StrainMaster

Advanced Digital Image Correlation Systems
for Optical Full Field Measurement of
Material Strain, Displacement and Shape

LAVISION
FOCUS ON IMAGING

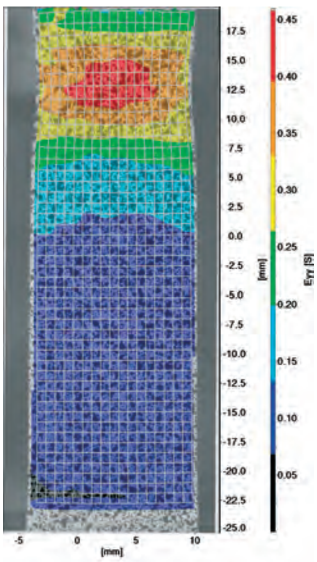
StrainMaster

Optical Technology for Full Field Strain Measurement

StrainMaster from LaVision combines the most advanced **Digital Image Correlation** (**DIC**) algorithms with the highest quality hardware to provide a complete device for materials analysis. **StrainMaster** is applicable across all industries investigating material behaviour and gives fast, highly accurate results via an easy to use PC based interface.

A range of **StrainMaster** systems are available from portable field work machines to highly specialized lab versions. Any system can be tailored to suit your particular requirements, and are appropriate for both industrial and academic applications across a vast range of subject areas. Unlike many standard **Digital Image Correlation** (**DIC**) systems, LaVision's **StrainMaster** is insensitive to the speckle pattern distribution and in many cases the natural surface of the material is quite sufficient to allow the acquisition of highly precise displacement and strain data.

Applications



- tensile, compression, and bend testing
- material characterization
- ultra-fast impact and blast
- high temperature
- crack detection
- granular flows
- cyclic fatigue
- sub-surface defects
- Fluid-Structure Interaction

StrainMaster can be supplied as a complete turn-key system or as stand alone software for importing and processing images from an external source such as a Scanning Electron Microscope (SEM). The system offers a complete solution and data management system able to drive hardware, acquire images, process data, validate and display or export information. LaVision's approach to Image Correlation means that all of the pertinent information is visible and the user chooses the level of post-processing. Whilst intelligent smoothing may be appropriate for standard materials undergoing tests in the elastic regime, this may not be appropriate in other cases where local discontinuities may be present but their onset cannot be predicted. The LaVision approach allows the user to inspect the raw displacement results prior to deciding upon the type of filtering necessary.

System Features

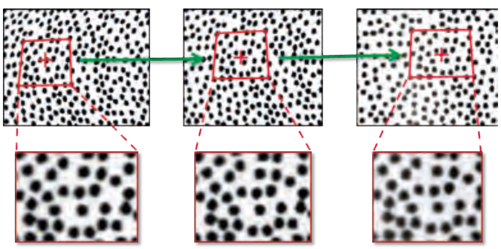
- complete camera integration including high-speed devices
- StrainMaster controller for synchrnoisation of devices with external analogue signals
- total control over post-processing - raw data is always available
- compact and robust mechanics
- complete control, analysis, and data management within one software package
- fast and accurate processing
- live gauge extensometer mode with optional scaled analogue output for strain control
- dedicated Add-on for MATLAB®, and export formats including ABAQUS® INP

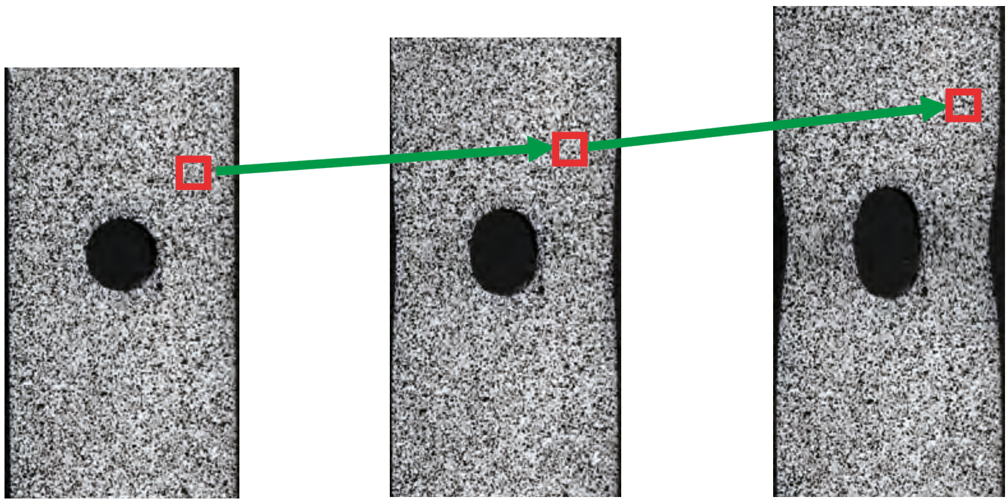
StrainMaster
Digital Image Correlation

Digital Image Correlation (**DIC**) is a method to compute local displacements in a sequence of images showing some kind of specimen deformation. The images are discretized into small subsets of NxN pixels, and the algorithm tracks the pattern within each subset. Where the pattern matching is maximized (or the differences minimized), this represents the local displacement. Repeating this across the entire image for all subsets yields a full field map of data, which is similar to having thousands of virtual extensometers or strain gauges on the sample surface. Moreover, by using a stereoscopic camera setup and corresponding calibration routines, DIC is also able to access out of plane displacements and changes in surface topology.

