    - CoP 17: Ramberg-Osgood parameters (from tensile tests)

The UNCERT Partners acknowledge the financial support received from the European Commission, without which it would have been impossible to do this work.

For further information, please contact Tony Fry

Engineered Mate...
Research
- Mechani...

Related Re...
Mechanical Testi...
General Measure...
Measurement Te...


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**www.npl.co.uk/science-technology/.../uncertainties-in-mechanical-testing-uncert**

# UNCERT Procedure

CONTENTS



- Developed by material testing experts
- Following same format, in line with GUM
- Worked examples included

## Sources of Uncertainty in $K_{1C}$ testing (Uncert CoP3)

| Column Nb. ① | ② | ③ | ④ | ⑤ | ⑥ | ⑦ | ⑧ |
|---|---|---|---|---|---|---|---|
| Sources of Uncertainty | | Measurements | | Uncertainties | | | |
| Source | Value (1) or (2) | Measurement Affected | Nominal or Averaged Value (Units) | Type | Probabl. Distribt. | Divisor ($d_v$) | Effect on Uncertainty in Measurement |
| **Apparatus** | | | | | | | |
| Load Cell | 1% (1) | $P_Q$ | 72.5 (kN) | B | Rectang. | $\sqrt{3}$ | 0.419 kN 1) |
| Extensometer | 0.5% (1) | $P_Q$ | 72.5 (kN) | B | Rectang. | $\sqrt{3}$ | nglg. |
| Plotter Y | 0.5% (1) | $P_Q$ | 72.5 (kN) | B | Rectang. | $\sqrt{3}$ | nglg. |
| Plotter X | 0.5% (1) | $P_Q$ | 72.5 (kN) | B | Rectang. | $\sqrt{3}$ | nglg. |
| Knife Edges Thickness | 1.5 to 2 mm (1) | $P_Q$ | 72.5 (kN) | B | Rectang. | $\sqrt{3}$ | nglg. |
| Caliper | 0.05 mm (1) | W<br>B<br>a | 60 (mm)<br>30 (mm)<br>30.38 (mm) | B | Rectang. | $\sqrt{3}$ | 0.029 mm 2) |
| **Method** | | | | | | | |
| Alignment | - | $P_Q$ | 72.5 (kN) | B | Rectang. | $\sqrt{3}$ | nglg. |
| Speed | 0.3-1.5kN/s | $P_Q$ | 72.5 (kN) | B | Rectang. | $\sqrt{3}$ | nglg. |
| **Environment** | | | | | | | |
| Room Temperature | 2 °C (1) | $P_Q$ | 72.5 (kN) | B | Rectang. | $\sqrt{3}$ | nglg. |
| **Operator** | | | | | | | |
| Graph Interpretation | 2.49 % (2) | $P_Q$ | 72.5 (kN) | A | normal | 1 | 1.805 kN 3) |
| Thickness Measurement | 0.23 % (2) | B | 30 (mm) | A | normal | 1 | 0.069 mm 4) |
| Width Measurement | 0.23 % (2) | W | 60 (mm) | A | normal | 1 | 0.138 mm 5) |
| Crack Length Measurement | 0.23 % (2) | a | 30.38 (mm) | A | normal | 1 | 0.070 mm 6) |
| **Test Piece** | | | | | | | |
| Specimen Thickness | 0.5 % (1) | B<br>$P_Q$ | 30 (mm)<br>72.5 (kN) | B | Rectang. | $\sqrt{3}$ | 0.087 mm 7)<br>0.209 kN 8) |
| Specimen Width | 0.5 % (1) | W<br>$P_Q$ | 30 (mm)<br>72.5 (kN) | B | Rectang. | $\sqrt{3}$ | 0.173mm 9)<br>0.209 kN 10) |

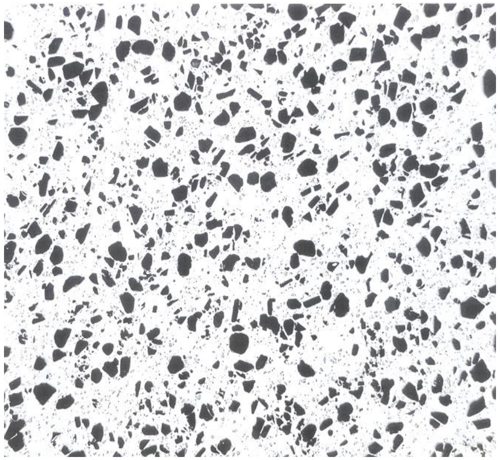
*(1) permissible range for the measurand according to the test standard*
*(2) maximum range between measures made by several trained operators, on the same test*

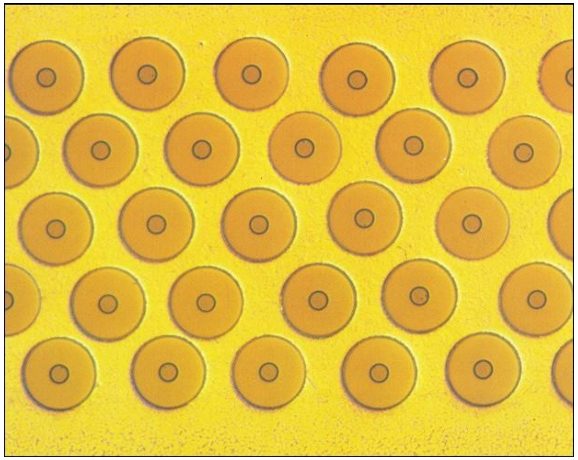
# NPL Specific Modulus Testing

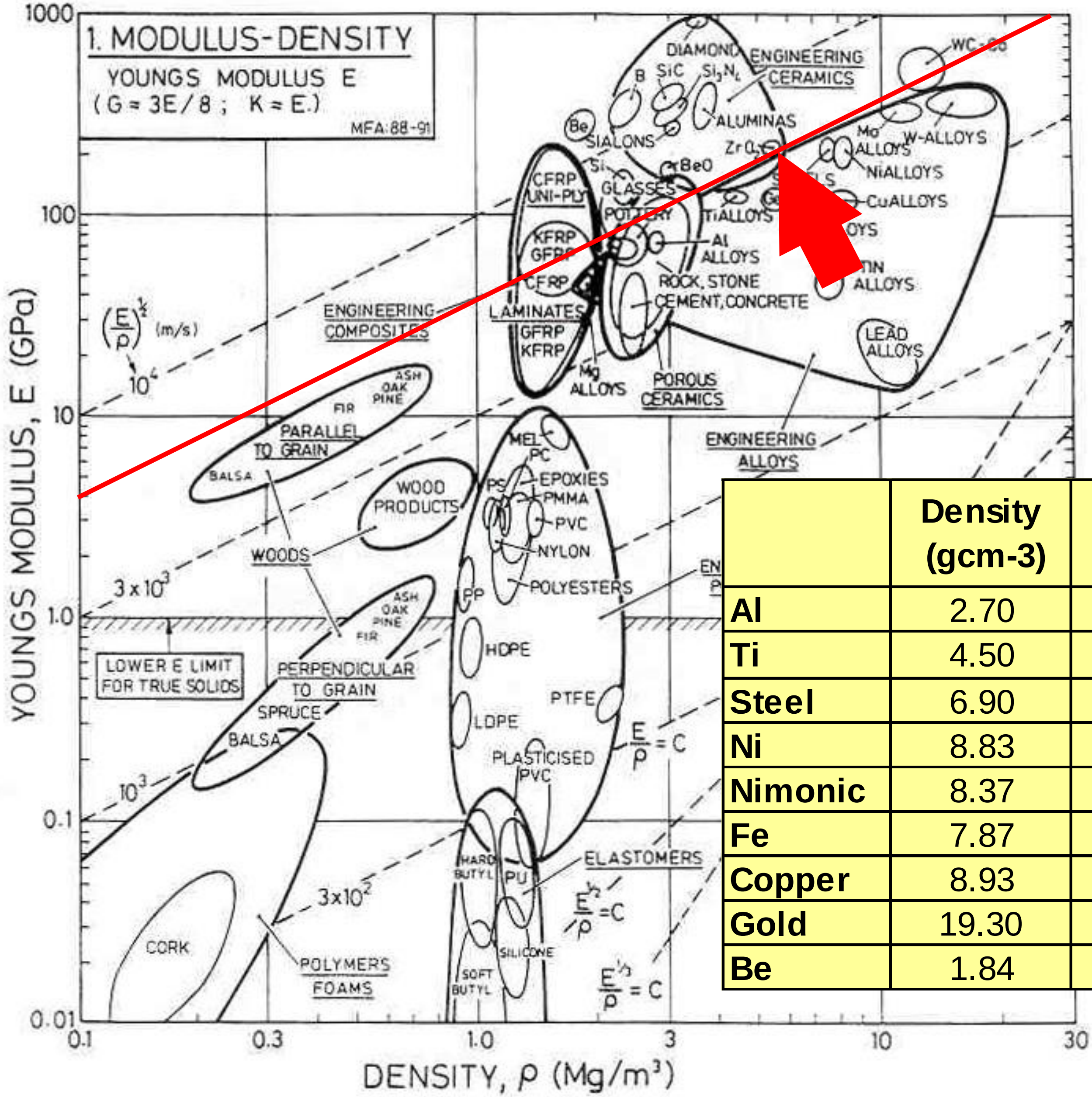
- FIA Regulations require that all metallic materials with a <u>specific modulus</u>, $E_{spec}$, of over **35 GPa/gcm$^{-3}$** must be supplied for testing
- No specific advice or guidelines on test method
  - How to measure modulus – tensile or dynamic ?
  - Only ASTM standards exist
- NPL was approached to advise on testing and measurement issues
- Initial tolerance was **40 +/- 10 GPa/gcm$^{-3}$**

- Driven by interest in using MMCs
- Combinations of metal and ceramic
  - Typically Al, Ti, Steel alloys
  - with SiC, $Al_2O_3$, TiC, $TiB_2$
  - Particles, whiskers, fibres
- Properties can be tailored by varying Vf of reinforcement

- Significant increases in specific strength & stiffness
- Reduction in ductility and $K_{Ic}$








**40 GPa/gcm-3**

Figure taken from the Cambridge Engineering Selector (CES)

Courtesy of Prof Mike Ashby &

| | Density (gcm-3) | Modulus (GPa) | Espec (GPa/g cm-3) |
|---|---|---|---|
| **Al** | 2.70 | 73.0 | 27.0 |
| **Ti** | 4.50 | 120.0 | 26.7 |
| **Steel** | 6.90 | 210.0 | 30.4 |
| **Ni** | 8.83 | 190.0 | 21.5 |
| **Nimonic** | 8.37 | 218.0 | 26.0 |
| **Fe** | 7.87 | 205.0 | 26.0 |
| **Copper** | 8.93 | 121.0 | 13.5 |
| **Gold** | 19.30 | 80.0 | 4.1 |
| **Be** | 1.84 | 275.0 | 149.5 |

# NPL Specific Modulus Uncertainty Budget

| Material Code | NPL ID | Density, (g cm$^{-3}$) | Modulus, E (GPa) | Specific Modulus, $E_{spec}$ (GPa / g cm$^{-3}$) |
|---|---|---|---|---|
| X | **1** | 2.903 | 111.4 | 38.4 |
| | **2** | 2.901 | 112.2 | 38.7 |
| | **3** | 2.902 | 112.7 | 38.8 |
| | **4** | 2.902 | 111.7 | 38.5 |
| | **5** | 2.905 | 112.2 | 38.6 |
| | **6** | 2.906 | 112.1 | 38.6 |
| | **7** | 2.902 | 111.9 | 38.6 |
| | **8** | 2.905 | 112.5 | 38.7 |
| | **9** | 2.904 | 111.7 | 38.5 |
| | **10** | 2.904 | 112.1 | 38.6 |
| **Mean** | | **2.903** | **112.1** | **38.6** |
| **Std. Dev.** | | **0.002** | **0.4** | **0.1** |

