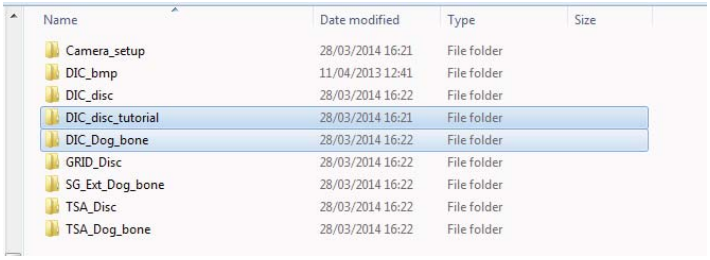
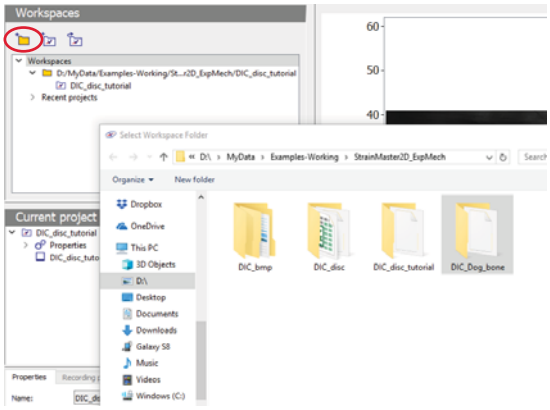
Before we start

1. **Log in**
2. **Create a new folder in My Documents (=H:\[Your DaVisProjectsName])**
3. **Transfer data from \\soton\ude\courses\SESG6031 to My Documents (=H:\[Your DaVisProjectsName]) including *.exp files**
   - DIC_disc_**tutorial**
   - DIC_Dog_bone



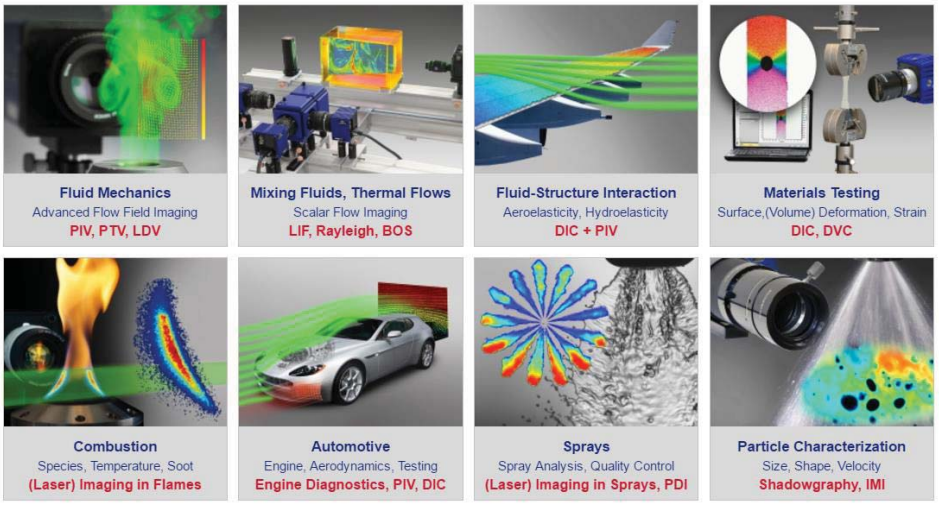
4. **The address of the software licence server is 192.168.168.174**
5. **You may need to search for the licence**
6. **The licence file you will need when you install the DaVis software on your own machine is here: \\soton\ude\Courses\SESG6031\Software\Davis**



1. Select add new workspace (add both DIC_Dog_bone and DIC_disc_tutorial)
2. The projects appear below the relevant workspace

LaVision Imaging Systems

FOCUS ON OPTICAL MEASUREMENT SOLUTIONS



The Digital Image Correlation process

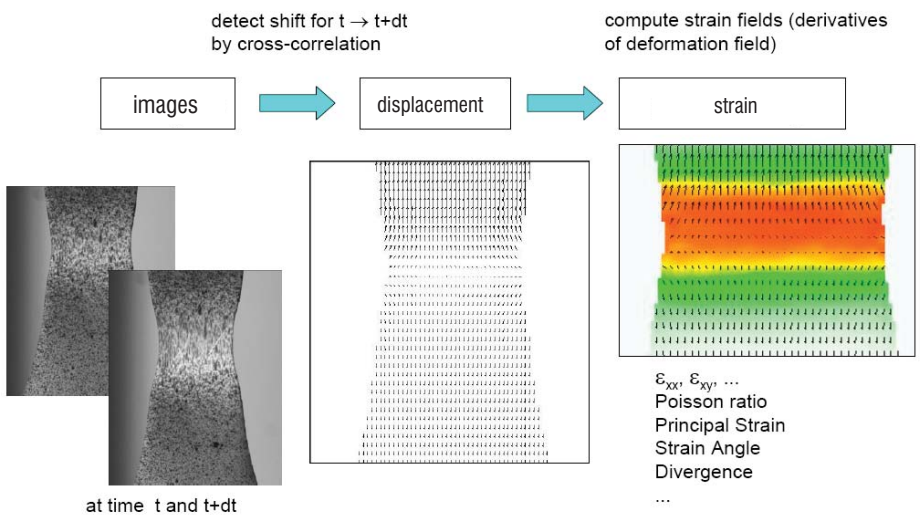
Hardware Set-up	• Camera and lighting set-up • Good and bad practices
Sample Preparation	• What makes a good pattern • How to apply the speckle
Calibration	• Appropriate mode to use • Surface height calculation
Imaging	• Importance of resolution • Timing, image sequences, frame rate, synchronisation
Calculate Displacements	• The construction of DIC algorithms • Interpolation, shape function, matching and correlation
Extract Strain Data	• Filtering and post-processing displacement data • Strain calculation from displacements
Result	• Displaying data • Exporting data and extracting values

