PYRO DYNAMICS

APPLICATION NOTES

VALIDATION OF DIC MEASUREMENTS

Correlated Solutions Inc VIC-3D, 3D - Digital Image Correlation

For Non Contact Full Field

Displacement and Strain Measurement & Frequency Analysis.

A Brief Application Note on the Tests Carried out by Pyrodynamics

At Various Organizations in India using VIC-3D, 3D DIC System.

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Displacement and Strain Measurement

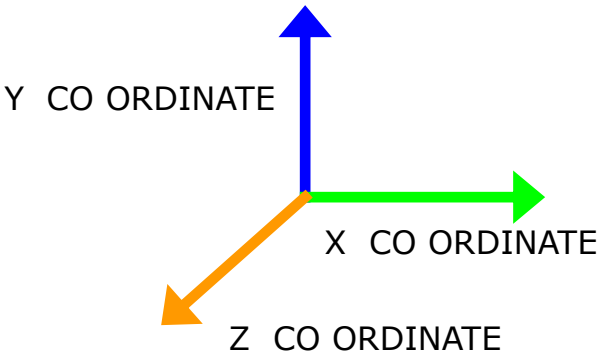
DIC Measures Displacements.

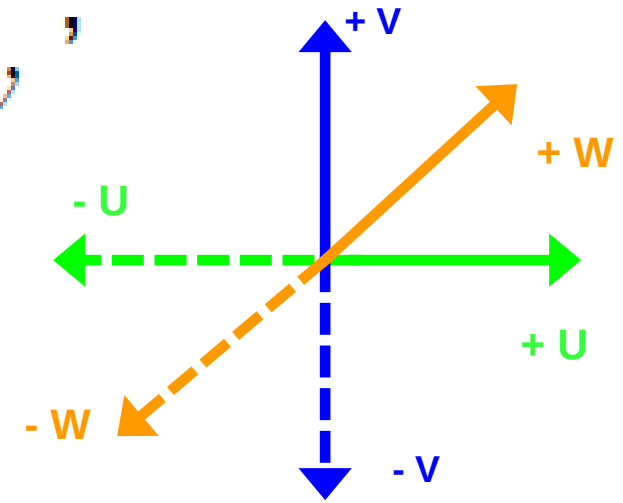
Strain is a Derivative of Displacement. Lagrange Strain tensor is used for calculation of Strains

Calculation of strains:

$$\varepsilon_x = \frac{\partial u}{\partial x}, \qquad \varepsilon_y = \frac{\partial v}{\partial y},$$