Results from tests on
10 specimens from the batch

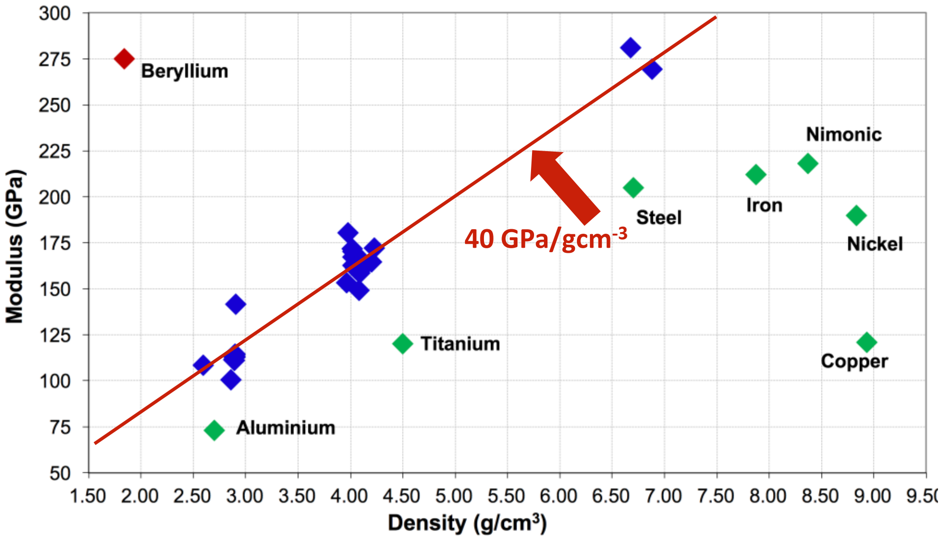
| Source of Uncertainty | Uncertainty | Measured Value | Uncertainty u (%) | Probability distribution | Divisor | u ($E_{spec}$) (%) |
|---|---|---|---|---|---|---|
| Force, F | See Note 1 | | 0.22 | Normal | 1 | 0.22 |
| Area, A | 0.02 mm$^2$ | 18 mm$^2$ | 0.11 | Rectangular | 1.732 | 0.06 |
| Strain, ε | 10 με | 1000 με | 1.00 | Rectangular | 1.732 | 0.58 |
| Modulus analysis method | 0.25 GPa | 112.1 GPa | 0.22 | Rectangular | 1.732 | 0.13 |
| Repeatability of E measurement | 0.4 GPa | 112.1 GPa | 0.26 | Normal | 1 | 0.36 |
| Density | 0.004 gcm$^{-3}$ | 2.903 gcm$^{-3}$ | 0.14 | Rectangular | 1.732 | 0.08 |
| Repeatability of density measurement | 0.002 gcm$^{-3}$ | 2.903 gcm$^{-3}$ | 0.07 | Normal | 1 | 0.07 |
| | | | | | **Combined Standard Uncertainty** | **0.73** |
| | | | | | **Expanded Uncertainty (k=2.00, 95%)** | **1.47** |

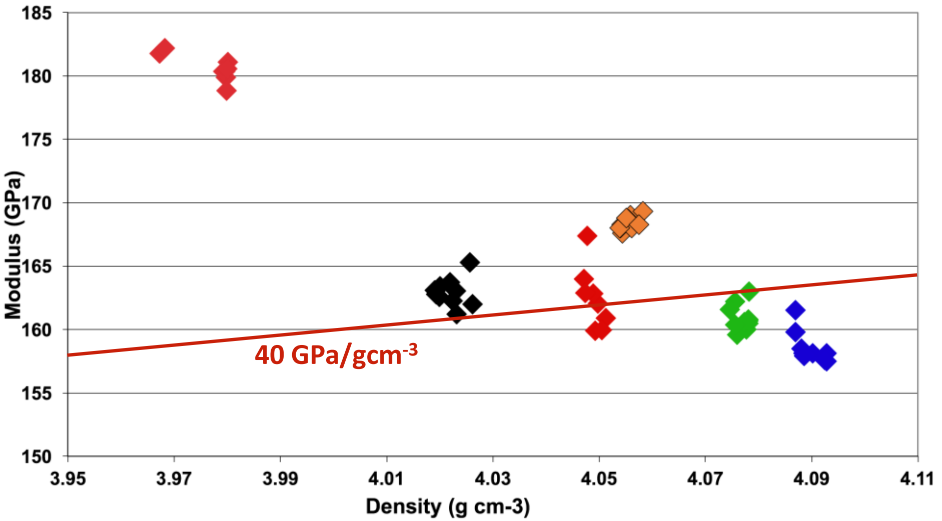
Specific modulus Uncertainty Budget

Based on these results the specific modulus for the batch of material should be reported as:
$E_{spec}$ = 38.6 ± 0.6 GPa / g cm$^{-3}$ .. to a confidence level of 95%.

**This reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor, which provides a level of confidence of approximately 95%.**

# The value of accurate measurement and low uncertainties




Pushing it to the limit !

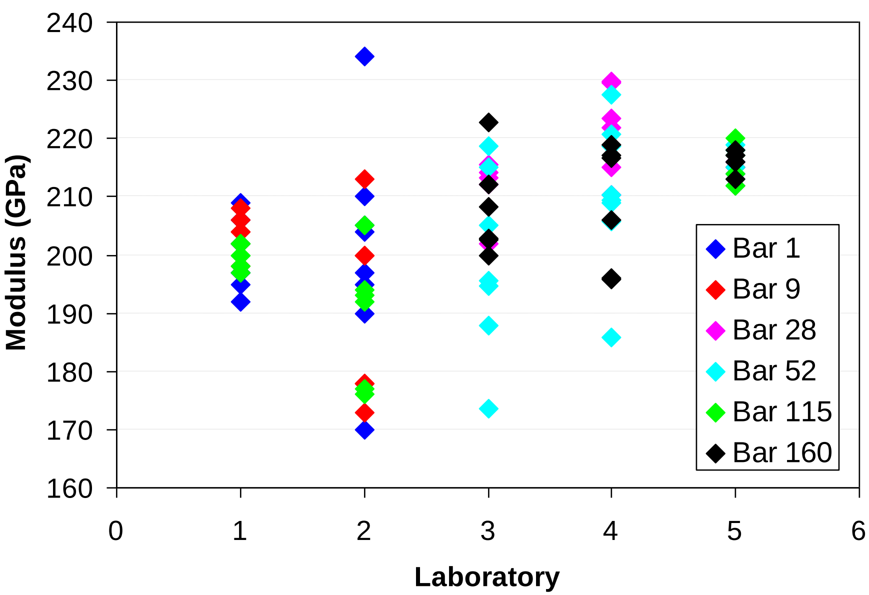
40 GPa/gcm$^{-3}$

Dedicated test method & accurate strain measurement permit subtle variations in material composition for

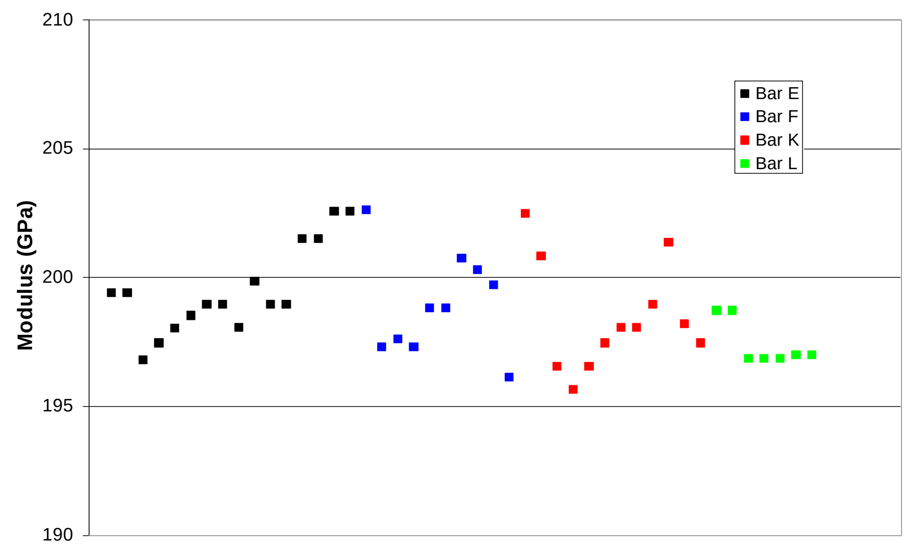
maximum performance benefit

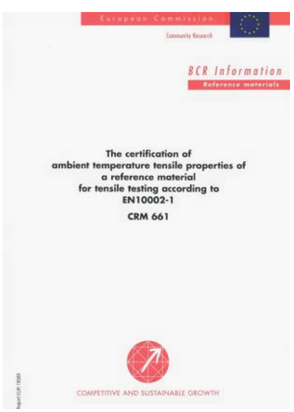
# Scatter in Modulus data - Intercomparisons

## Nimonic 75: CRM 661 Modulus Data (2000)




## Mild steel (Unwin 1895)

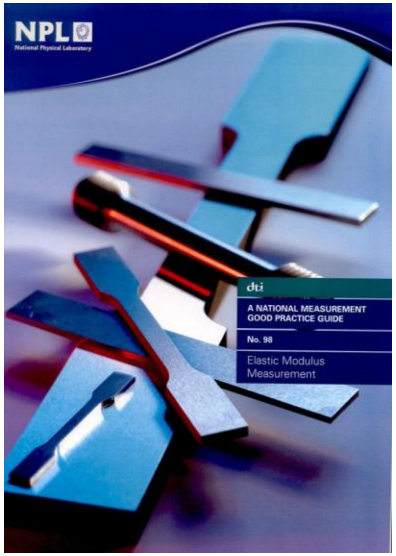


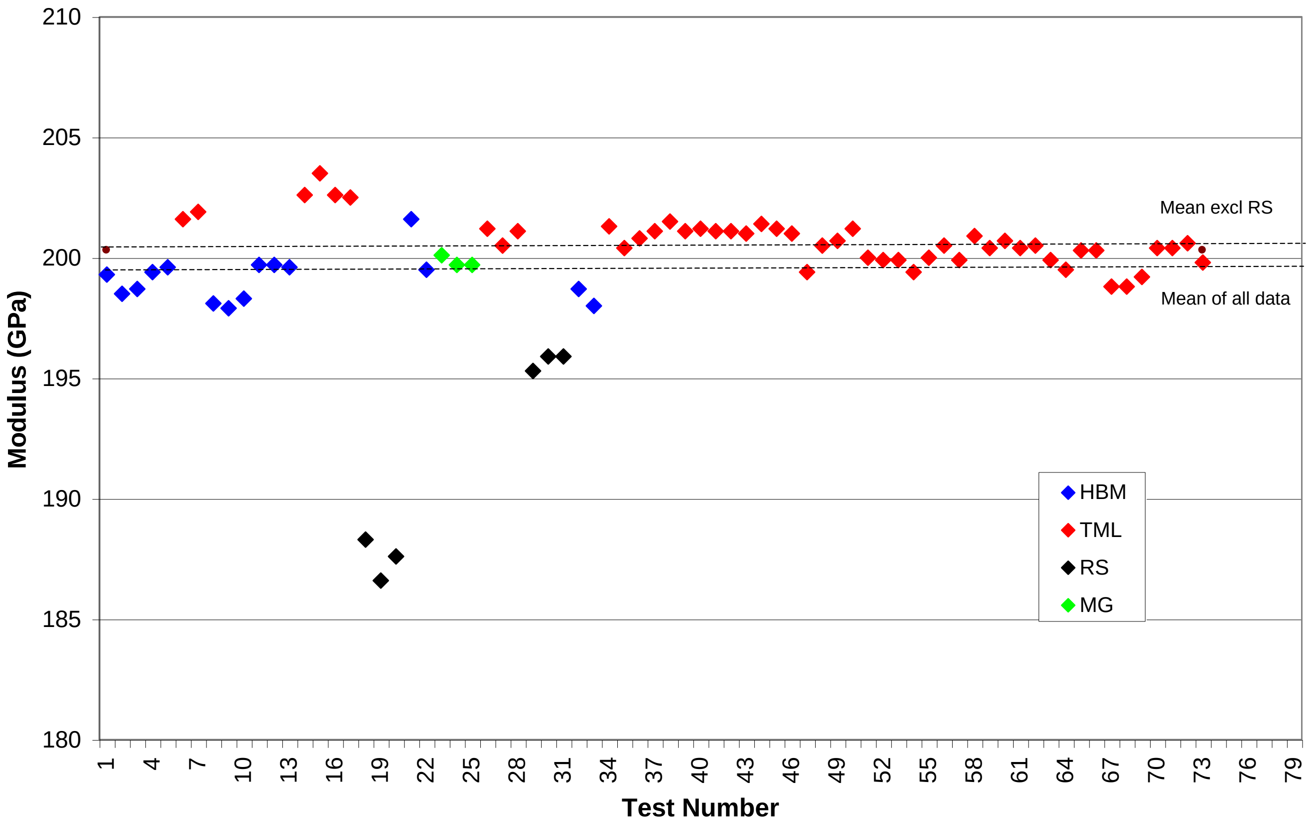




- Improvement is still required !
  - Dedicated test method and strain measurement
- VAMAS TWA32 intercomparison activity