Matching Local Subset Pattern

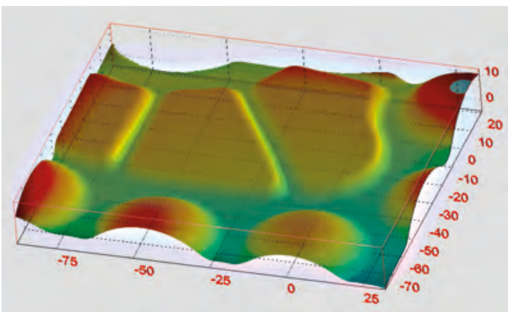
Within the **StrainMaster DIC** software a Least Squares Matching (LSM) approach with subset deformation is used to match the pattern in combination with higher order spline interpolation of the greyscale images.



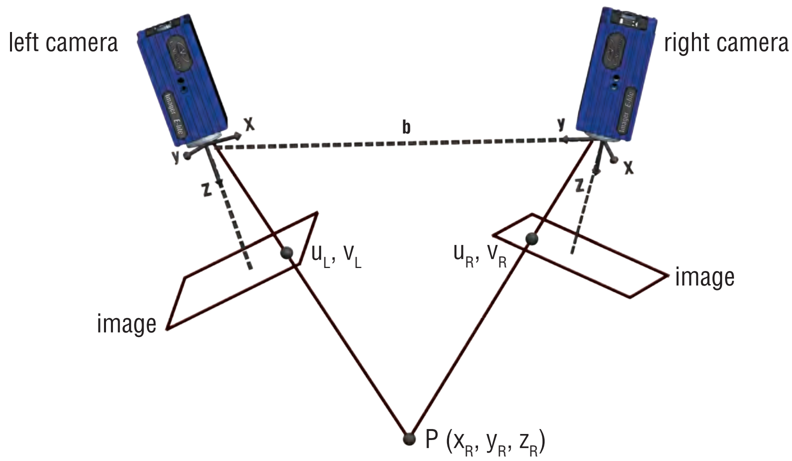


Usually, the displacement field is calculated relative to the specimen in its undeformed state (typically the first image in the sequence). In cases where the deformation is relatively small the pattern in image N is matched directly back to the reference image. However for large deformations the local pattern experiences significant changes, and a sum of differential approach is used whereby the pattern is matched between successive images and then summed in a Lagrangian co-ordinate system.

3D Stereoscopic DIC



In 3D stereoscopic DIC systems two cameras view the surface of the specimen. The camera system is calibrated such that the relationship between raw and world space is known. By matching the pattern between cameras and using the calibration model, the height and z-displacement of the surface can be calculated. This depth perception system works like our eyes do.



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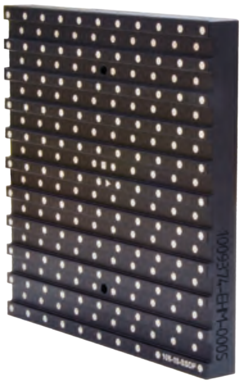
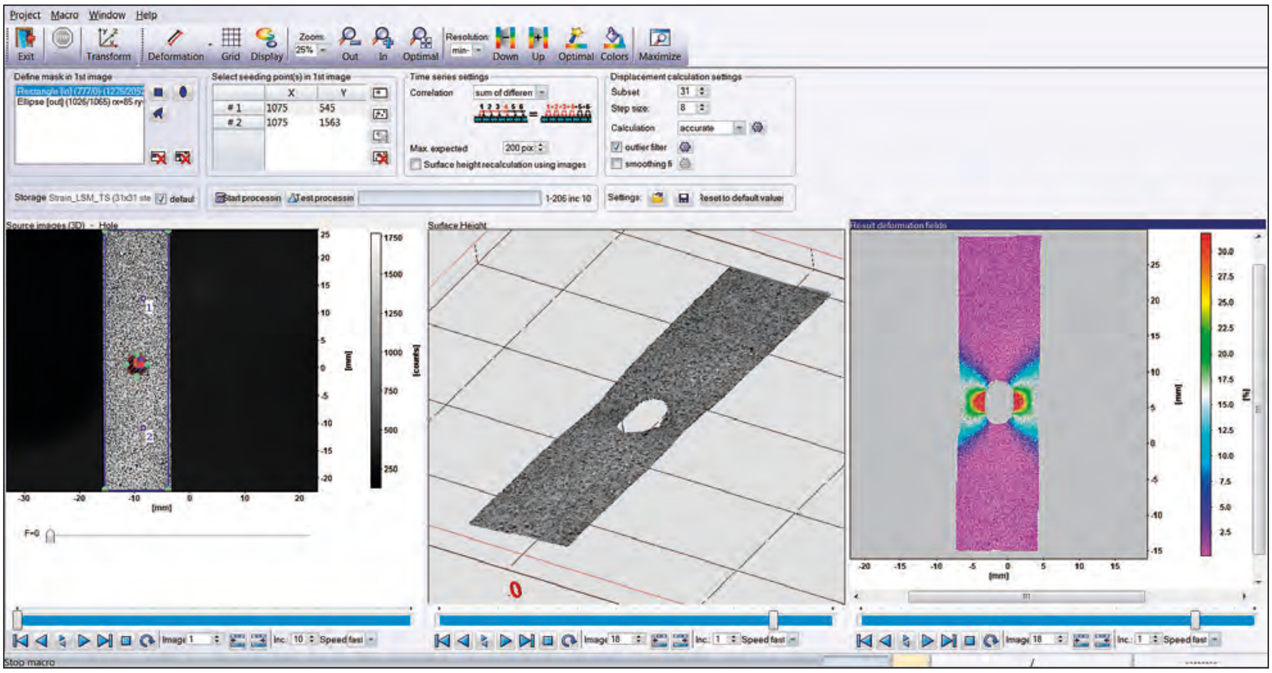
Comprehensive DIC software