$$\gamma_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}$$





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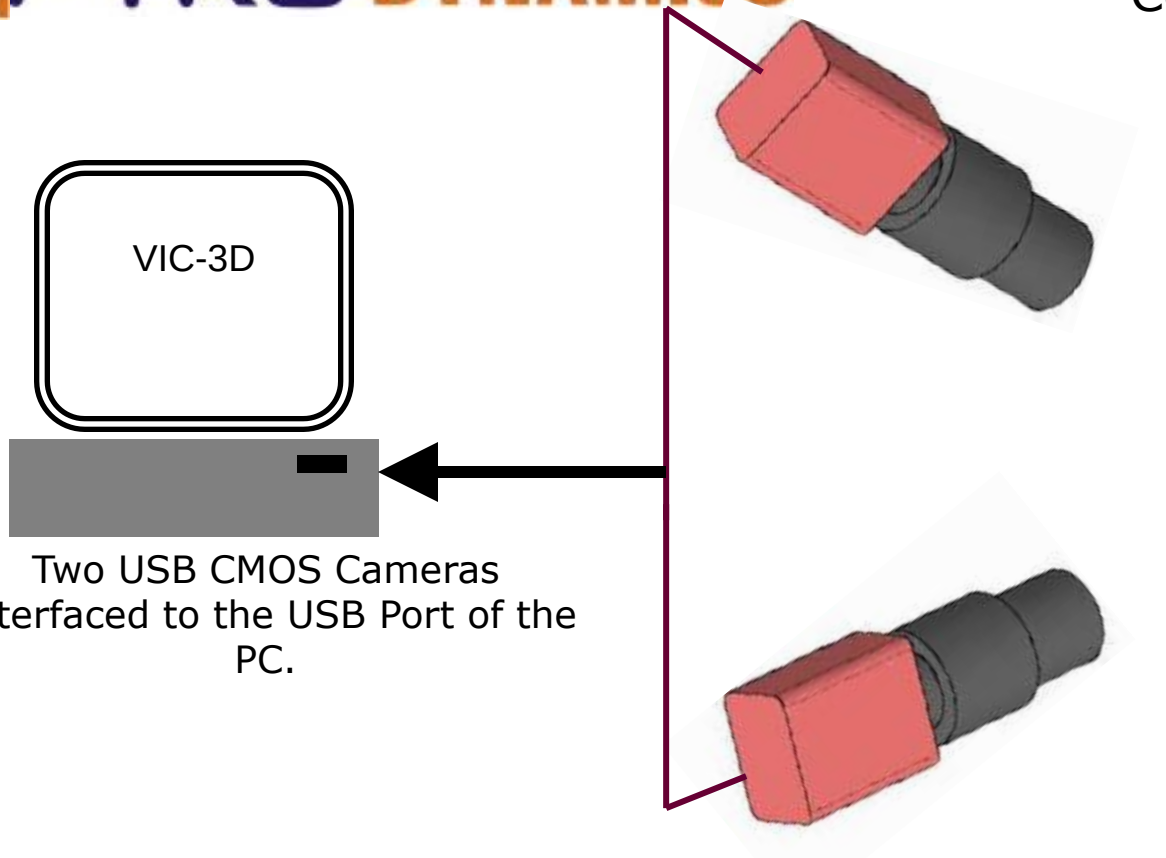
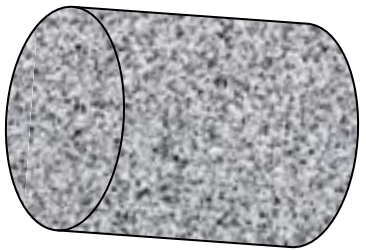
VIC- 3D, 3D Digital Image Correlation System.



Two USB CMOS Cameras Interfaced to the USB Port of the PC.



Displacement and Strain Measurement In-Plane Direction
(X and Y Direction)
And
Out of Plane Direction
(Z Direction)

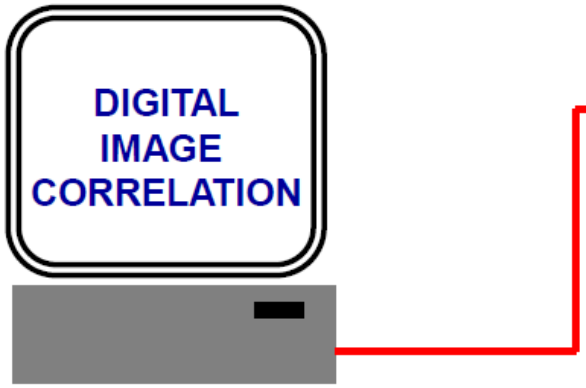
Results Obtained from 3D Digital Image Correlation

Contour Co Ordinates:- X, Y and Z ; Displacement:- u, v and w.

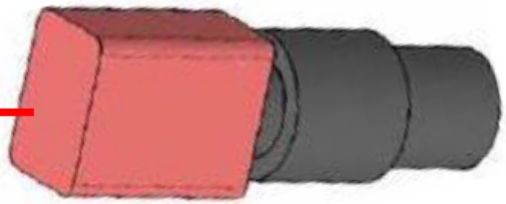
Strains:- ε_{xx} , ε_{yy} , ε_{xy} , ε_1 , ε_2 , Von Mises, Tresca

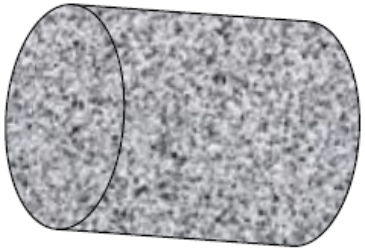
and Directions of Principal Strains

PYRO DYNAMICS 2D, DIC SYSTEM.



Fire Camera interfaced to the
Fire Wire Port of the PC.





Displacement and Strain Measurement
In-Plane Direction
(X and Y Direction).