# Value of "Reference Specimens"

- Tensile test on a fibre reinforced MMC
- 70+ tests over 15 years to check set up
- Loaded elastically (to 0.1% (1000 µe))
- Using strain gauges (Double sided strain measurement)

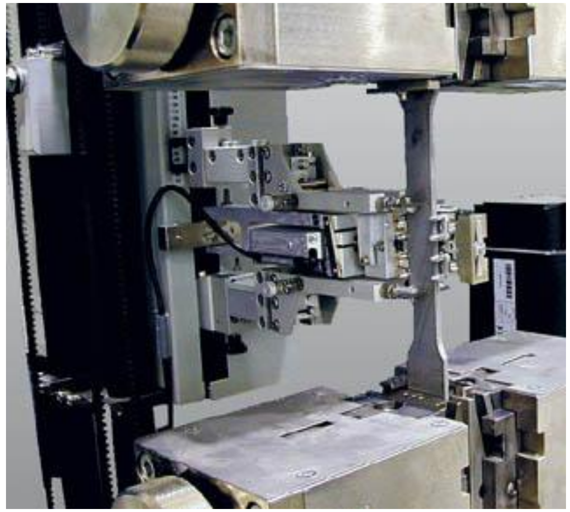


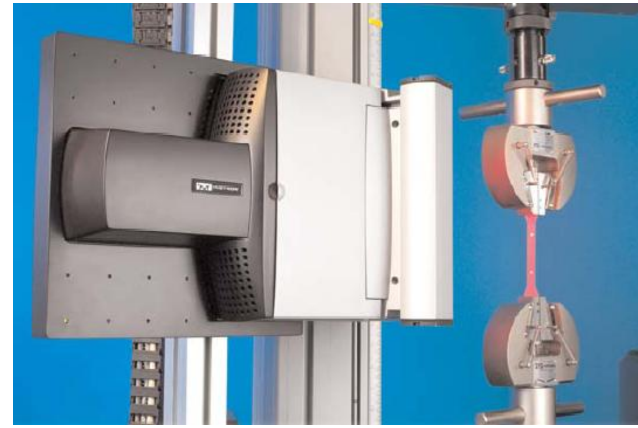



# Useful links

- GUM (& Supplements)
  www.bipm.org/en/publications/guides/gum.html
- UKAS document M3003
  www.ukas.com/library/Technical-Information/Pubs-Technical-Articles/Pubs-List/M3003.pdf
- NPL uncertainty guides
  www.npl.co.uk/publications/uncertainty-guide/
- JCGM: Joint Committee for Guides in Metrology
  www.bipm.org/en/committees/jc/jcgm/
- UNCERT Codes of Practice
  www.npl.co.uk/science-technology/engineered-materials/research/mechanical/uncertainties-in-mechanical-testing-uncert

# Conventional Strain measurement methods used in Materials Testing

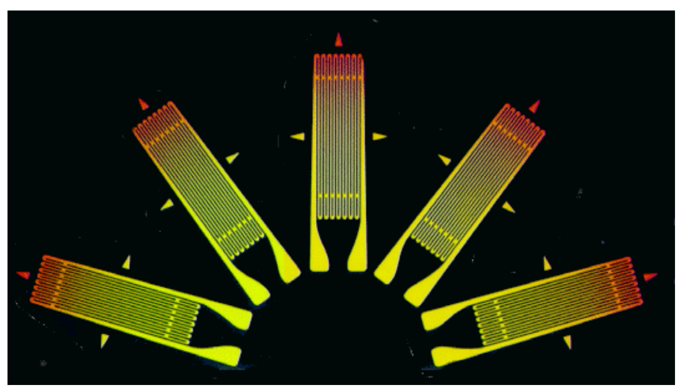





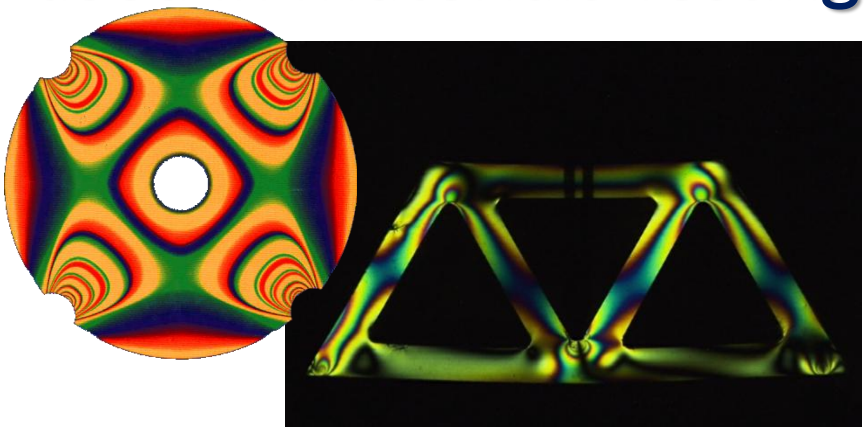
**Non contact video extensometry**

**Mechanical extensometry**

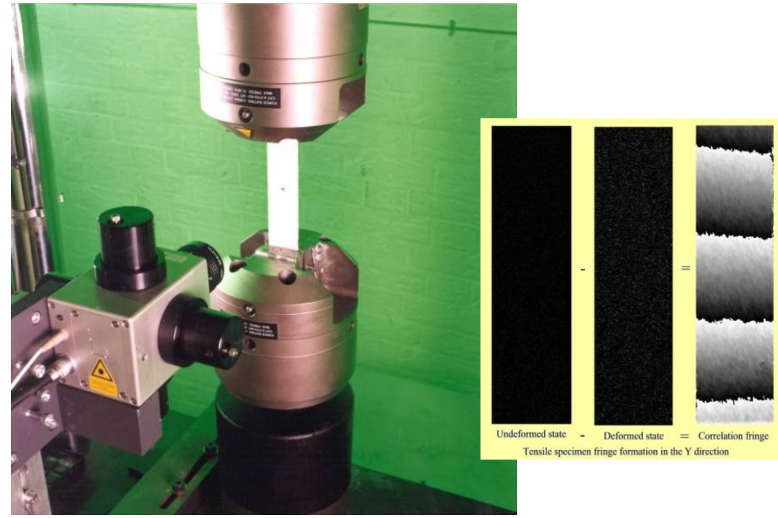
**Strain gauges**



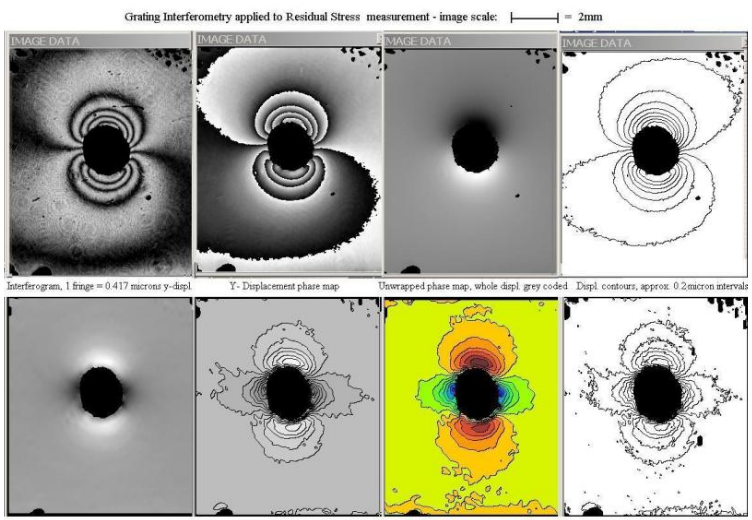
# Non-contact Strain measurement methods used in Materials Testing



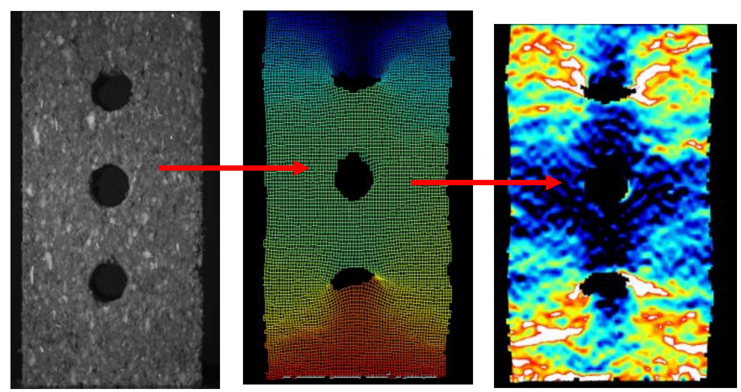
Photoelasticity




ESPI
(Electronic Speckle Pattern Interferometry)




Moiré/grating interferometry

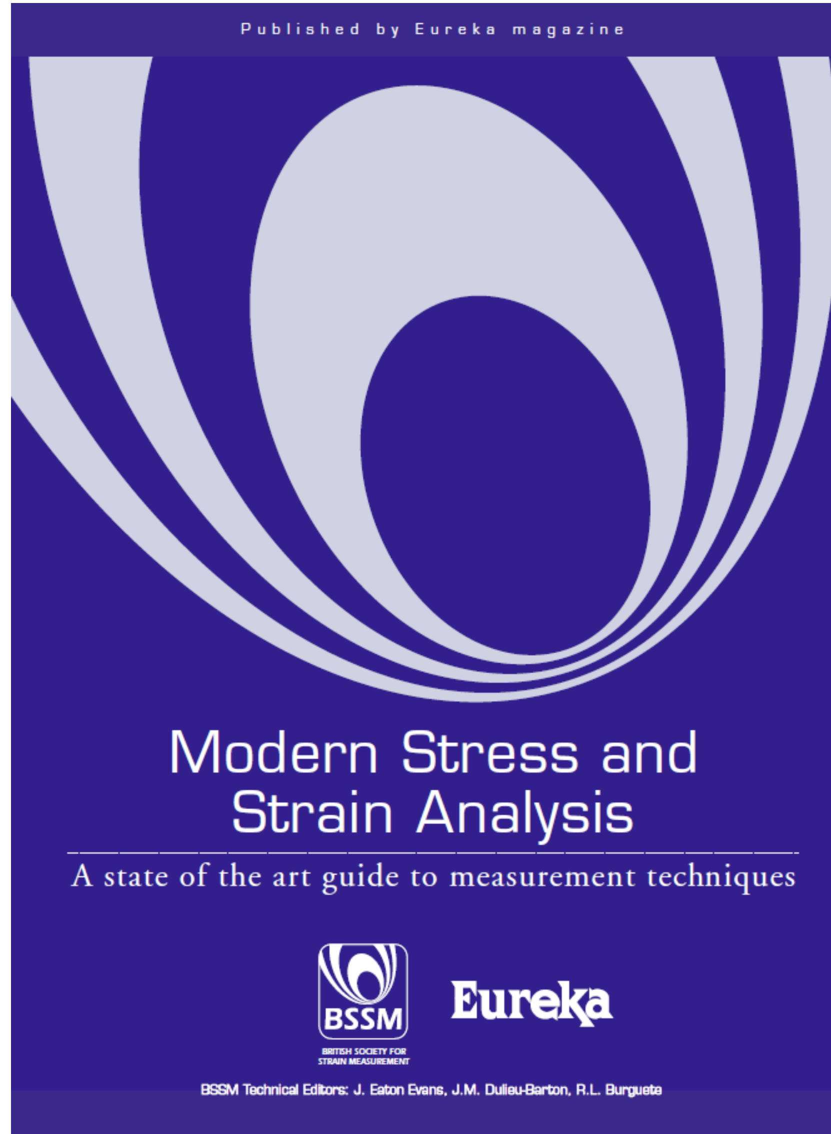


Spec image Vector map Strain map

DIC (Digital Image Correlation)