The **StrainMaster** software features a simple workflow enabling users to get reliable results quickly.

- set-up aids including focus and dynamic range indication
- one view 3D calibration in less than 60 seconds, and advanced polynomial calibration modes for configurations such as stereo microscopes
- accurately synchronized image and analogue input acquisition via the recording dialogue, or import images from a standalone camera
- flexible masking of the image to define the zone(s) of interest
- choice of time-series mode, subset parameters, and calculation type
- ability to inspect the quality of the raw data before post-processing
- calculate strain (Lagrange, von Mises, Tresca)
- apply virtual extensometers and gauges to the surface
- generate a report or export data (in formats including MATLAB® and ABAQUS®)



Advanced Processing

In addition to the standard easy-to-use interface, **StrainMaster** benefits from being built on the powerful DaVis platform, providing extensive flexible features which are needed in research environments. The batch processing mode allows the user to process multiple sets of images with pre-defined parameters, and it is possible to include user defined macros. A wealth of processing functionality can be found and utilized such as non-linear filters, smart algorithmic masking and much more.

Two-way Interface

Having acquired a set of results the user is able to automatically generate a report, read it directly into MATLAB® or export in specific formats

- MATLAB® Add-on
- ABAQUS®
- point cloud
- movies
- standard image and text formats

It is also possible to include any file (Word®, Excel®, PDF, PowerPoint®) into your experimental DaVis project.

StrainMaster

Full Control

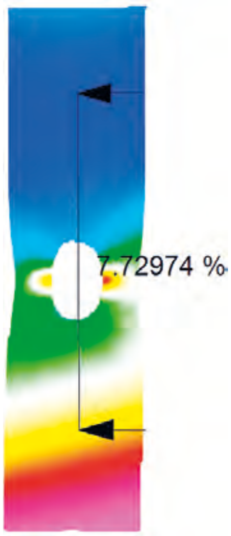
The DaVis platform offers complete hardware control, with no need to rely on home-made triggering or separate multiple control programmes. It is possible to build acquisition loops and specialized timing schemes.

- standard and high-speed cameras
- data loggers for analogue data acquisition
- translation stages
- pulsed light sources

Phase locked recording of cyclic events such as fatigue testing is possible with the **StrainMaster** Controller, and post-triggering of high-speed events such as Split-Hopkinson pressure bar tests is straightforward.

Operating in live mode, or as a post-process, it is possible to apply virtual extensometers or strain gauges to the specimen surface. This approach using optical techniques has several advantages over conventional mechanical devices:

- non-contacting
- no need to choose extensometer position before the test
- is not damaged if the specimen fails
- can be used where the specimen is in solution or an environmental chamber