The Digital Image Correlation process

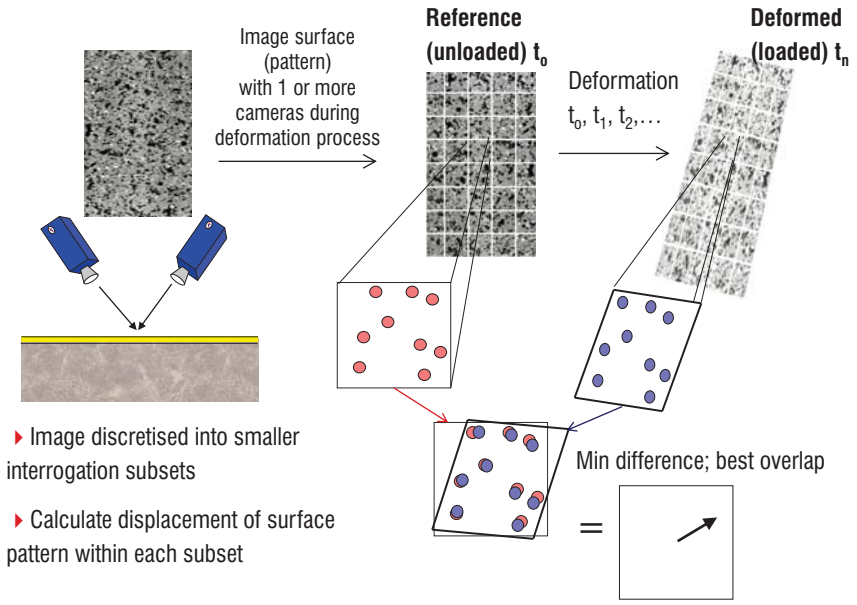
Reminders only in this lecture

Hardware Set-up	*Covered in previous lectures and in the lab*
Sample Preparation	*Covered in previous lectures and in the lab*
Calibration	*Covered in previous lectures and in the lab*
Imaging	*Covered in previous lectures and in the lab*
Calculate Displacements	• The construction of DIC algorithms • Interpolation, shape function, matching and correlation
Extract Strain Data	• Filtering and post-processing displacement data • Strain calculation from displacements
Result	• Displaying data • Exporting data and extracting values

DIC gives full field Displacement and Strain



Digital Image Correlation



- Image discretised into smaller interrogation subsets
- Calculate displacement of surface pattern within each subset

From Prof Pierron's lecture…

- **Digital Image Correlation (DIC) is becoming a common tool in experimental mechanics**
- **However, relatively *new*: commercial systems around 20 years old**
- **DIC : Easy and fast?**
- **Many parameters: speckle, camera (noise), lens (distortion), lighting (heating, saturation …), subset size, step size, virtual strain gauge size**
- **Influence of the choice of these parameters? Uncertainty estimation?**

Imaging set-up

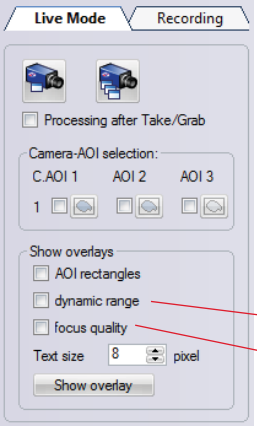
Calibration

Recording

Background / Reminder from the Lab

Live Grabbing of Images

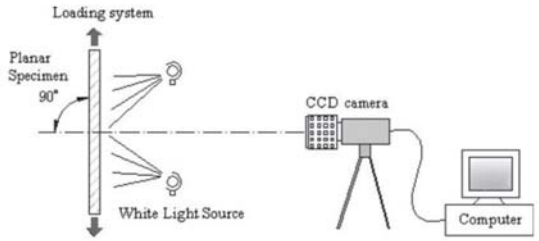
- **Normally easiest to optimise the imaging set-up by viewing the sample first (then calibrate later)**



Reminders regarding the set up:

- Orientate sensor with sample (fill the image with the sample)
- Position the camera(s) correctly
- Optimise the lighting (avoid reflections)
- Exposure time, lighting, f#
- Focussing

Scaling : 2D only



Accurate 2D DIC requires:

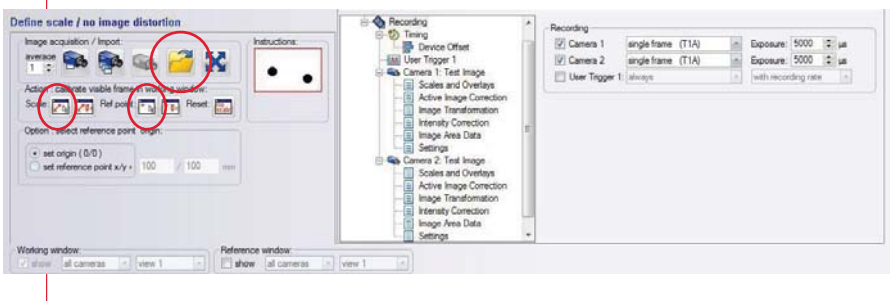
- Planar sample
- Camera is perpendicular to sample surface OR a 2D calibration
- Negligible displacement in z direction (z movement = artificial strain)

Typically appropriate to use where sample is loaded to small strain magnitudes (<10%) in tensile test machines

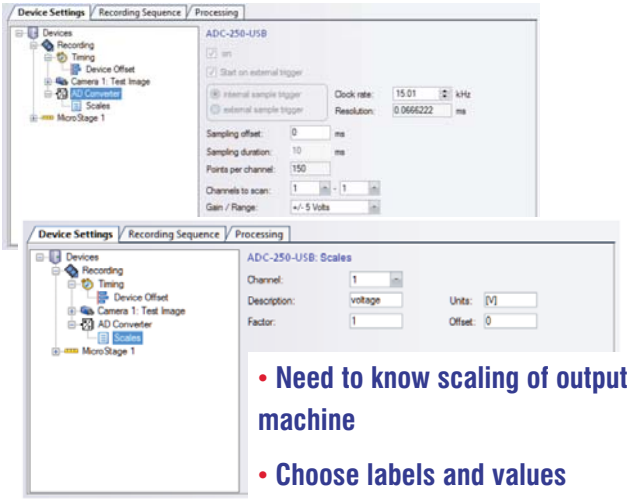
Scaling

Icon on toolbar

- Take an image, or load an image
- Define scale and ref point
- ***You should not need to rescale the provided projects***



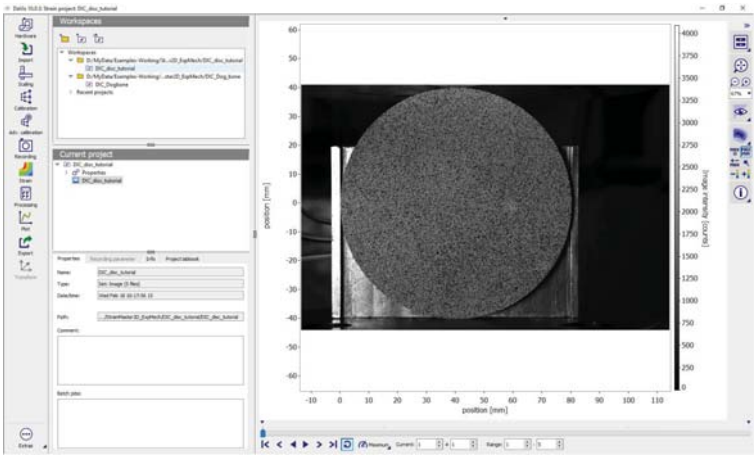
ADC settings – recording analogue signals