# Experimental mechanics "toolbox"

- Strain gauges
- Extensometry
- Full field imaging
- Diffraction techniques
- Residual stress measurement
- Digital Image Correlation
- Moiré Interferometry
- Speckle Pattern Interferometry
- ThermoElastic Stress Analysis (TSA)
- Photoelasticity
- Photogrammetry
- Virtual Fields Technique
- Acoustic emission
- Magnetic methods

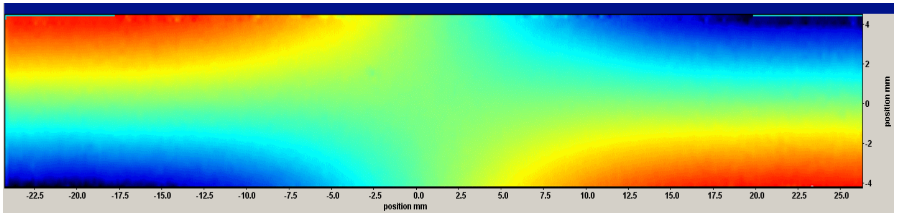


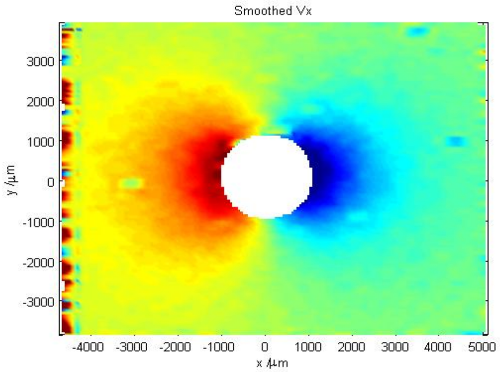
# Why DIC ?

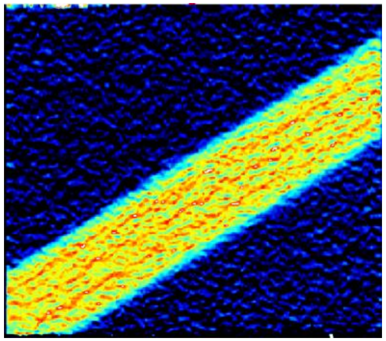
- DIC provides direct comparison of displacement cf analysis
  of complex fringe patterns (ESPI, Moiré)
- Full field technique – wealth of information
- Good spatial and strain resolution
- Minimal sample preparation & long working distances
- No laser safety issues (cf ESPI)
- Insensitive to vibration and rigid body motion (cf ESPI, Moiré)
- Applications are not material specific nor size dependent
  - from NANO !! to large components
- Relatively simple experimental set up (but computer intensive)

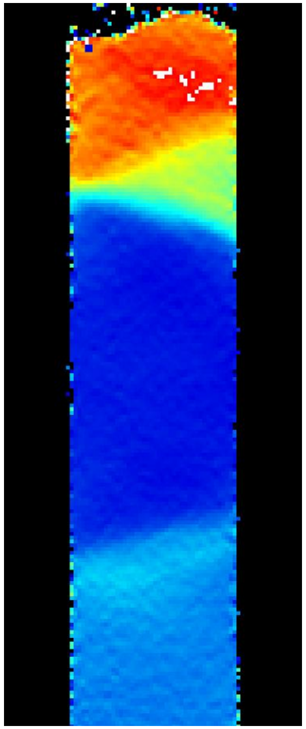
- DIC is not cited in any Materials Testing Standards (but neither are strain gauges !)
- Needs line of sight
- DIC for test machine control ?
- DIC is not suitable for all strain applications

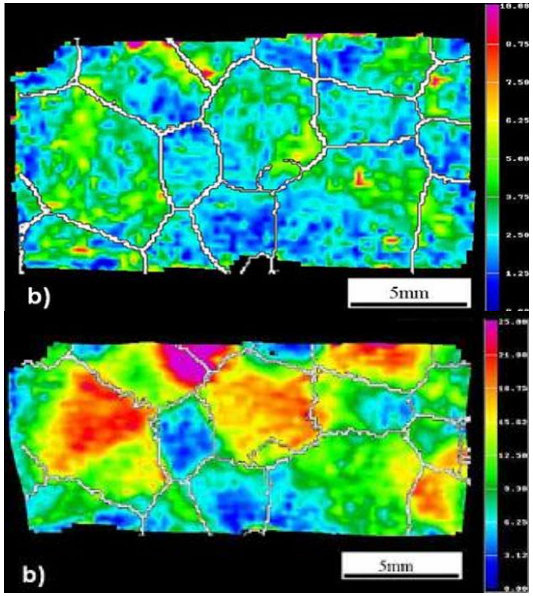
# Examples of DIC in Materials Testing

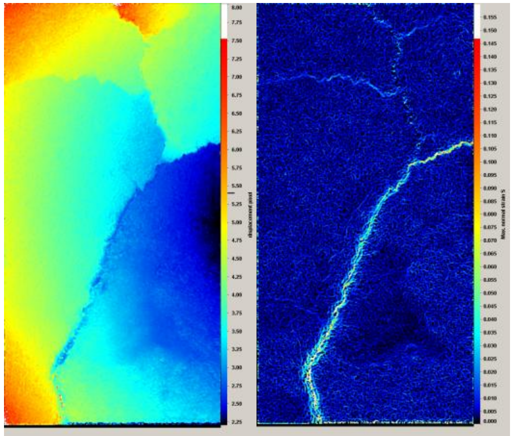


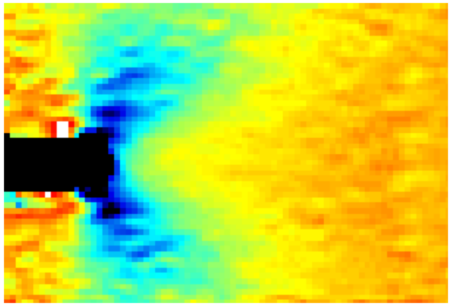



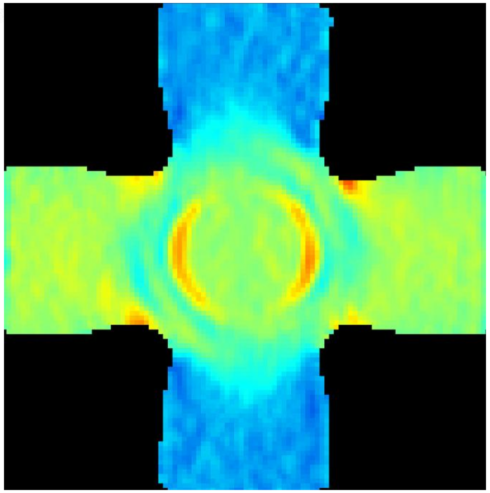



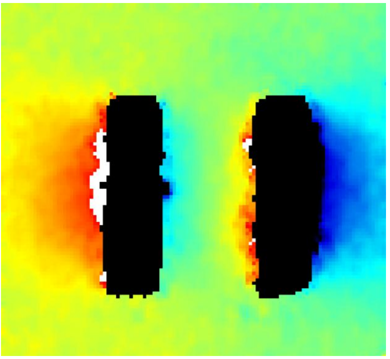








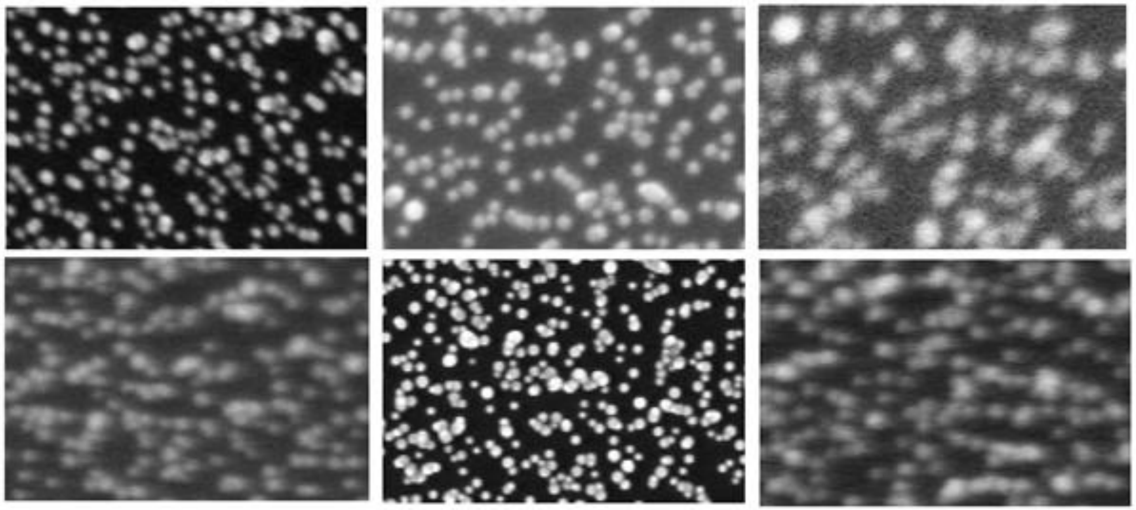


# Potential issues contributing to DIC Uncertainty

Helps to identify what is important and what can be controlled

- Test setup
- Camera alignment and stability
- Lens distortions
- Camera resolution and field of view
- Lighting
- Vibration
- System/image stability
- Surface pattern – scale, contrast, distribution of pattern features etc
- User expertise
- DIC software itself
- Image preprocessing – averaging
- Image noise
- DIC subset/window size
- Strain field uniformity
- Number of images
- Choice of reference image
- DIC processing conditions
- Correlation algorithms
- Potential out of plane displacement – 2D v 3D
- Test environment
- Temperature effects
- Inherent material variability
- Post processing of DIC data
- Use of 3rd party software
- Dedicated "fixed" setup cf multipurpose
- ………..
- ………..

# iSTRESS Imaging & system performance tests



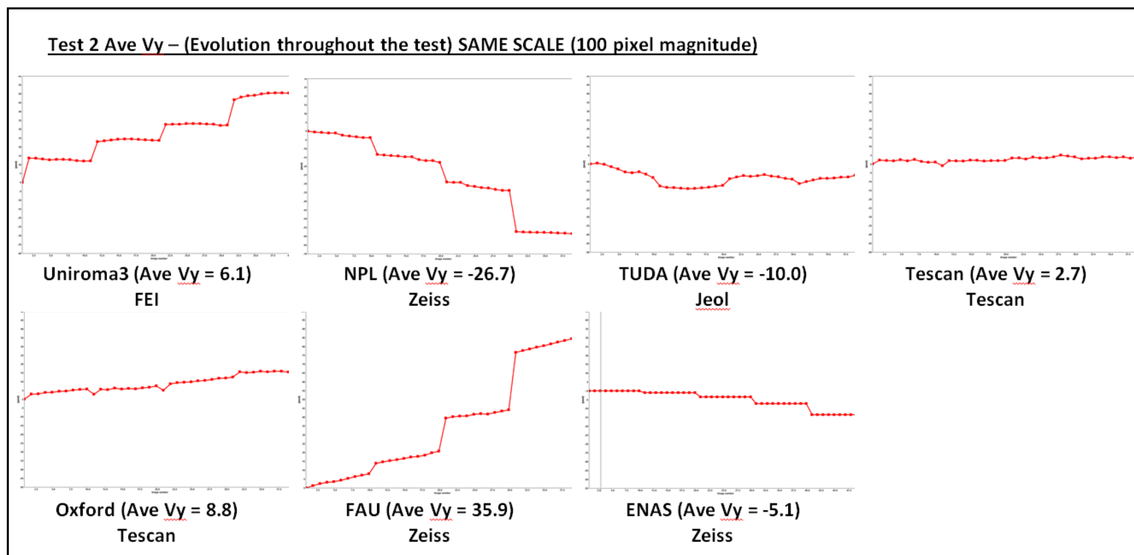
Representative images of the reference samples (Pt dots on Si wafer)
- showing the variation in quality, noise and resolution