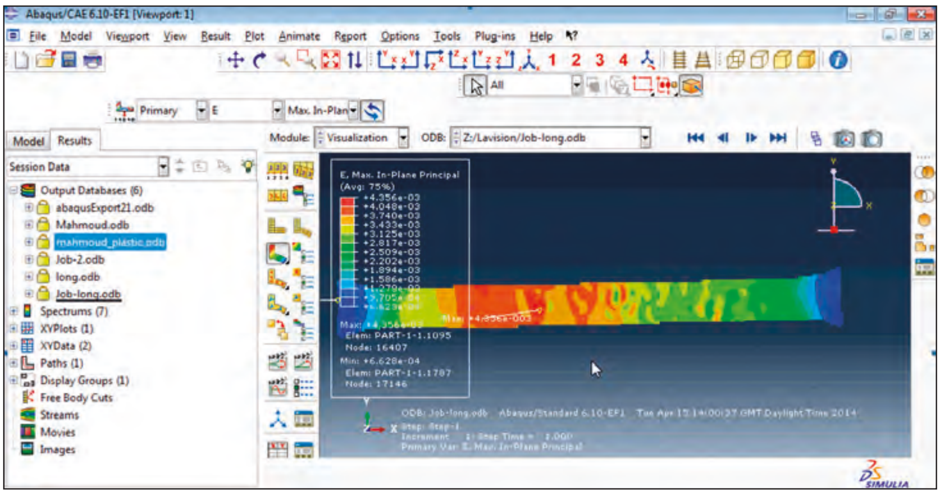


Open hole tensile test images and results (pages 3,4,5), courtesy of Prof. C.R. Siviour and Prof. R.C. Reed, University of Oxford

In live mode the strain measured by the virtual extensometer can be outputted via optional 16 bit D/A converter as a scaled voltage, allowing the user to configure this in a strain control scheme. The beauty of DIC is that it allows comparison of extensometer and full field data, often revealing that the full field data offers far more insight into the material behaviour.

Finite Element Analysis

A common use of full field experimental data is to compare with and validate Finite Element simulations. To facilitate this it is possible to export data in ABAQUS® INP format, allowing the user to compare experiment and simulation within the ABAQUS® post-processor, and even think about utilizing experimental data as boundary conditions for the simulation.



Crack Growth Analysis

StrainMaster includes a crack growth analysis module to identify and track crack development in materials, reporting crack length and crack opening. This module works with non-speckled surfaces and the standard **StrainMaster** hardware.

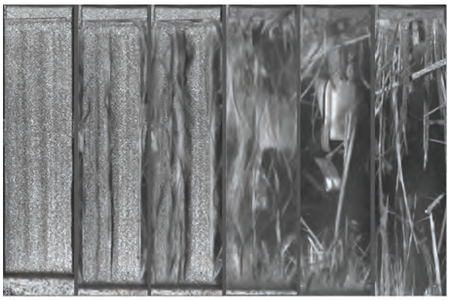
StrainMaster
for Industrial and Research Testing

The range of applications where **StrainMaster** has been applied is vast, spanning all research sectors and specimen scales, from microscale to metres. A few examples are shown here but further detailed examples can be found in our separate application notes.

Aerospace

Composite materials are extensively used in aerospace and other high performance applications, particularly where speed and manoeuvrability are primary considerations. Full-field data-rich imaging techniques are used to provide a better understanding of the behaviour of composite materials subjected to high strain rate loading, such as those experienced during shock and blast loading.

The example shown comes from the University of Southampton where an Instron VHS test machine was used for high strain rate testing of a composite specimen. A test methodology was also developed to gather data synchronous with Infra-Red imaging techniques, and utilize Thermoelastic Stress Analysis (TSA) to make further calculations. This kind of data is invaluable in validating and optimizing computational simulations.

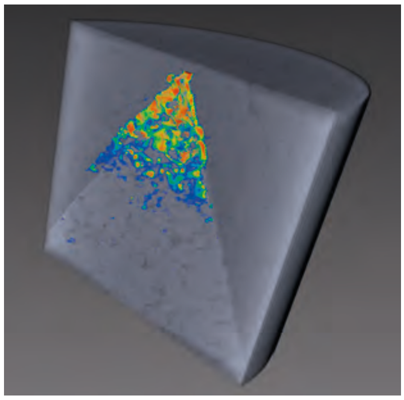


Sample - tested to failure, courtesy of Prof. J. Barton, University of Southampton

Energy

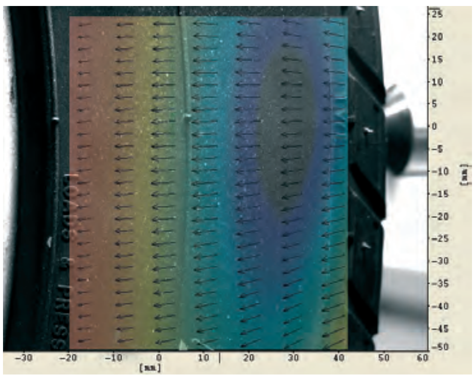
Graphite is an important component in several current and future design of nuclear fission reactors, and the structural integrity of the graphite moderator is critical to the safe operation Advanced Gas Reactors (AGRs). Radiolytic oxidation degrades nuclear graphite strength while fast neutron irradiation causes dimensional changes which in combination can cause damage to the reactor core.

Digital Volume Correlation (**DVC**) was successfully applied to X-ray Computed Tomography images of nuclear graphite. It allowed the calculation of full volume displacement and strain results, and enabled the crack opening displacement under load to be measured, revealing cracks before they can be identified in the raw image.