- Need to know scaling of output from test machine
- Choose labels and values

Using
DaVis StrainMaster
Software

Workspaces (are folders that) contain projects

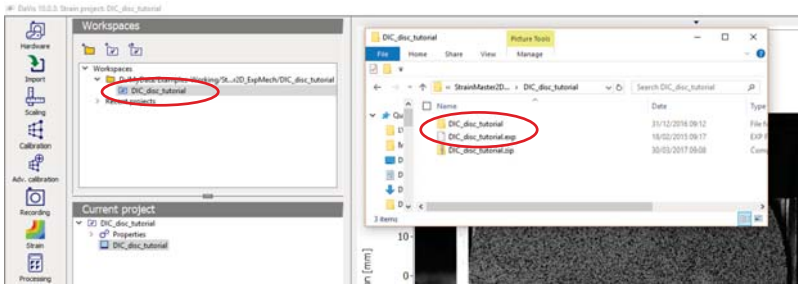


1. Select add new workspace
2. The projects appear below that workspace

Projects contain the images and data

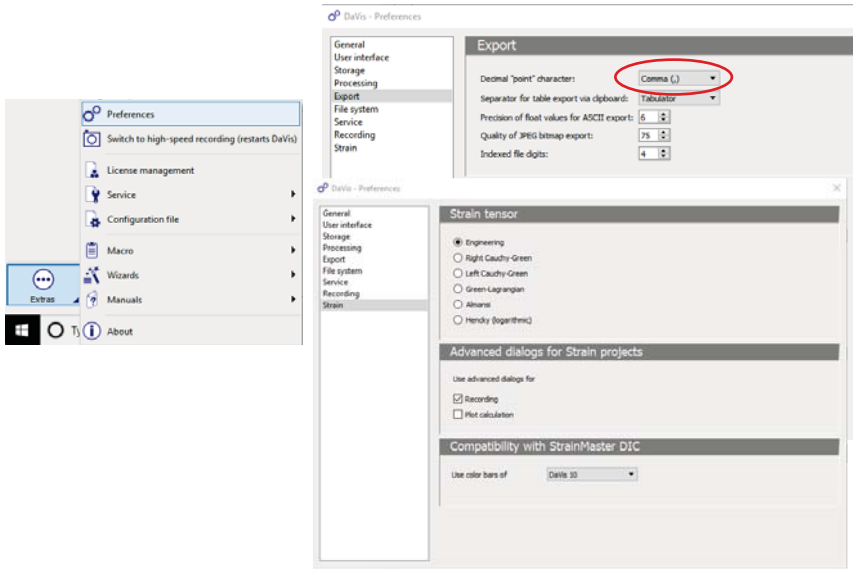
Note that in windows explorer, a project consists of:

- **A folder containing the images, calculated data, etc**
- **A *.exp file which defines the project**
- **You need the folder and the *.exp file when moving a project from one PC to another**



Inside a project

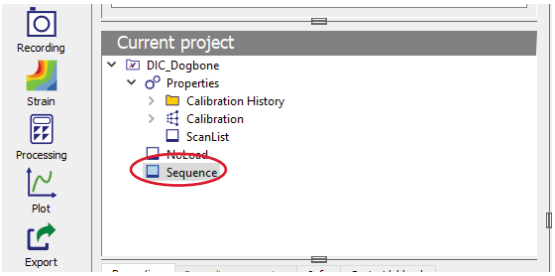
Preferences



Displacement Calculation

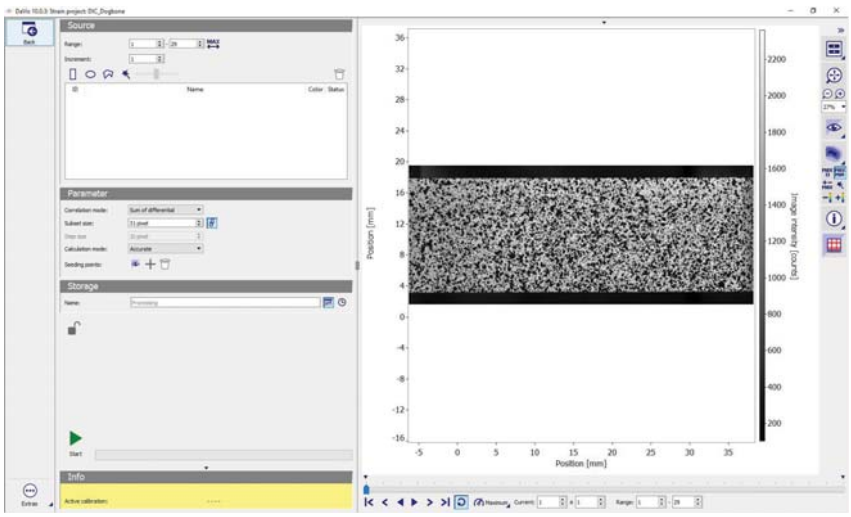
Calculate Displacement (and strain)

- Click on an original image sequence in one of your projects

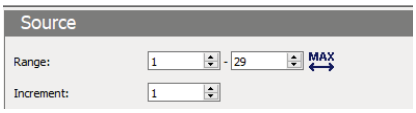


- Then click Strain

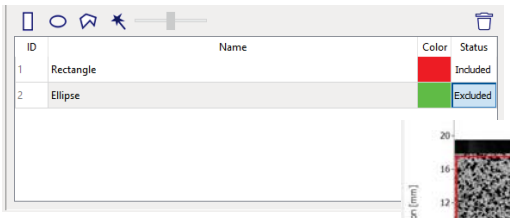
Calculate Displacement (and strain)

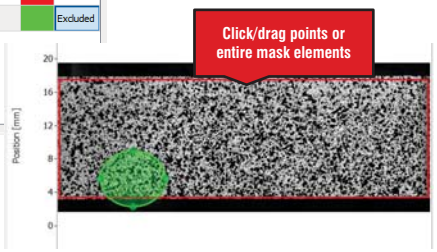


Calculate Displacement (and strain) (1)



- Process all or part of the sequence?
  - Select a range
  - Select an increment (skip images)





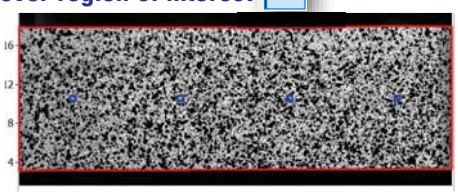
- Masking (define area of interest)
  - Define the region using geometric shapes
  - ... Or use automask

Do I need to mask the image?