FIB Systems examined

4x Zeiss, 2x Tescan, 1x FEI, 1x Jeol

**Test 2:** After a Dwell of 20 mins, 10 x images, No translation

- Motion due to image drift (charging) and/or stage creep
- Issue – in extreme cases had to change FOV to accommodate, reducing resolution and increasing potential uncertainty



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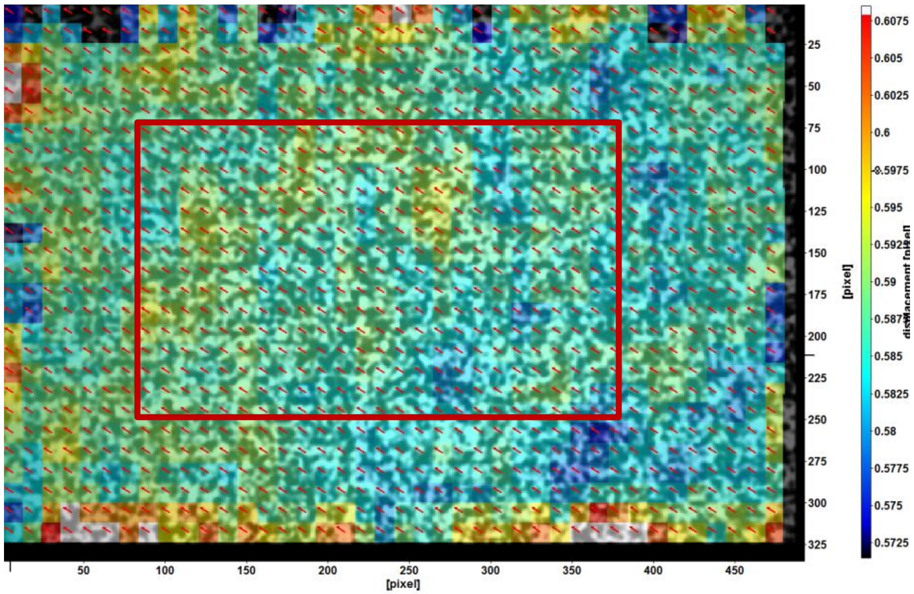
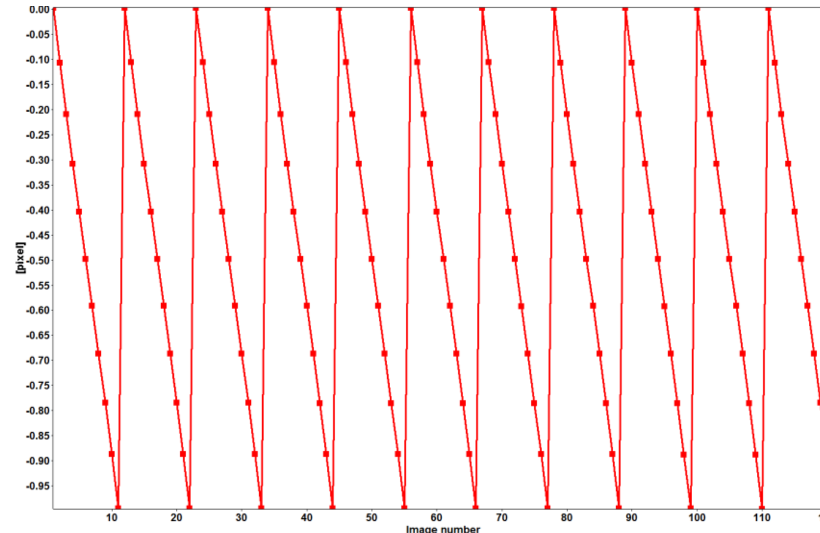
- Post processing of DIC data
- Use of 3rd party software
- Dedicated "fixed" setup cf multipurpose
- ………..
- ………..

# SEM DIC Challenge – NPL DIC analysis

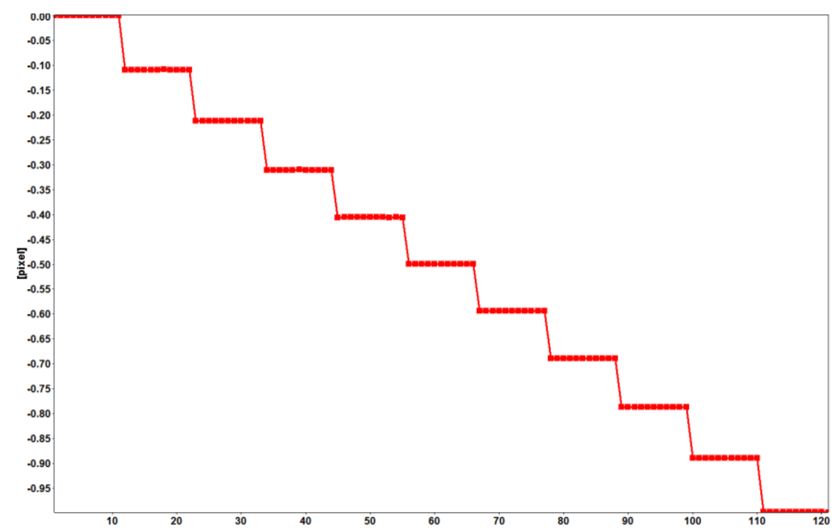



Variation in Vx

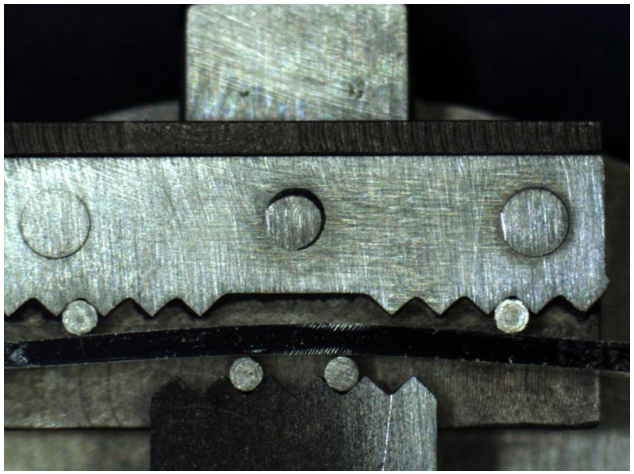
**Image sets for software testing and verification**

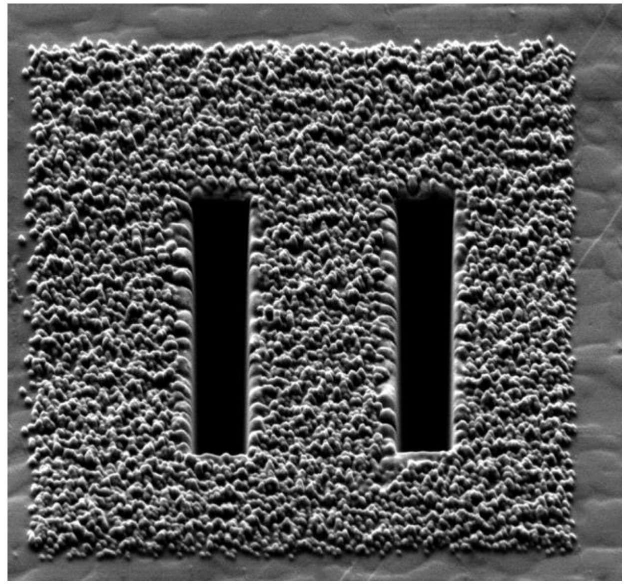
- Using High Contrast Image Set 2
- 15 x 2D DIC image sets with different strain and displacement fields
- Results show output for 0.1 pixel shifts from 0 to 1 pixel in both the x and y, analyzed using standard NPL DIC conditions

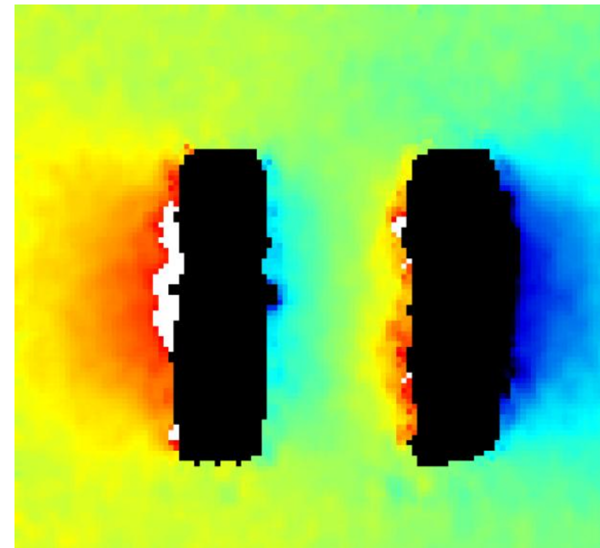


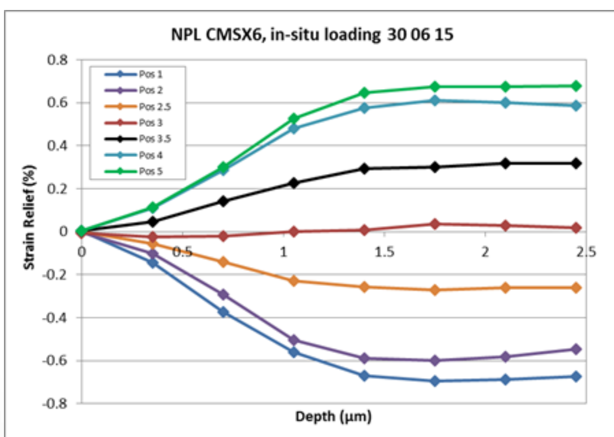

Variation in Vy

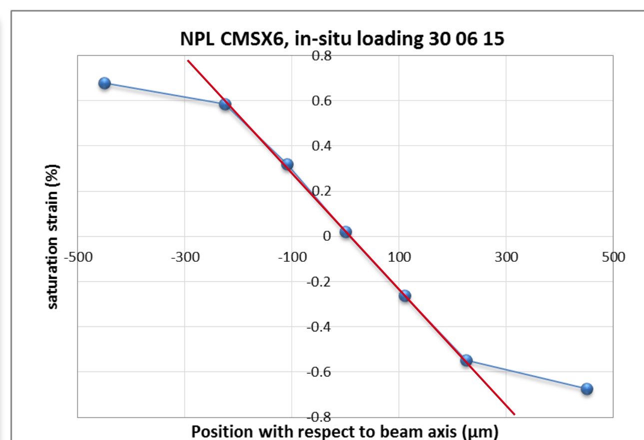
# Validation – using 4 pt bend elastic loading