Strain visualization of a stable crack in a chevron notch test specimen, courtesy of Prof. J. Marrow University of Oxford

Automotive



The performance of the materials used in the automotive industry, and of the components manufactured using those materials is critical to safety, and an important factor in creating a light-weight fuel efficient design. With ever increasing emissions targets, automotive engineers need to investigate every aspect of construction in modern vehicles, necessitating a deep understanding of the integrity of traditional and composite materials.

As well as investigating panel deformation or exhaust manifold expansion, **StrainMaster** can be utilized to investigate dynamic events such as tyre squash. This can even be done on a rolling road setup through the use of high-speed cameras or phase locked measurements.

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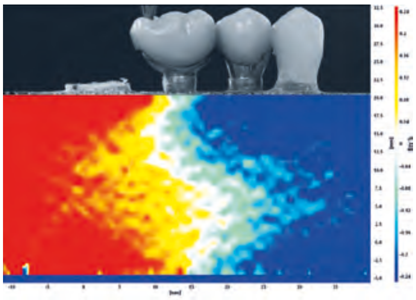
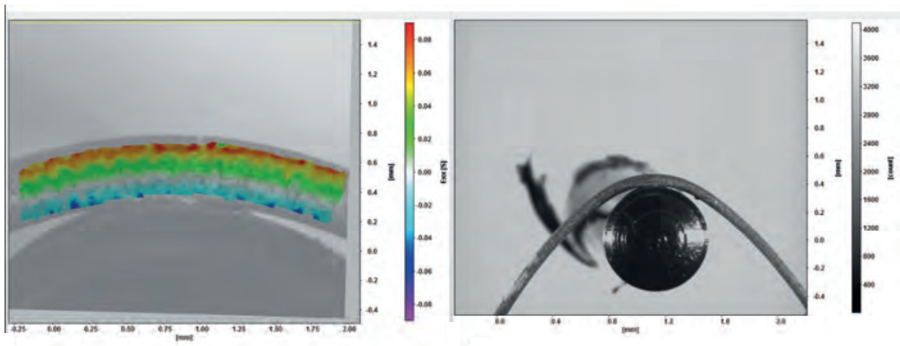
Biomedical

DIC and **DVC** have been successfully applied to skin tissue, bone, teeth (see left) and implants. Biomechanical applications often require very small fields of view necessitating specialized optics. One such example is the study of Nitonol shape memory alloy which is used in endovascular stent graft systems produced by Vascutek Ltd. By using a **StrainMaster** system equipped with a stereo microscope it was possible to gain an understanding of the functional behaviour of small scale (< 0.5 mm diameter) Nitinol wire.



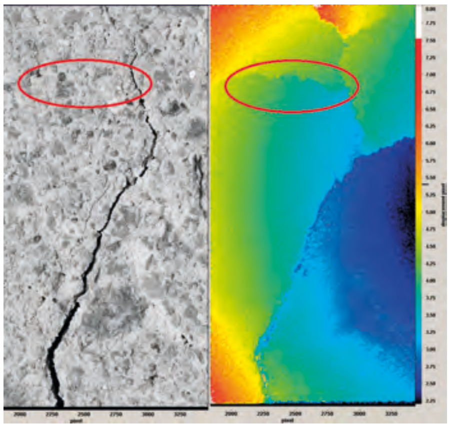
Analysis of implant-supported dental restorations, courtesy of Dr. R.Tiossi, Dental School of Ribeirao Preto, University of Sao Paulo, Brazil



Strain map on the surface of the specimen illustrating the compressive and tensile sides of the wire, courtesy of Vascutek Ltd.

Civil

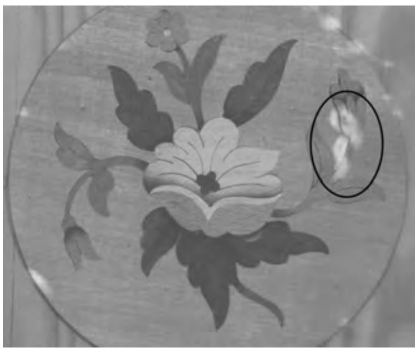
StrainMaster is well suited to civil engineering applications such as beam deflection or crack propagation in concrete. In the example on the right **DIC** has been used to identify the crack location within part of a concrete structure. The natural pattern of the concrete lent itself well to the approach.



Identification of cracks propagating through concrete, courtesy of Dr. J. Lord, National Physical Laboratory

Arts and Conservation

Historic furniture has very delicate materials which are susceptible to humidity changes; a parameter which cannot always be easily controlled in historic houses or old museum buildings. It is therefore beneficial to be able to identify a strain hot spot on a piece of furniture, fresco painting, or tapestry before significant damage occurs.



Courtesy of Dr. N. Luxford, UCL Institute for Sustainable Heritage

Digital Image Correlation can use the natural pattern of the material to identify defects before they are visible to the eye, and in the example shown the lifting of a piece of the marquetry surface has been identified.

Many more Applications

- geological study of rock deformation
- structural health monitoring
- marine structures and components
- food and beverage industries

These two pages have given only a small selection of the possibilities and many more can be found in the more detailed application notes available on the LaVision website.