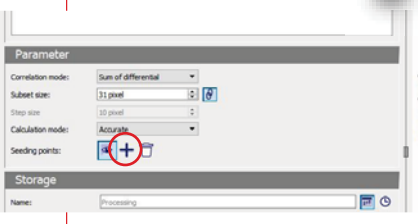
- **No..... But.....**
- **By masking you do not make the software try to calculate displacements where there is no sample => increased calculation speed**
- **If you do not mask there can be increased noise in the displacement (and hence strain) results at the sample edges**
- ***You only need to define the mask for the reference image : The mask follows the sample movement!***

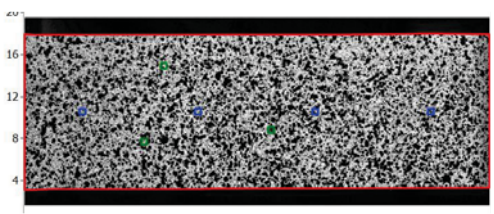
Calculate Displacements (2) - Seed points

- **Seed points = first subset locations used in matching process**
- **Automatically distributed over region of interest**



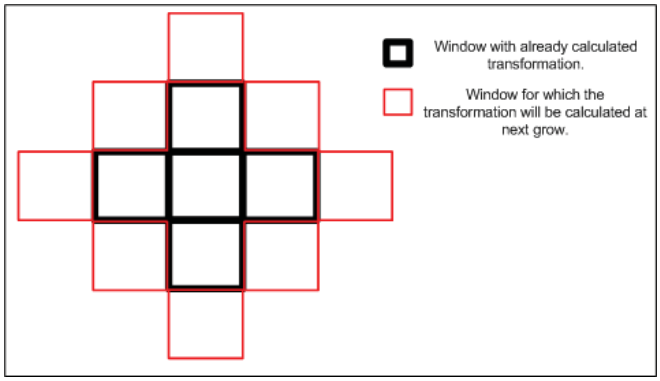
- **You can manually add seed points**





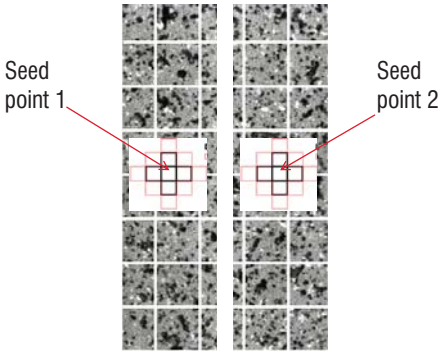
Subset matching – region grow

- Seed points provide the predictor as to where adjacent subsets should search
- Adjacent cells then provide prediction regarding likely displacement and inform their neighbours where to search

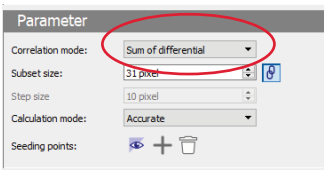


When should I define seed point locations?

- Region grow stops at boundary of sample
- If the sample has more than one zone, or separated parts, then you should ensure that at least one seed point exists per zone
- The matching (region grow) evolves from each seed point



Calculate Displacements (3) – Correlation Mode



Rel to first : 

- Use this mode when the displacement between first and last image is <subset size
- Highest accuracy (no error summing)

Sum of differential : 

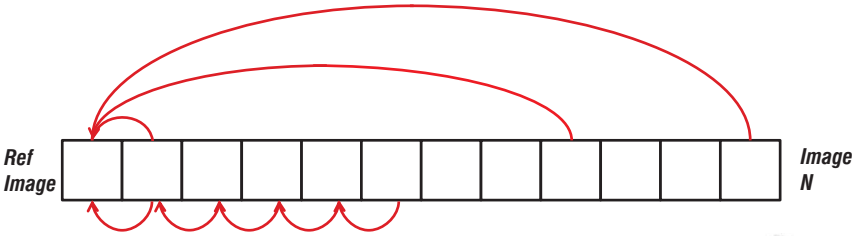
- Use this mode when the displacement between first and last image is >subset size
- Lower accuracy (due to error summing) but a safer calculation mode

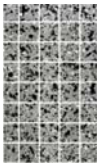
Differential : 

- Use this mode only when you need to know displacement relative to previous image
- Normally only used for granular flows

Large displacements = sum of differential

- Due to large change in sample shape, pattern has deformed too much at image N to be able to match directly back to reference image



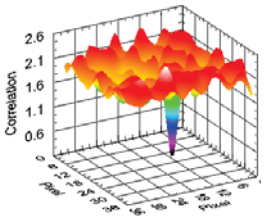


- Use **sum of the differential** (1+2, 2+3, 3+4, ...) displacements mode
- Disadvantage of sum of differential = errors are summed

A reminder from Prof Pierron's lecture

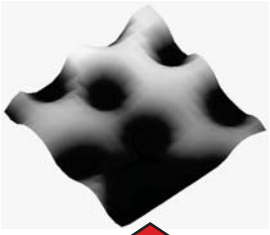
The three important components of 2D-DIC

Matching



Always zero-normalised sum of squared difference

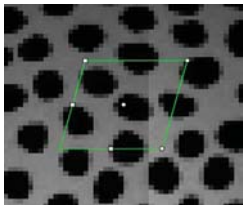
Interpolation



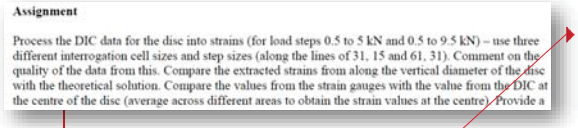
Can be chosen

Always Affine

Shape Function



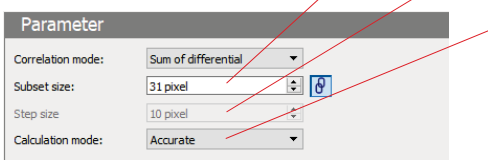
Calculate Displacements (4) – calculation scheme

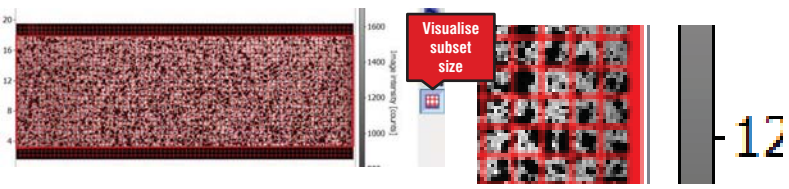


Assignment

Process the DIC data for the disc into strains (for load steps 0.5 to 5 kN and 0.5 to 9.5 kN) – use three different interrogation cell sizes and step sizes (along the lines of 31, 15 and 61, 31). Comment on the quality of the data from this. Compare the extracted strains from along the vertical diameter of the disc with the theoretical solution. Compare the values from the strain gauges with the value from the DIC at the centre of the disc (average across different areas to obtain the strain values at the centre). Provide a

- **Subset** size (NxN pixels) = local matched region
- Step size (= grid spacing)
- Determines number of iterations, **correlation criteria**, **shape function**.... how hard the system is made to work



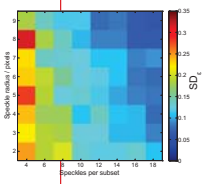


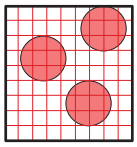
What is the best subset size?