ISTRESS

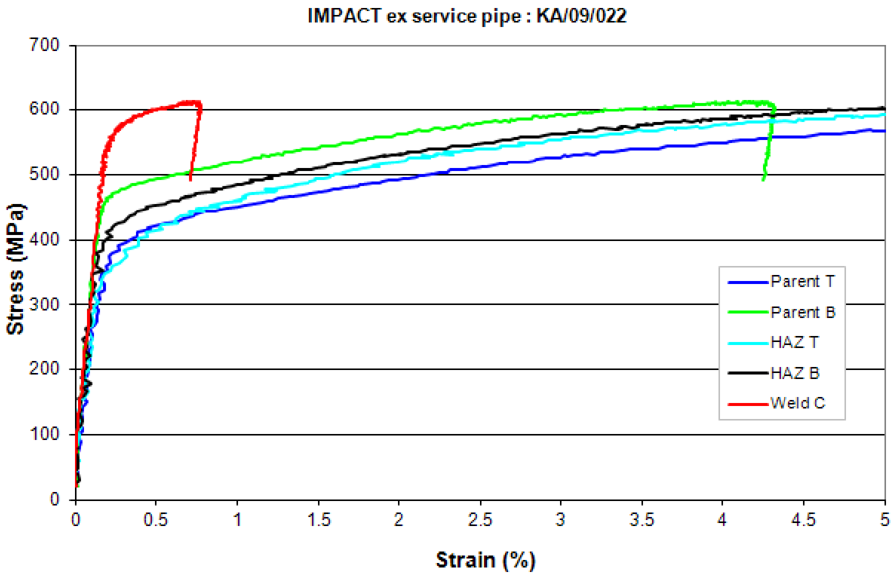
SEVENTH FRAMEWORK PROGRAMME

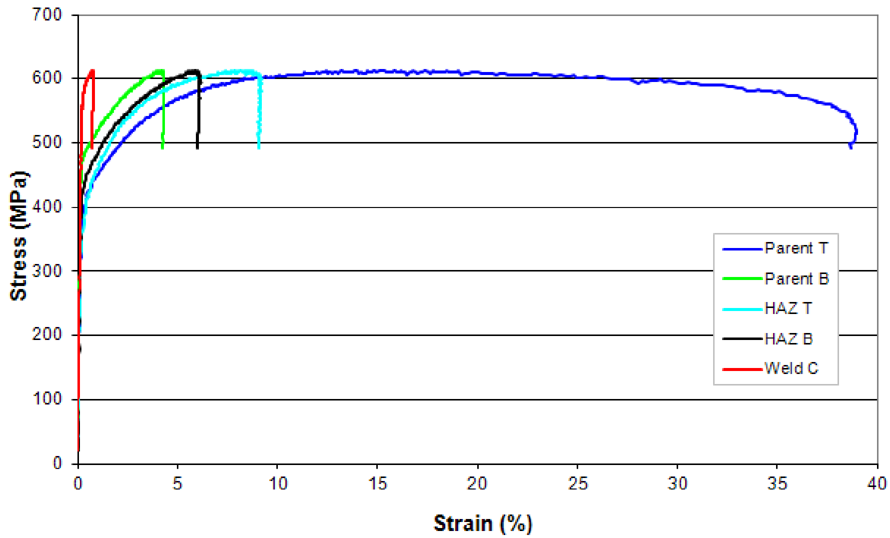
# Potential issues contributing to DIC Uncertainty

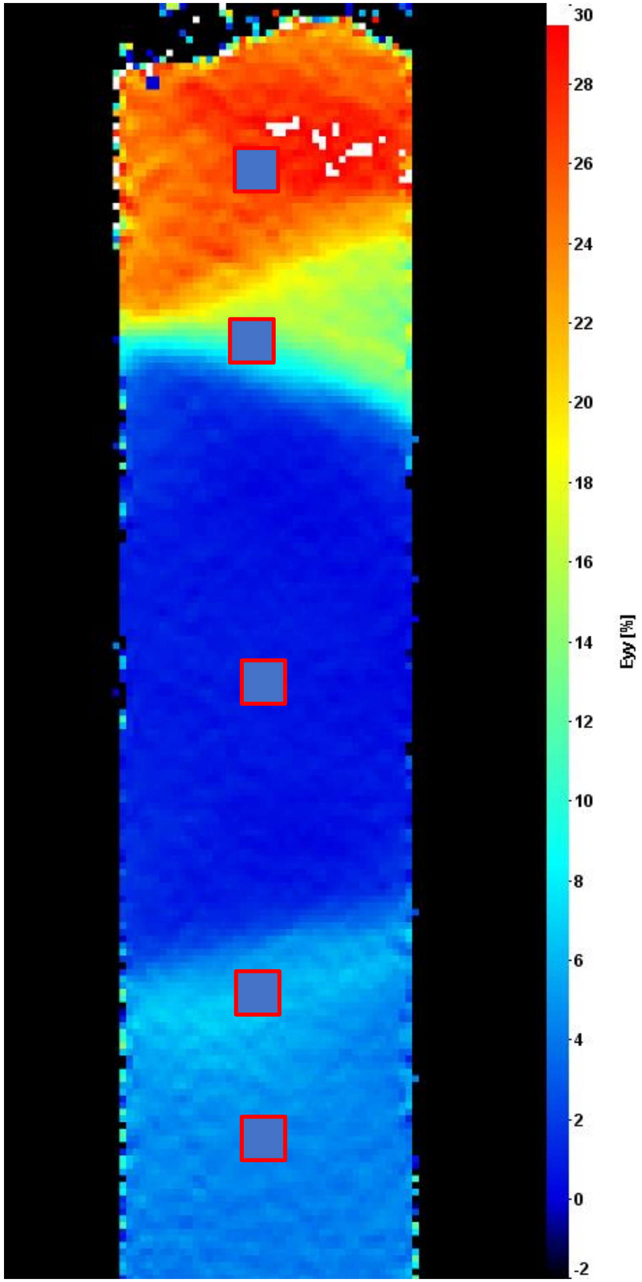
Helps to identify what is important and what can be controlled

- Test setup
- Camera alignment and stability
- Lens distortions
- Camera resolution and field of view
- Lighting
- Vibration
- System/image stability
- Surface pattern – scale, contrast, distribution of pattern features etc
- User expertise
- DIC software itself
- Image preprocessing – averaging
- Image noise
- DIC subset/window size
- Strain field uniformity
- Number of images
- Choice of reference image
- DIC processing conditions
- Correlation algorithms
- Potential out of plane displacement – 2D v 3D
- Test environment
- Temperature effects
- Inherent material variability
- Post processing of DIC data
- Use of 3$^{rd}$ party software
- Dedicated "fixed" setup cf multipurpose
- ………..
- ………..

# Cross weld example



# Potential issues contributing to DIC Uncertainty

Helps to identify what is important and what can be controlled

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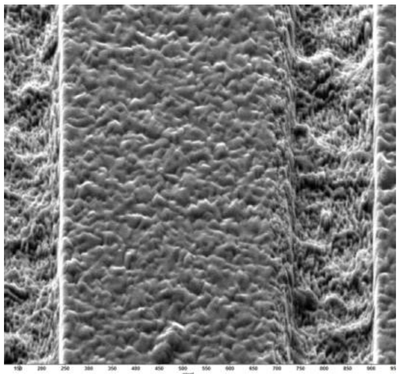
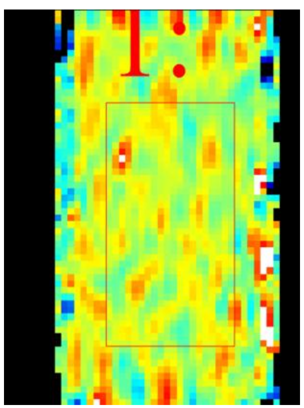
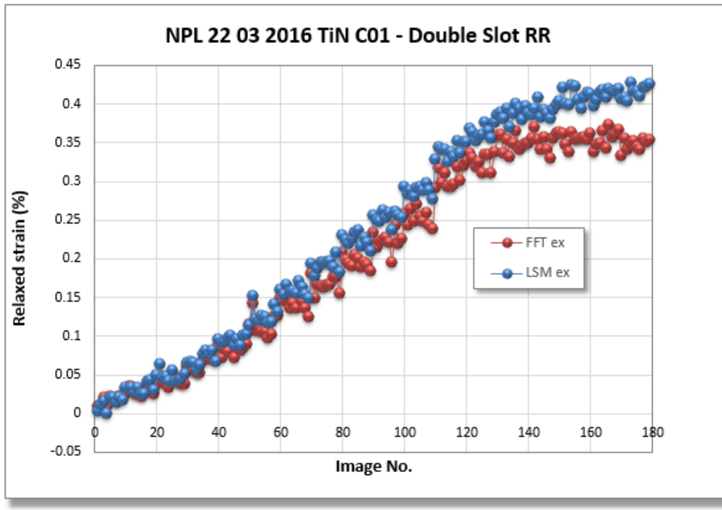
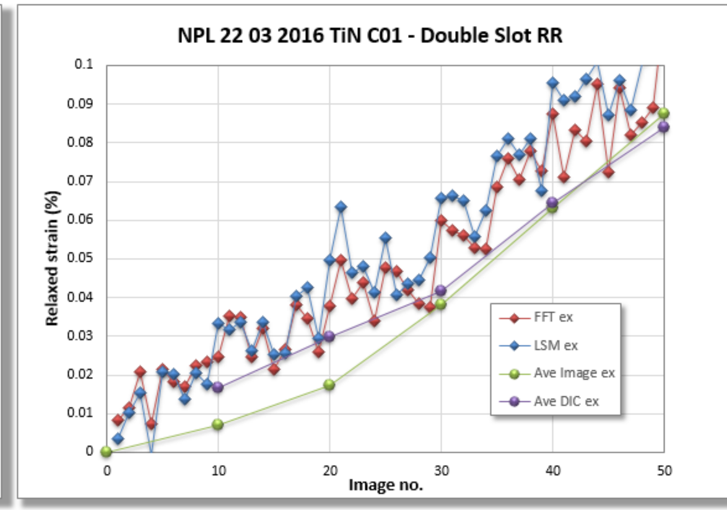
- Dedicated "fixed" setup cf multipurpose
- ...........
- ...........

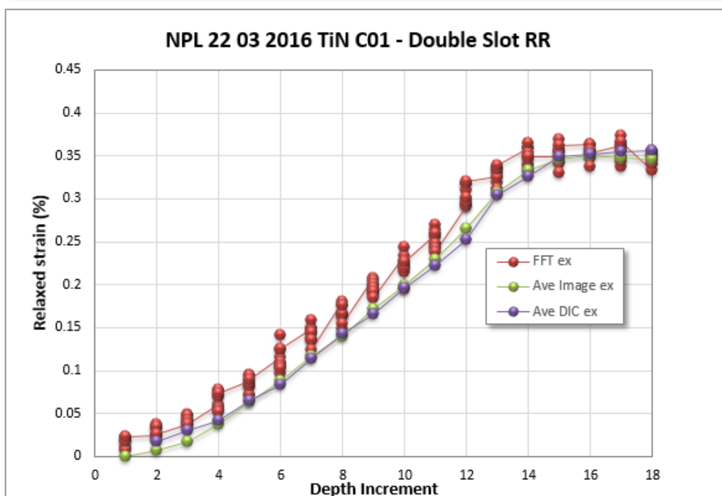
# iSTRESS Double Slot – DIC processing issues