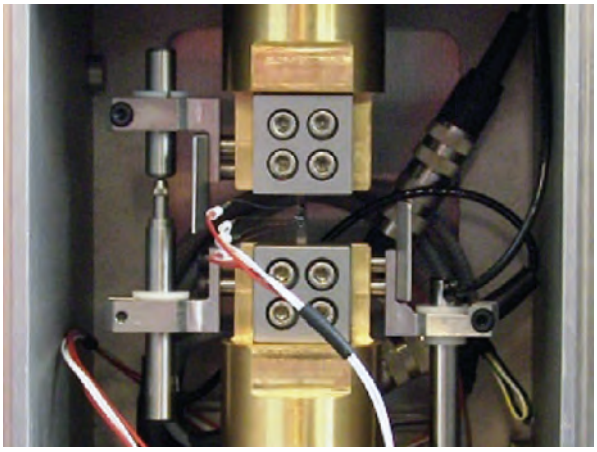
StrainMaster

Upgrades and Specialist Applications

Understanding of strain rate effects on material behaviour is important in the case of structures subject to dynamic, shock, impact or blast loading. Full-field data-rich imaging techniques are used to provide a better understanding of composite, metal, and plastic material characteristics at high strain rates. High-speed **StrainMaster** systems feature fully integrated high-speed cameras with kHz frame rates.

Small Scale Micro-DIC

Understanding the mechanical and material behaviour of microscale components is extremely challenging and there is often a lack of detailed information on microelectronic or biomedical materials in terms of stress-strain behaviour. LaVision offers stereo microscope based 3D DIC systems which allow the user to collect and analyze full field shape and strain in sub millimetre ranges. This information is extremely valuable in validating complex Finite Element simulations.



Courtesy of Dr. B. Grant et al, School of Materials, University of Manchester

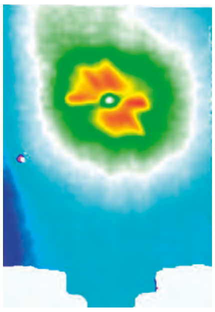
High Temperature DIC

Measuring the strain response during loading at high temperature is a key capability for determining the mechanical and thermophysical properties of materials that are to be used at elevated temperatures. This topic is especially important in applications such as power generation, automotive engines, and gas turbine combustors, where the material may be operating beyond normal temperature limits. LaVision offer dedicated solutions for high temperature DIC measurements in terms of lighting, optics, and surface preparation

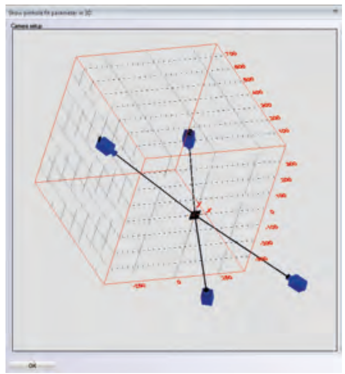
StrainMaster

Multi-Camera Systems

The dual level, two-sided calibration plates allow more than two cameras to be calibrated within a single co-ordinate system. Together with the advanced PTU X controller, these cameras are accurately synchronized to obtain surface measurements from both sides of a panel, for example.

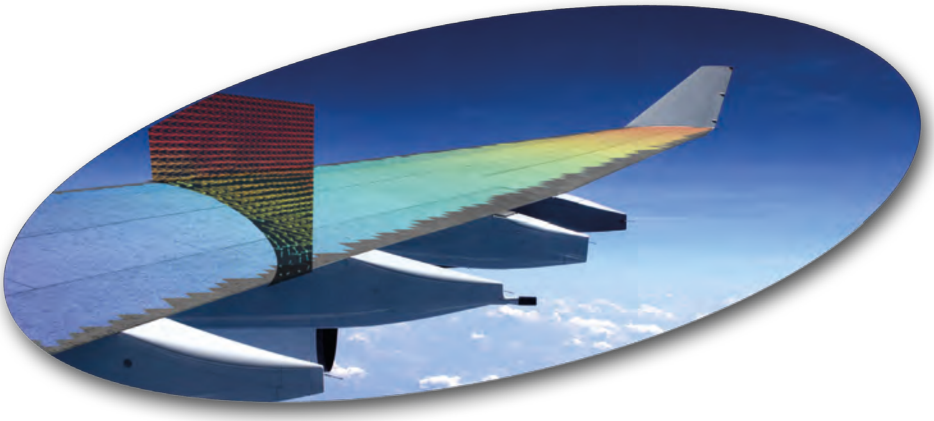


Thickness map of an impact damaged composite panel, courtesy of X. Sun and Dr. S. Hallett, University of Bristol



Fluid-Structure Interaction (FSI) Combined Fluid Flow and Surface Deformation

Interaction between air or water flow and a structure surface profile can result in a change in the fluid flow path, which in turn causes pressure changes on the surface and can influence the shape. This interaction between fluid and structure may result in periodic or cycling instabilities which can establish **Fluid Induced Vibrations** (FIV). LaVision offer systems which can simultaneously measure and quantify the fluid and surface behaviour. By coupling our PIV and DIC technology we are able to measure the **Fluid-Structure Interaction** behaviour.