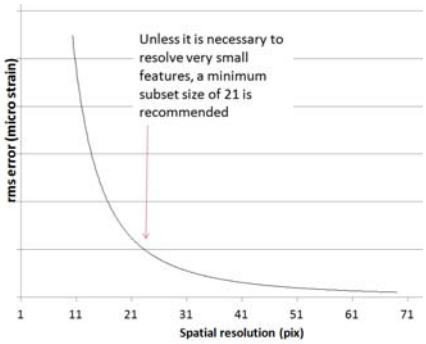
- Depends on pattern
  - Require speckle with 2-5 pixels diameter
  - At least 3 features per subset

Inspect visually to determine <u>minimum</u> subset size

- The minimum subset size might not be the best. There is a compromise between spatial resolution and error





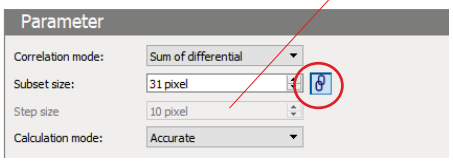


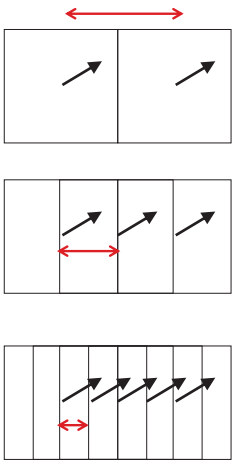
- DaVis minimum = 9 pix
- Practical minimum ≈ 21 pix
- Typical = 31 pix

= subset size

Calculate Displacements (5) – calculation scheme

- Step size (= grid spacing)

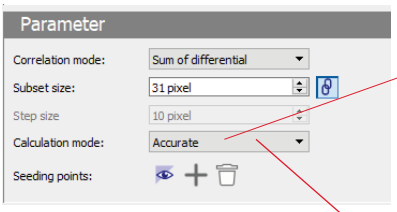




Notes on step size

- **Why?**
- **Changing the step size does not improve the fundamental spatial resolution**
- **But changing the step size does do the following :**
  - It affects the data grid resolution (number of displacement vectors)
  - Smaller step size increases ability to describe/locate discontinuities (e.g. Cracks).
  - decreasing step size (oversampling), can be helpful if applying the smoothing filter – *see later*
  - **Typical step size = 0.3*[subset size] = 10 pix**

Calculate Displacements (5) – calculation scheme



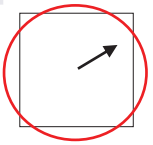
- Determines maximum number of iterations, correlation parameters, **interpolator**.... how hard the system is made to work

	Fast	Medium	Accurate
Subset weighting	Square (normal)	Gaussian	Gaussian
Grey scale interpolator	Bilinear	Bilinear	6th Order Spline

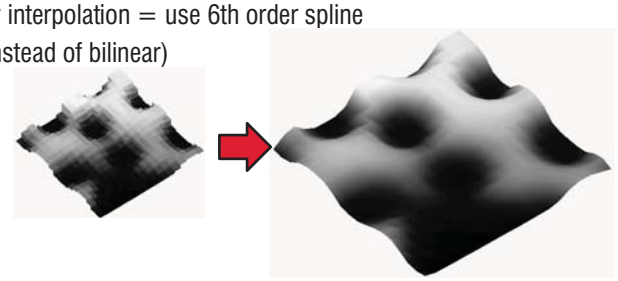
Calculate Displacements (5) – calculation scheme

	Fast	Medium	Accurate
Subset weighting	Square (normal)	Gaussian	Gaussian
Grey scale interpolator	Bilinear	Bilinear	6th Order Spline

- Round windows = a Gaussian weighting is applied to the correlation function, i.e. Pixels closer to the centre of the subset have a greater influence



- High accuracy interpolation = use 6th order spline interpolator (instead of bilinear)



Display of data

2D Display

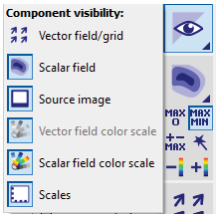
- **Identify what you want to display**

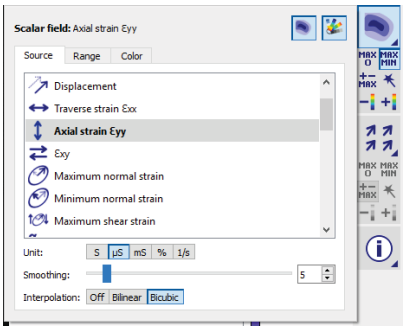
  vectors/grid

  scalars as colour contours

  Source image

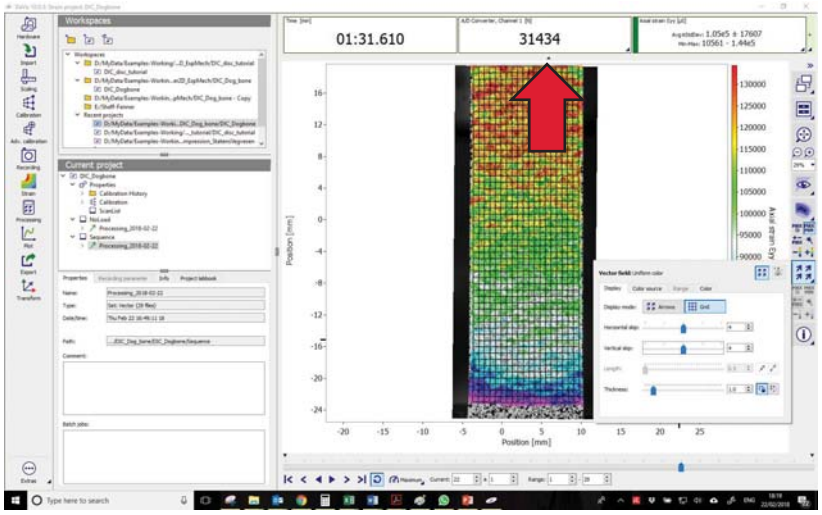
- **Choose the scalar quantity, the units, and any smoothing for displayed data**





Display

- **Activate the info bar by clicking small triangle (Load, time,…)**

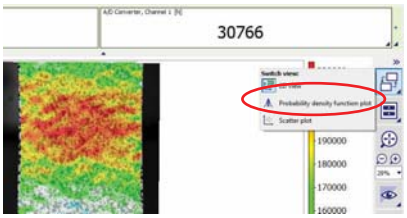


Checking data quality

Image Filtering

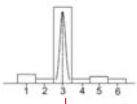
Post-processing

pixel (peak) locking



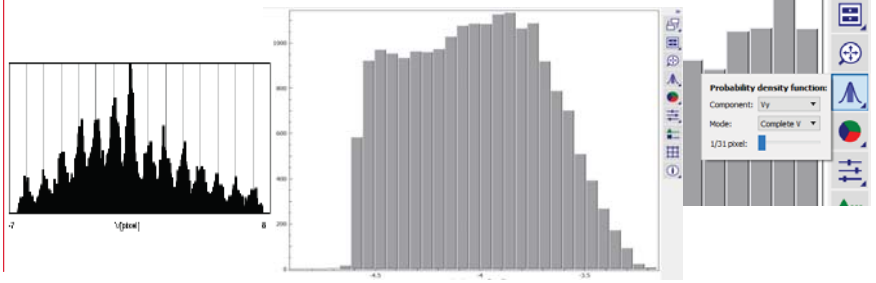
Any bias towards integer values indicates pixel locking