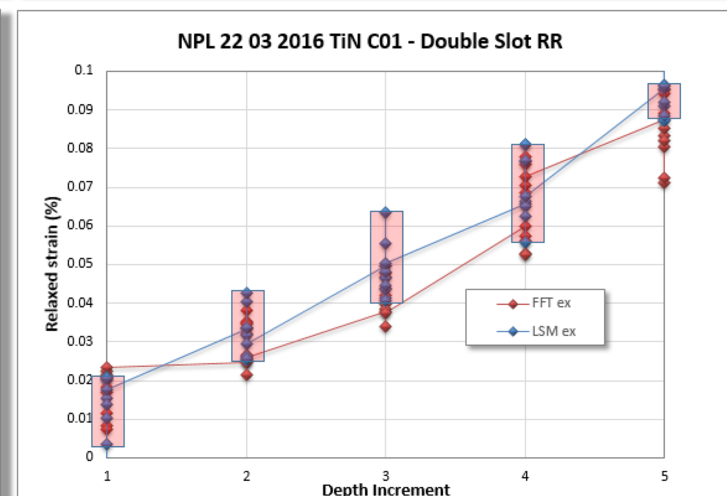




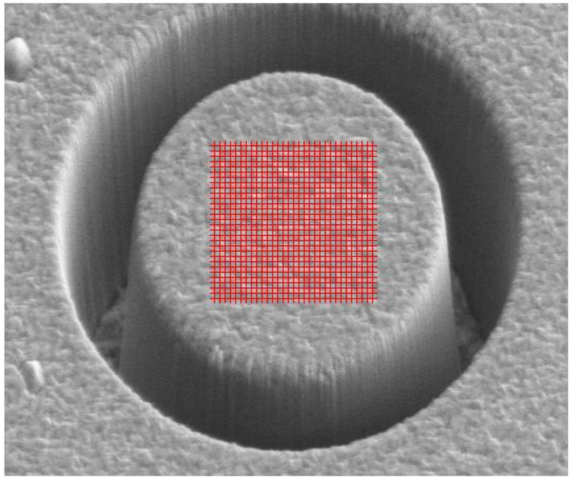


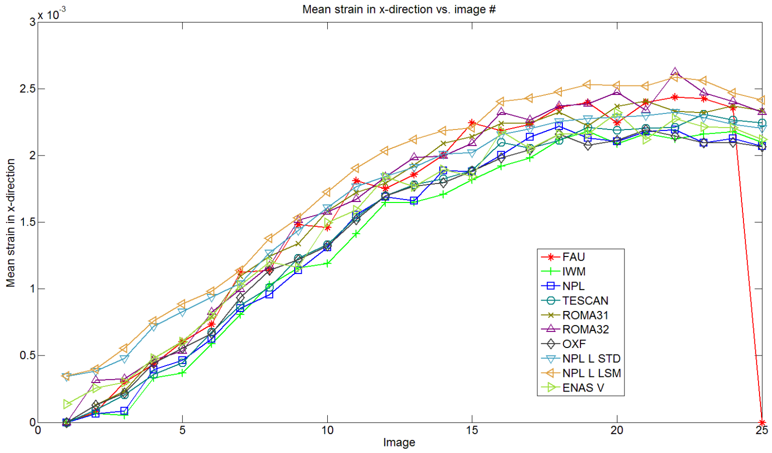



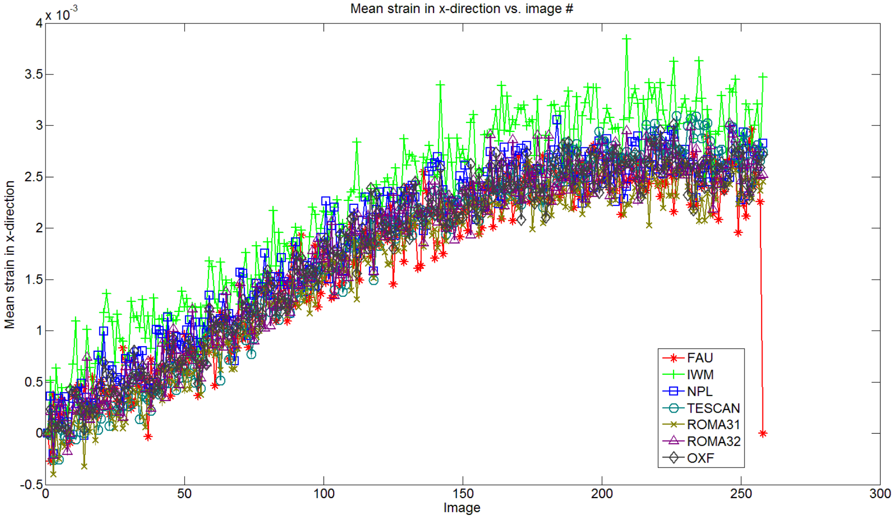



# iSTRESS Round Robin – Effect of Image averaging and different DIC software/users






- Ring Core geometry in TiN coating
- Good quality data
- Milling in 25 steps, 10 images each step
- Analysed using different DIC software using agreed parameters



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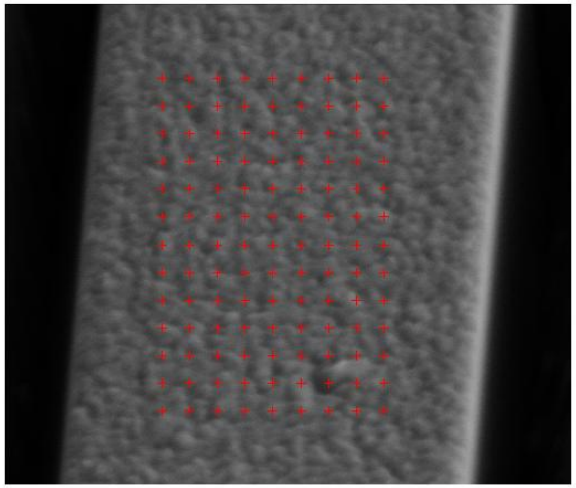
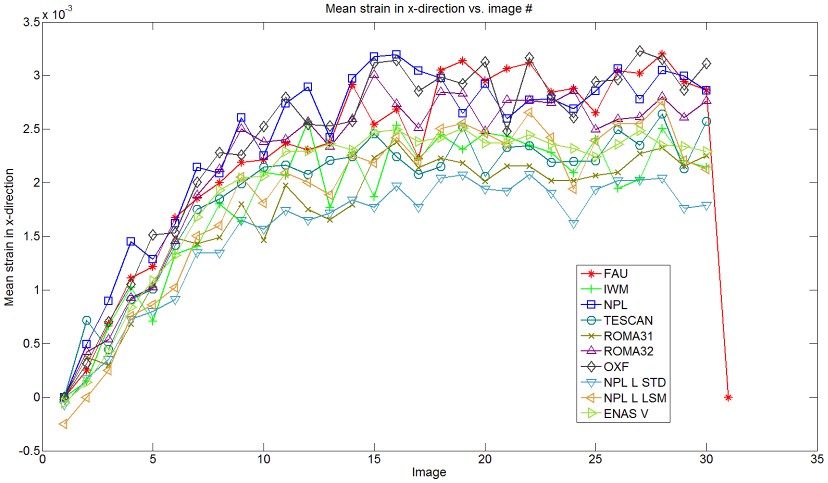
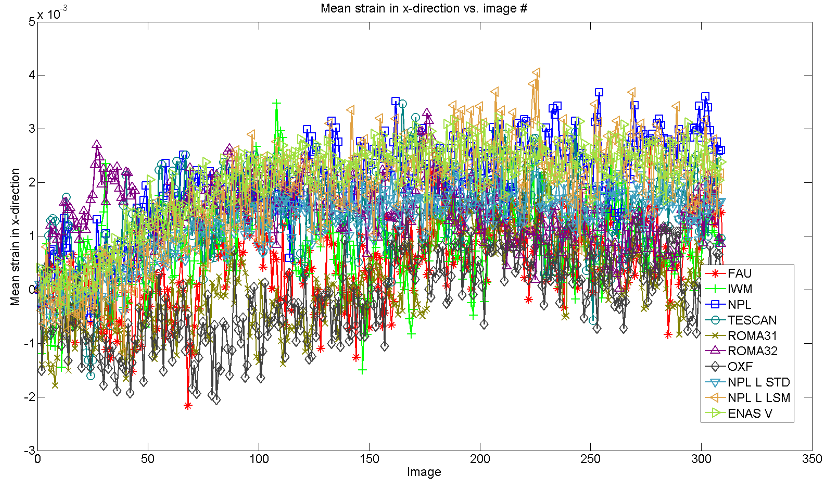





- Double Slot geometry in TiN coating
- Poor quality data – noisy, poor contrast
- Milling in 30 steps, 10 images each step
- Analysed using different DIC software using agreed parameters

- Data could be “improved” through significant post processing



# Potential issues contributing to DIC Uncertainty

Helps to identify what is important and what can be controlled

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- Correlation algorithms
- Potential out of plane displacement – 2D v 3D
- Test environment
- Temperature effects
- Inherent material variability
- Post processing of DIC data
- Use of 3rd party software
- Dedicated "fixed" setup cf multipurpose

Some will be more important than others

Other uncertainties associated with the test method are also important and should be considered and included in the Uncertainty Budget

# More Useful links

- SEM Challenge
  https://sem.org/dic-challenge/

- iSTRESS website
  http://www.stm.uniroma3.it/iSTRESS

  TENSTAND reports and files
  http://www.npl.co.uk/science-technology/engineered-materials/research/mechanical/tensile-testing-standards-and-tenstand/

- SPOTS
  http://cordis.europa.eu/result/rcn/83262_en.html

- VAMAS website
  www.vamas.org/

# SEM DIC Challenge

SEM Society for Experimental Mechanics

ABOUT EVENTS COMMUNITIES AWARDS PUBLICATIONS MEMBERSHIP

## DIC Challenge

The purpose of the DIC challenge is to supply the image correlation community with a set of images for software testing and verification. This is to include both commercial codes and university codes. The use of a common image data set removes the experimental errors associated with multiple hardware setups created by a typical, specimen-based, round-robin style test. The DIC code itself is then isolated and more easily evaluated independent of other experimental considerations. The DIC Challenge will be conducted under the auspices of the Society for Experimental Mechanics (SEM) under the direction of the DIC Challenge board. The purpose of the challenge is not to rank the existing codes, but to provide a framework in which all codes can be tested, validated and improved for use in experimental mechanics.

All information will be freely disseminated at the DIC Challenge website and open to all. While the images and results are open to all, there may be a requirement to limit the number of participating university codes. The open site still allows researchers to download the images and compare with the published results from the participating codes. All results will be posted and tied to the code used for the analysis. That is, each code used will be identified by name and tied to their results. Because of this, all analysis will be done by the code developers themselves. This removes any issues or concerns about misuse of the software by a third party.

Test images will be created both experimentally and synthetically. It is hoped that for all three stages of the DIC challenge we will be able to have both types of images. It will be the responsibility of the DIC board members to create and evaluate the images to best test and challenge the DIC codes. Details of the creation of the images will be recorded in a published paper so participants can understand how the images were created.

Answers will be supplied for some image sets (sample), but not for others (blind). The sample images will be supplied to allow the developers access to images similar to the blind tests but with known solutions to aid in the improvement of their code. The use of blind data sets is important to better mimic an actual experiment where the final answer is unknown; requiring the user to pick the "best" software settings without the aid of knowing the solution.

### DIC Challenge Board

The DIC Challenge Board will create the DIC challenges, moderate and compile the tests, and disseminate and interpret the results. The board will consist of users of DIC software with enough expertise in the use of DIC codes to be able to fairly create image sets and evaluate the results. Code developers will not be involved on the board to remove any suspicion of unfairness or conflicts of interest.

### DIC Board Members

Phillip Reu – Chairman
Bertrand Wattrisse (EU)
Wei-Chung Wang (Asia)
Evelyne Toussaint (EU)
Hugh Bruck (US)
Sam Daly (US)
Ramon Rodriguez-Vera (Latin/South America)
Florian Bugarin (EU)

### Challenge Datasets

2D-DIC

3D-DIC

SPOTS Static Test Item

### Example Data:

High Contrast Subpixel Contrast Images

Low Contrast Subpixel Contrast Images

https://sem.org/dic-challenge/

# iSTRESS Website

ROMA TRE UNIVERSITÀ DEGLI STUDI — Materials Science & Technology

Missing Plug-in

iSTRESS › iSTRESS Home page

iSTRESS iSTRESS-extranet

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Last modified at 4/28/2014 8:12 PM by Marco Sebastiani

Page Rating

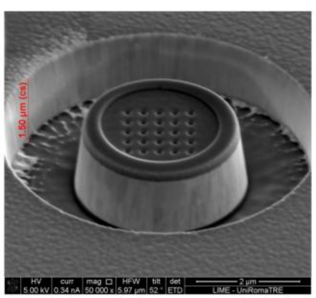
Categories
No categories were selected

Project Title: Pre-standardisation of incremental FIB micro-milling for intrinsic stress evaluation at the sub-micron scale

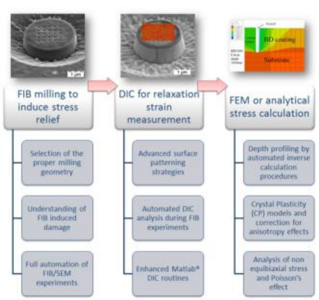
Current status: The project started on January 1st 2014.

Intrinsic (or residual) stresses, resulting from manufacturing or processing steps, mostly define the performance and limit the lifetime of nanostructured materials, thin films, coatings and MEMS devices. The established techniques for micron-scale measurement of residual stress still have strong limitations, e.g. in terms of spatial resolution, lack of depth sensing, their applicability on non-crystalline materials or accessibility to industry. In this project, a European consortium is established to develop an innovative, highly reproducible and automated measurement protocol for the analysis of residual stress distribution on a (sub)micron-scale, based on incremental focused ion beam (FIB) milling, combined with high-resolution in situ Scanning Electron Microscopy (SEM) imaging and full field strain analysis by digital image correlation (DIC). The activities will focus on the implementation and pre-standardisation of fully automated FIB-SEM, DIC and inverse stress calculation procedures, together with a quantitative analysis and modelling of FIB induced artefacts and stress-structure-properties relationship for the selected materials and devices. The final aim of the project will be the development of innovative design rules, implemented into simulation and optimization tools under coordination of industry partners, for the production of residual stress-controlled nanostructured and amorphous materials, with specific focus on (i) multi-layered nano-coatings, (ii) micro/nano-crystalline and amorphous materials, (iii) MEMS and 3D metal interconnects. The project is expected to realize a breakthrough in measurement, standardization and modelling ability of the residual stress distribution at the (sub)micron scale. The measurement techniques and the simulation tools will provide SMEs in particular with enabling technologies for the design and efficient production of innovative micro-devices with improved in-service performance and substantially reduce development costs.