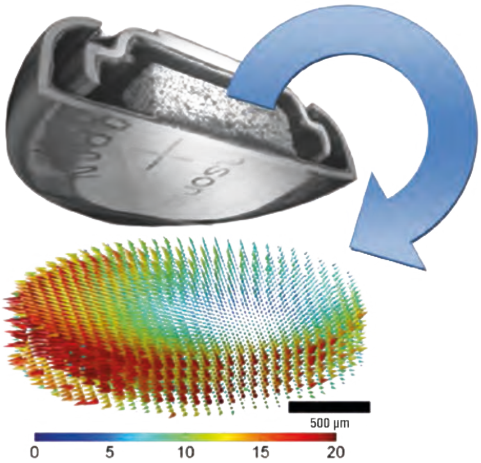
Combined Infra-Red Temperature and Strain Measurements

Materials and components are often subjected to combined mechanical and thermal loads, and it is essential for design and test engineers to understand strain response during these combined loading scenarios. By combining an IR camera with the **StrainMaster** system it is possible record temperature and strain distributions and correlate the two quantities. The **StrainMaster** software can easily calibrate and include infra-red camera images within the project.

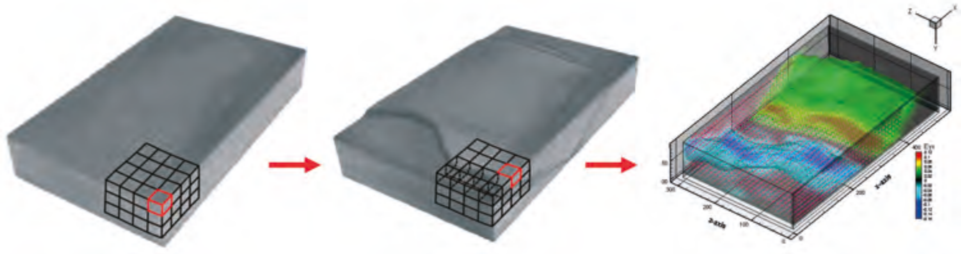
StrainMaster

Going beneath the Surface

StrainMaster Digital Volume Correlation (**DVC**) is a powerful extension of DIC and provides full volume 3D strain and displacement measurements. The material's natural or artificially introduced internal pattern is tracked between subsequent volumes, as illustated below for the case of a „sand box" tectonic plate simulation. The obtained 3D full-field displacement and strain maps allow the user to truly understand the subsurface material behaviour and validate complex simulations, and in the case below visualize the shear bands developing between the base and pop-up structure.



Cutaway view of the reconstructed image of the battery and vectors showing dilation in the charged state, courtesy of Dr. D. Eastwood, School of Materials, University of Manchester



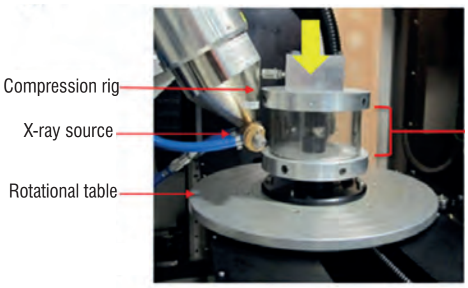
Tomographic strain analysis of 3D XCT analogue experiment using Digital Volume Correlation (DVC), image courtesy of Dr. J. Adam, Department of Earth Sciences, Royal Holloway University of London

DVC is one of few full volume measurement techniques which can validate sub-surface strain behaviour

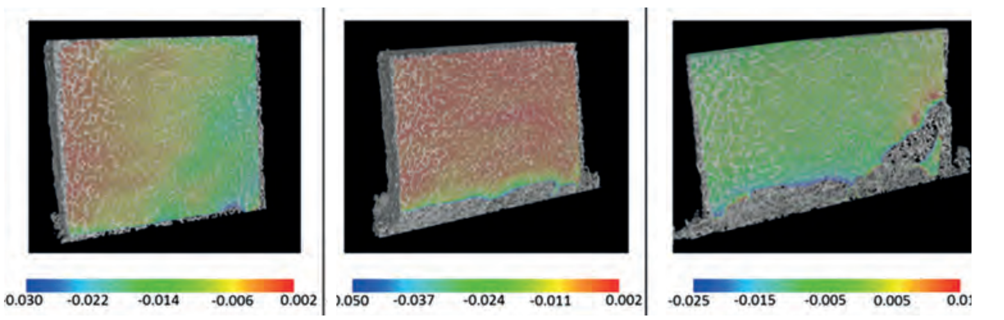
- import from any volume imaging device with no volume size restrictions
- 3-dimensional 3-component (3D3C) displacement field in a complete volume
- identify cracks and discontinuities before they are visible in the image
- rigid body shift correction and volume alignment routines
- over 1 million nodes can be calculated per volume
- advanced direct correlation with deformed interrogation volumes and multi-pass iterations.
- displacement precision better than to 0.01 voxels

Use Volume Images from X-ray Computed Tomography

Images are typically acquired from X-ray Computed Tomography (X-ray CT) systems, but can equally be obtained by Magnetic Resonance Imaging (MRI), confocal microscopes, Optical Coherence Tomography (OCT) or via optical tomography for transparent media; for which LaVision offers its patented Tomographic reconstruction algorithms as an add-on.