- **Pixel locking occurs because**



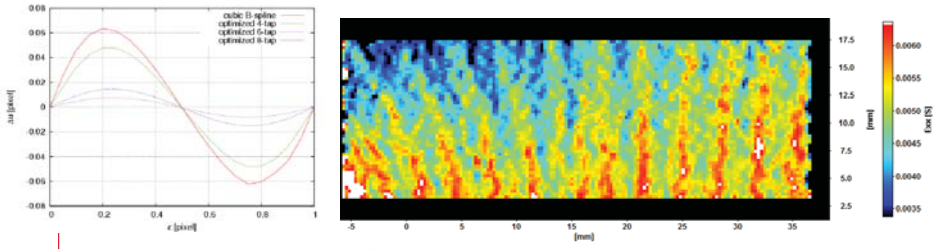
Speckle/features too small (<1 pixel diameter)

- Interpolation scheme introduces bias



Pixel (peak) locking

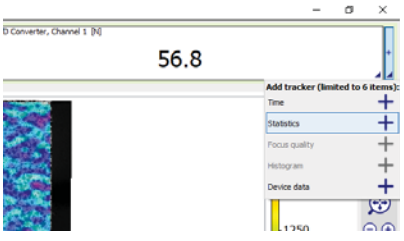
- **Banding visible between 0.2% and 1% Strain**
- **Peak locking due to systematic error with bilinear image interpolation scheme**



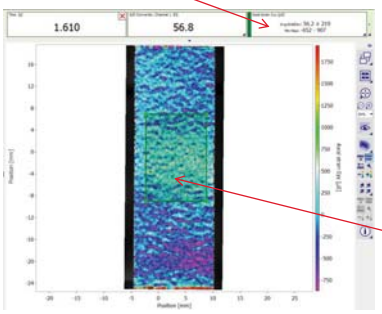
- **If you are measuring <1% strain you may see this effect in your results (in "fast" calculation mode).**
- **<u>Solution : use "accurate" mode which utilises spline grey-scale interpolation</u>**

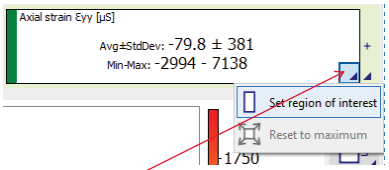
Uncertainty – looking at local statistics

- **Top right of screen -> statistics**
- **Select region of interest**
- **Statistics are relevant to whatever quantity is displayed at the time**



Statistics



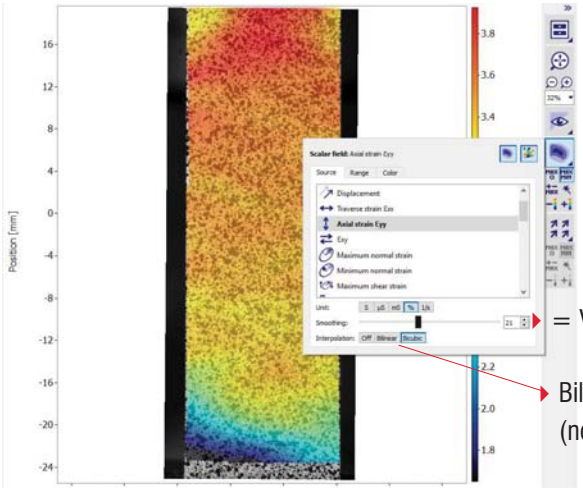


Define area for statistics

Post-processing

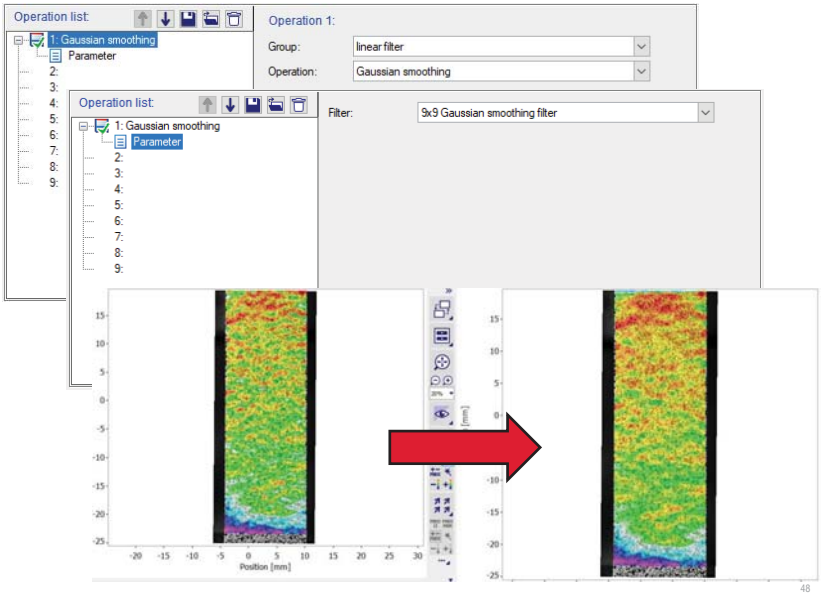
Smoothing / data fitting

Smoothing/Filtering the displayed values



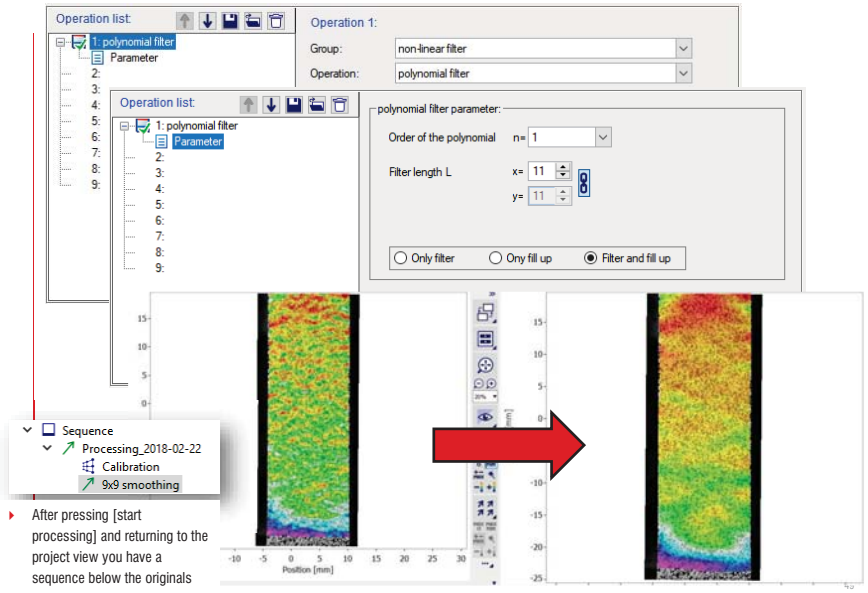
- **For display only – exported data is still the raw (unsmoothed) values**
- If you want to process (e.g. smooth) the data for export – see next pages