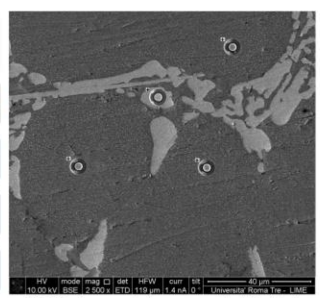

http://www.stm.uniroma3.it/iSTRESS/



FIB-DIC micron-scale ring-core method. Application on a Gold thin film on Silicon Substrate




Main experimental/calculation steps of the FIB-DIC procedure for residual stress analysis



FIB-DIC micron-scale ring-core method. Residual stress mapping on a multi-phase material

# TENSTAND website and files

NPL

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## Tensile Testing - Standards and TENSTAND

Introduction | Workpackages & Reports | ASCII data files | Partners

Engineered Materials

Research

### Workpackages and Reports

The project consisted of four technical activities as detailed below:

- **Literature Review** of tensile test machine control characteristics, modulus determination and inter-comparison exercises, and data suitable for the assessment of uncertainty.

  Click here to download the TENSTAND Test Method Review (PDF 10.1 MB)

- **Evaluation of Digital Tensile Software Specification of Software,** including evaluation of mathematical and graphical methods and preparation of ASCII format tensile data sets of typical engineering alloys. A series of data sets have been generated for validation of test machine and analysis software and for determining the designated material properties such as Proof Stress, or Upper and Lower Yield Stress, Tensile Strength, and Elongation at Fracture using testing machine manufacturers' commercial software and in-house university and industrial software.

  Click here to download the TENSTAND Software Validation Evaluation (PDF 2.29 MB)

  Click here for details of the ASCII datafiles

- **Modulus Measurement Methods:** Evaluation of methods algorithms used for determining tensile modulus by software validation using a) ASCII tensile data sets and b) by mechanical testing. The report compares modulus values determined using alternative techniques.

  Click here to download the TENSTAND Modulus Measurement Methods report (PDF 2.23 MB)

- **Evaluation of Machine Control Characteristics:** Work was carried out to examine the influence of test machine control, i.e. permitted speed changes during the test in the Standard, achieved through a test programme using a selection of materials, including the Certified Tensile Reference Material CRM661, and at other industrial relevant materials.

  Click here to download the TENSTAND Machine Control Tests report (PDF 2.53 MB)

### Tensile ASCII datafiles

These ASCII formatted data sets have been developed for the validation of tensile testing machine software, and for the determination of materials parameters by comparison with agreed values establish through the TENSTAND intercomparison.

Files can be downloaded as a complete set by clicking the link at the bottom of the following table:

| File | Material | Tensile behaviour |
|---|---|---|
| 01 | Nimonic 75, CRM | Monotonic yielding |
| 06 | Nimonic 75, CRM | Monotonic yielding |
| 10 | 13% Mn Steel | High work hardening |
| 13 | S355 Structural steel | Upper and lower yield |
| 17 | 316L Stainless steel | Monotonic yielding |
| 22 | Tin coated packaging steel | Stress softening |
| 30 | Sheet steel - DX56 | Low work hardening |
| 38 | Aluminium sheet - hard AA5182 | Stepped yielding |
| 42 | Aluminium sheet - soft AA1050 | Non-linear |
| 46 | Aluminium sheet - soft AA5182 | Serrated yielding |
| 50 | Sheet steel - DX56 | Low work hardening |
| 53 | Sheet steel - ZStE | Upper and lower yield |
| 57 | Synthetic data | Monotonic yielding |
| 61 | Synthetic data with 0.5% noise | Monotonic yielding |
| 63 | Synthetic data with 1% noise | Monotonic yielding |
| **Click here to access the whole set of datafiles - Zip file** | | |

**www.npl.co.uk/science-technology/engineered-materials/research/mechanical/tensile-testing-standards-and-tenstand**

**TENSTAND outputs used and cited in new ISO 6892  Standard for Tensile Testing of Metals**

# SPOTS, VAMAS

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European Commission

CORDIS

Community Research and Development Information Service

European Commission > CORDIS > Projects & Results Service > Optical metrology for strain measurement

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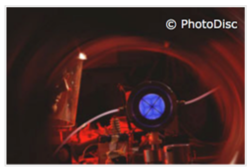
## SPOTS Result In Brief

Project ID: G6RD-CT-2002-00856
Funded under: FP5-GROWTH

### Optical metrology for strain measurement

***The SPOTS project focused on the specification of standards and reference materials necessary for the full exploitation of the benefits of optical techniques of strain measurement.***

Designers of parts and structures that are subject to load and stress normally aim to use materials and energy in the most cost-effective way. In addition to this, the more advanced the material used, the higher the degree of the induced complexity. On the basis of a non-contacting approach, optical strain measurement techniques enable the assessment of engineering artifacts subject to in-service loading.




Optical methods of strain measurements focus on the removal of uncertainties with the aid of detailed comprehensible stress data. This data enables the design of more reliable, safer, lighter and stronger products and devices with less uncertainty. The optimised designs do not involve any unnecessary material waste, which is particularly important for a wide range of industries including aerospace, automotive and biomedical applications.

Urged by this, the SPOTS project provided a better insight to the standards and reference materials used for realising the full potential of the optical strain measurement technology. Key project results include optimised methodologies, physical and virtual reference materials as well as recommendations for traceability routes. The use of accepted standards and calibrations results in rigorous strain datasets and thus, enhances confidence in the measurement procedures. For further information click at: http://www.opticalstrain.org/

DE ES FR IT

### Related information

**Report Summary** Specification of reference materials (D7, D9, D14)

### Subjects

Measurement Methods - Reference Materials

http://cordis.europa.eu/result/rcn/83262_en.html

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VAMAS

**Full field optical stress and strain measurement**
Technical Work Area 26

**Call for Participation**

Project 2
**Validation and Integration of Numerical simulations and ExperimentS (VINES)**

**Objectives**

The principal objective of this project is to develop guidelines and a standard methodology for the comparison of experimental strain and deformation measurements to numerical simulations of cyclic, transient and non-linear dynamic events. To this aim the project will cover the following areas:

- Development of suitable reference materials that allow traceability and calibration of full-field optical methods under dynamic conditions
- Optimisation of methodologies for both optical measurement and computational modelling and simulation
- Create draft documentation for Submission to ISO as a TTA.

It is planned to link with the EU funded project Advanced Dynamic Validations using Integrated Simulation and Experimentation – ADVISE (see www.dynamicvalidation.org) under the 7th Framework Programme to disseminate its output and provide a forum for the standardization aspects.

**Background and Standardization Needs**

The previous SPOTS project produced a draft standard document covering calibration and evaluation of full field optical methods for strain measurement. This project dealt with standards for the calibration of static test measurements and it was felt that the development of techniques suited to dynamic calibration would benefit the increased requirement for dynamic testing. This requirement has arisen from the continual increase in the need for safer and more reliable forms of transport.

Crash and impact testing is of major importance during the evaluation of a vehicle's ability to survive a collision and maximise occupant survival. The production of standards for impact assessments will be of great benefit in this area of industrial activity as it will provide a consistent basis for measurement and comparison with simulation.

**Work Programme**

- Evaluation of Advanced Tools for Simulation & Experimentation
- Assessment of Dynamic Calibration Methods and systems
- Experimental Validation by Case Studies
- Conferences, specialist workshops, discussion forums

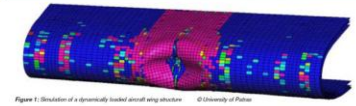

*Figure 1: Simulation of a dynamically loaded aircraft wing structure © University of Patras*

*Figure 2: The video images show a typical bird impact on a generic or idealised leading edge aircraft structure. Tests were performed to 'calibrate' a numerical model of the test event. This approach enables certification of leading edge structure based on validated models rather than tests using expensive aircraft test sections. © Airbus 2009*

**Deliverables and Dissemination**

- Evaluate and feedback on methods developed by the ADVISE project for experimental measurement calibration and validation of numerical simulations of dynamic events,
- Draft document for consideration as a Technology Trend Assessment (TTA).
- Liaison with organizations that have interests in the subject of Simulation and Experimentation (NAFEMS, BSSM, SEM, etc.)

**Status**

Approved for startup. Additional participants welcome.

**For more information on participation, please contact:**

**Dr. Richard Burguete**
Chair, VAMAS TWA 26
richard.burguete@airbus.com
www.twa26.org

**www.vamas.org**

March 2010

http://www.vamas.org

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VAMAS

**Modulus Measurements**
Work Area 32

**Validation of the test method for the measurement of the tensile elastic modulus**

**Background**

The need for improved elastic modulus measurement was highlighted in the CIPM Working Group on Materials Metrology report that found extremely poor reproducibility in tensile elastic modulus proficiency testing.

This poor reproducibility was also encountered during the certification of the existing BCR 661 reference material. This material has been produced to serve as a tensile reference material, and based on an interlaboratory exercise it has been assigned several tensile testing related certified values (proof stresses, elongation at fracture, reduction in area at fracture, tensile strength). However, the obtained elastic modulus values were not sufficiently reliable to serve as a certified value (an indicative value with a relatively large uncertainty is provided instead).

**Standardization Needs**

Standards EN10002-1 and ASTM E8 focus predominantly on measuring the full stress-strain curve. ASTM E111 covers elastic modulus measurement in more detail, but there are still issues with aspects of strain measurement and data analysis, which need to be resolved.

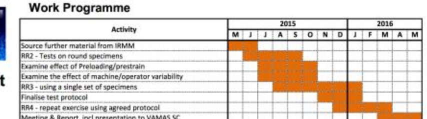
Recommendations from an EU funded project (TENSTAND) included the development of a separate dedicated tensile test for elastic modulus, but further groundwork and lobbying of the relevant standards committees is required to gain support. The collaborative project to examine aspects of the procedures and test methodology will be a valuable development.

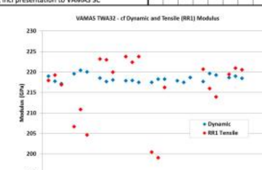
**Deliverables**

- VAMAS technical report on the interlaboratory comparison exercise
- Draft text for submission to an international standards development organization

**MORE PARTICIPANTS WELCOME**

**Work Programme**




**Measurement Traceability**

Through the MoU between BIPM (www.bipm.org/) and VAMAS, it is hoped an interaction will be developed with the Consultative Committees on length (CCL) and mass (CCM) to ensure best practice and traceability of the prime measurements made in elastic modulus tests.

**Funding**

Participation is based on in-kind effort by the partners.

**For more information:**

**Dr. Jerry Lord** Chair, TWA32
Email: jerry.lord@npl.co.uk

**Phase 1 Results**

'Indicated' modulus value for BCR 661
**E = 206.0 ± 21GPa**

NPL dynamic modulus characterisation
**E = 218.5 ± 0.9 GPa**

Phase I Tensile modulus
**E = 215.5 ± 8.0 GPa**

- Inherent variability in the BCR 661 reference material
- Initial data is looking very promising (reduced uncertainty)

**www.vamas.org**

September 2015

# Summary

- Uncertainty budgets are useful to examine and optimise the test setup
- Attention to detail is vital
- Capture the best quality images possible
- Understand what the DIC processing conditions do
- Do a quick test – check the suitability of image/pattern quality & DIC settings

- Reporting (proforma ?)
  - All relevant information
  - Images and displacement fields
  - DIC processing conditions
  - Calibration and validation checks
  - How the strain and displacements are calculated
  - Any post processing
  - Uncertainty

- Use the Resources available
  - SEM Challenge images, UNCERT procedures, BSSM, GUM, Standards, DIC websites, User Groups etc