Complete experimental test setup with yellow arrow showing compression direction



E_{zz} strain map for 1st, 3rd and 6th compression step, image courtesy of Dr. F. Gillard, Bioengineering Science Research Group, University of Southampton

Applications

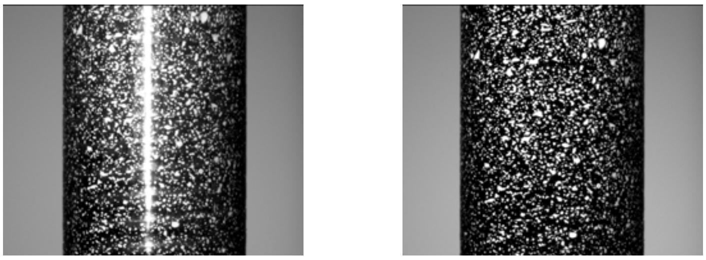
Biomechanical subjects such as the study of bone implants are well suited to DVC due to the natural inherent pattern, and DVC is able to determine the relative motion of bone and implant, for example. The example above shows bone under compression. However DVC is suited to many other applications including granular flow and powder compaction, composite testing, foams, concrete and many more.

StrainMaster

Compact and Portable DIC System

Suitable for a huge range of applications where flexibility and portability is essential, we have developed LaVision's StrainMaster Portable system to be appropriate for a wide range of applications. It allows the user to quickly and easily obtain full field data over the entire material surface. Ease of use is enhanced by the inclusion of polarization filters on the LEDs and lenses (patent EP1739403B1) to avoid undesirable specular reflections which can confuse the correlation algorithms causing reductions in data quality.

Polarized light



Speckled carbon fiber tube without (left) and with (right) polarized light

Standard 2D StrainMaster

Standard 2D StrainMaster mounting system includes:

- heavy duty tripod
- 1m lightweight horizontal rail
- 1x camera and 1x LED gearheads on sliding mounts

3D Stereo StrainMaster Upgrade

Standard 3D StrainMaster mounting system includes 2D system as above plus:

- additional 1x camera gearhead on sliding mount
- additional 1x LED gearhead on sliding mount

Optional Mechanical Add-ons

- longer rails for larger camera separation
- custom mounts for test machines
- adapter for vertical orientation

StrainMaster Controller

The StrainMaster Controller mounts on the camera rail controlling all triggering and synchronization.

- camera and pulsed LED power supplies
- ultra accurate 0.05 nansecond jitter between output lines
- A/D converter with 8 input and 2 output lines (optional)

Accessories

LaVision recognizes that research requires flexibility in the system configuration in order to carry out challenging and novel testing. We have a wide range of add-ons and accessories available including specialized lenses and illumination.

- a range of c-mount, f-mount, and specialized lenses
- airbrush for fine scale speckle application
- blue illumination and filters for high temperature testing (see left)

Blue LED illumination unit

StrainMaster
System Components

Depending on the application LaVision's **StrainMaster** systems integrate different light sources and cameras:

Standard camera	Model	Features
	Imager *E-lite* 2M Imager *E-lite* 5M	compact, high sensitivity, CCD cameras with 2 or 5 million pixel, a fast Gigabit Ethernet interface and frame rates up to 14 Hz*.
	Imager *M-lite* 2M Imager *M-lite* 5M	excellent image quality, fast, CMOS cameras with 2 or 5 million pixel, USB3 interface and frame rates up to 100Hz* (M-lite 2M) and 57 Hz* (M-lite 5M)
	Imager *X-lite* 8M Imager *X-lite* 11M Imager *X-lite* 16M Imager *X-lite* 29M	advanced progressive scan, fully programmable CCD cameras, high quality images, combined with high spatial resolution. Models are available with 8, 11, 16, 29 million pixel and frame rates between 1.7 and 8.5 Hz*.

High-speed camera	Model	Features
	Imager *MX* 4M	cost effective, high spatial resolution CMOS camera with 4 million pixel combined with frame rates up to 180 Hz*.
	Imager *HS* 4M	4 million pixel, incredible image quality, fastest data transfer and frame rates up to 1279 Hz at full resolution.
	Photron cameras (HighSpeedStar)	up to 4 million pixel CMOS cameras with frame rates up to 25.6 kHz* at full resolution and 1 MHz frame rates possible at reduced resolution, up to 288 GB on board RAM and extremely high sensitivity.
	Phantom cameras	

* depending on system configuration

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