Processing : Gaussian (and other) smoothing



Processing

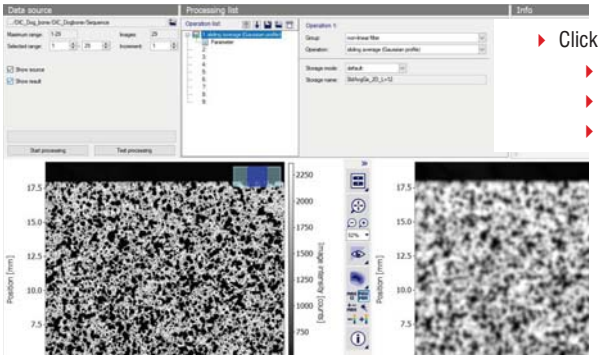
Processing : Polynomial (and other) smoothing



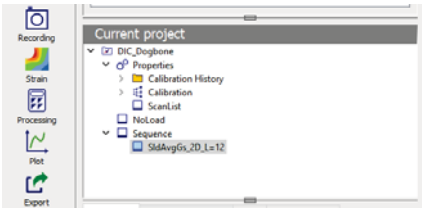
- After pressing [start processing] and returning to the project view you have a sequence below the originals

Processing

Smoothing can be done on images too (before DIC)



- Click on the image/data sequence
  - processing icon
  - linear filter
  - Gaussian filter (is one example)



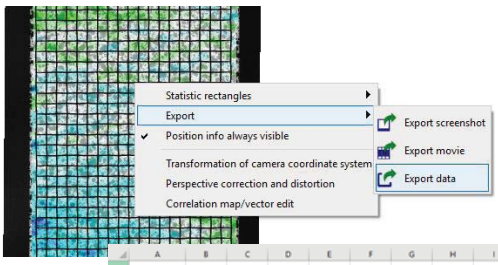
- After pressing [start processing] and returning to the project view you have an image sequence below the original images
- These images could then become the input for DIC processing

Exporting data

Extracting local data and line plots

Extracting full field strain data (single data map)

- **Right click – export – single displacement/strain maps**



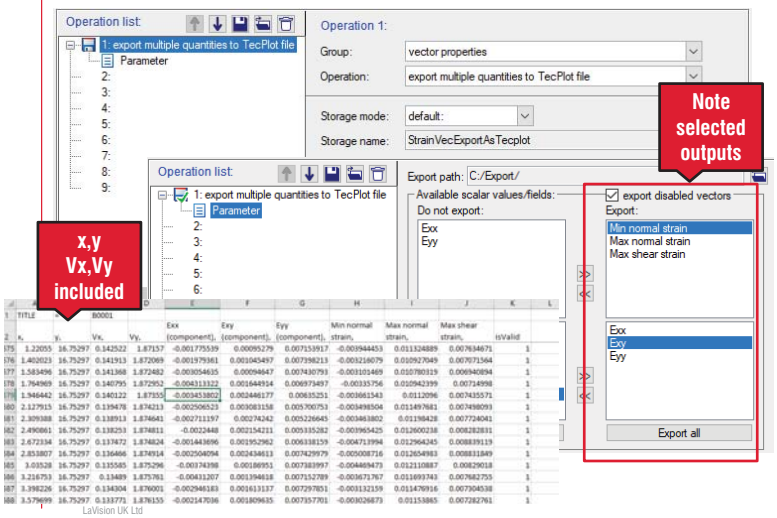
- To export data from single displacement fields

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	x [mm]	y [mm]	x-displacement [mm]	y-displacement [mm]	vector length [mm]	Exx [S]	Eyy [S]	Exy [S]	poisson ratio - Min/Max	poisson ratio - Exx/Eyy	poisson ratio - Eyy/Exx	poisson ratio - Max/min	maximum normal strain [S]	minimum normal strain [S]	maximum shear strain [S]	maximum shear angle [°]
1385	9.749781545	11.67172	-0.05419	4.904836	4.905135	-0.03707	0.111753	0.001059	0.331784	0.331739	3.01442	3.014011	0.1117609	-0.03708	0.0744207	-45.40755
1386	9.931254555	11.67172	-0.06123	4.905145	4.905527	-0.03835	0.10979	-0.00038	0.349266	0.34926	2.863198	2.86315	0.1097909	-0.038346	0.0740685	-44.8533
1387	10.11272756	11.67172	-0.06861	4.905212	4.905691	-0.03813	0.106592	-0.00121	0.357827	0.357766	2.795126	2.794648	0.1066023	-0.038145	0.0723737	-44.52008
1388	10.29420057	11.67172	-0.07545	4.905277	4.905857	-0.03711	0.103543	-0.00135	0.35848	0.3584	2.790179	2.789558	0.1035563	-0.037123	0.0703396	-44.45195
1389	-4.405113179	11.49025	0.361703	4.864457	4.877886	-0.03989	0.099882	-0.00176	0.399497	0.399364	2.50398	2.503148	0.0999038	-0.039911	0.0699075	-44.28018
1390	-4.22364017	11.49025	0.354337	4.864026	4.876915	-0.03756	0.100592	-0.00081	0.373465	0.373436	2.677837	2.677625	0.1005969	-0.037569	0.0690831	-44.66463
1391	-4.042167161	11.49025	0.34796	4.863274	4.875706	-0.03458	0.101217	0.000439	0.341652	0.341643	2.92703	2.926951	0.1012182	-0.034581	0.0678998	-45.18502
1392	-3.860694151	11.49025	0.341887	4.863007	4.87501	-0.03464	0.101455	0.001458	0.341536	0.341435	2.928817	2.927947	0.101471	-0.034656	0.0680635	-45.6138
1393	-3.679221142	11.49025	0.335516	4.863018	4.874578	-0.03447	0.101174	0.002227	0.340964	0.340726	2.934909	2.932859	0.1012105	-0.034509	0.0678598	-45.94029
1394	-3.497748133	11.49025	0.329403	4.863469	4.874612	-0.03286	0.099566	0.0029	0.330423	0.329996	3.030343	3.026427	0.0996297	-0.03292	0.0662748	-46.25409
1395	-3.316275124	11.49025	0.323591	4.863822	4.874575	-0.03204	0.096407	0.002068	0.332556	0.332325	3.0091	3.007015	0.0964401	-0.032072	0.0642559	-45.92223
1396	-3.134802114	11.49025	0.317854	4.863634	4.87401	-0.03201	0.09364	8.56E-05	0.341835	0.341834	2.925395	2.925391	0.0936396	-0.032009	0.0628245	-45.03904
1397	-2.953329105	11.49025	0.312129	4.863291	4.873297	-0.03065	0.093744	-0.00159	0.327099	0.326953	3.058542	3.057182	0.0937646	-0.03067	0.0622174	-44.26883
1398	-2.771856096	11.49025	0.30692	4.863013	4.872688	-0.0294	0.097091	-0.00121	0.302844	0.302761	3.302941	3.302033	0.0971025	-0.029407	0.0632547	-44.45147

Processing

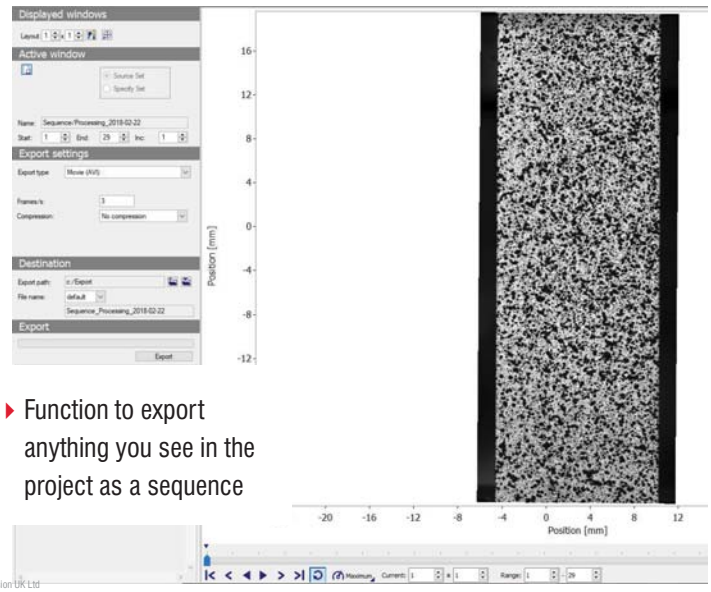
Extracting full field strain data (full set)

- **Via the processing menu**



Export

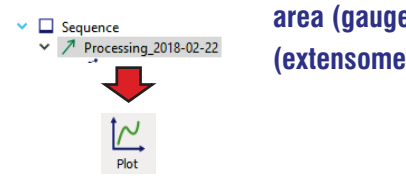
Export AVIs, sequences of images etc

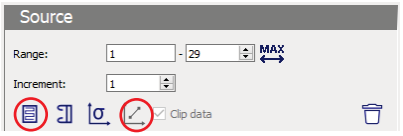


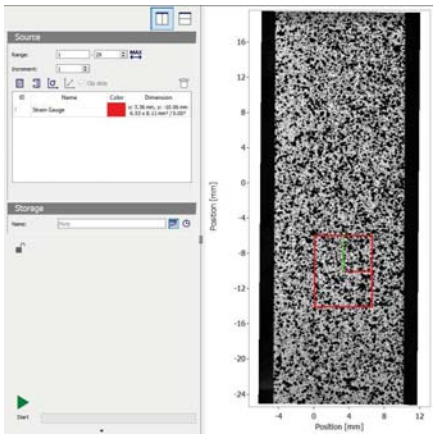
- Function to export anything you see in the project as a sequence

Other processing – extracting local data

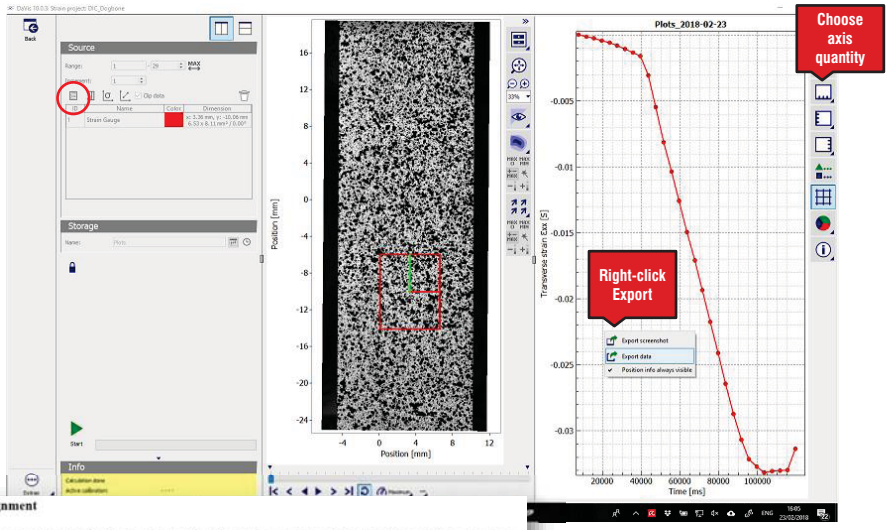
- Via the plot menu, extract local data over an area (gauge), strain between two points (extensometer) or local data along a line







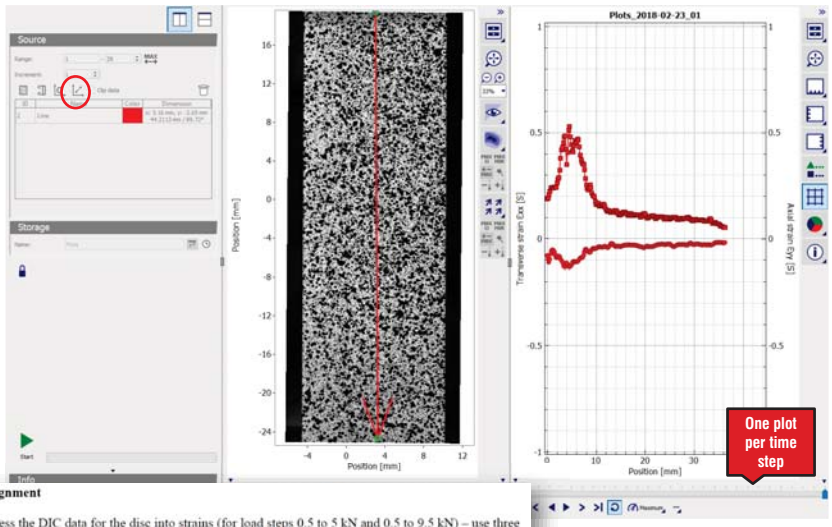
Extracting local data over an area



Assignment

Process the DIC data for the disc into strains (for load steps 0.5 to 5 kN and 0.5 to 9.5 kN) – use three different interrogation cell sizes and step sizes (along the lines of 31, 15 and 61, 31). Comment on the quality of the data from this. Compare the extracted strains from along the vertical diameter of the disc with the theoretical solution. Compare the values from the strain gauges with the value from the DIC at the centre of the disc (average across different areas to obtain the strain values at the centre). Provide a

Extracting local data along a line



Assignment

Process the DIC data for the disc into strains (for load steps 0.5 to 5 kN and 0.5 to 9.5 kN) – use three different interrogation cell sizes and step sizes (along the lines of 31, 15 and 61, 31). Comment on the quality of the data from this. Compare the extracted strains from along the vertical diameter of the disc with the theoretical solution. Compare the values from the strain gauges with the value from the DIC at the centre of the disc (average across different areas to obtain the strain values at the centre). Provide a

Extracting load data