Results Obtained from 2D Digital Image Correlation

Contour Co Ordinates :- X and Y

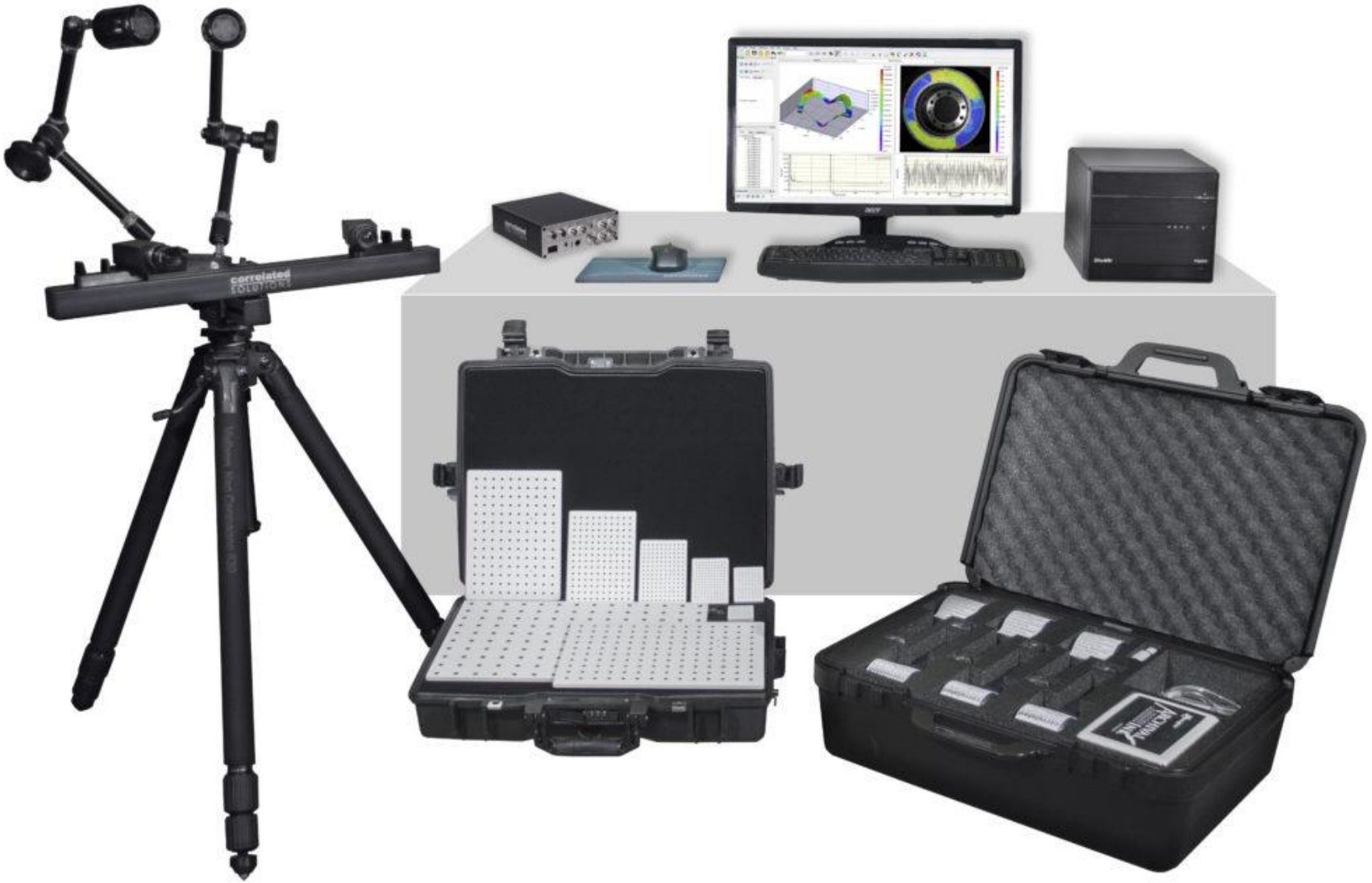
Displacement:- u and v.

Strains:- ε_{xx}, ε_{yy} , ε_{xy} , ε_1 , ε_2 Von Mises, Tresca and

Directions of Principal Strains

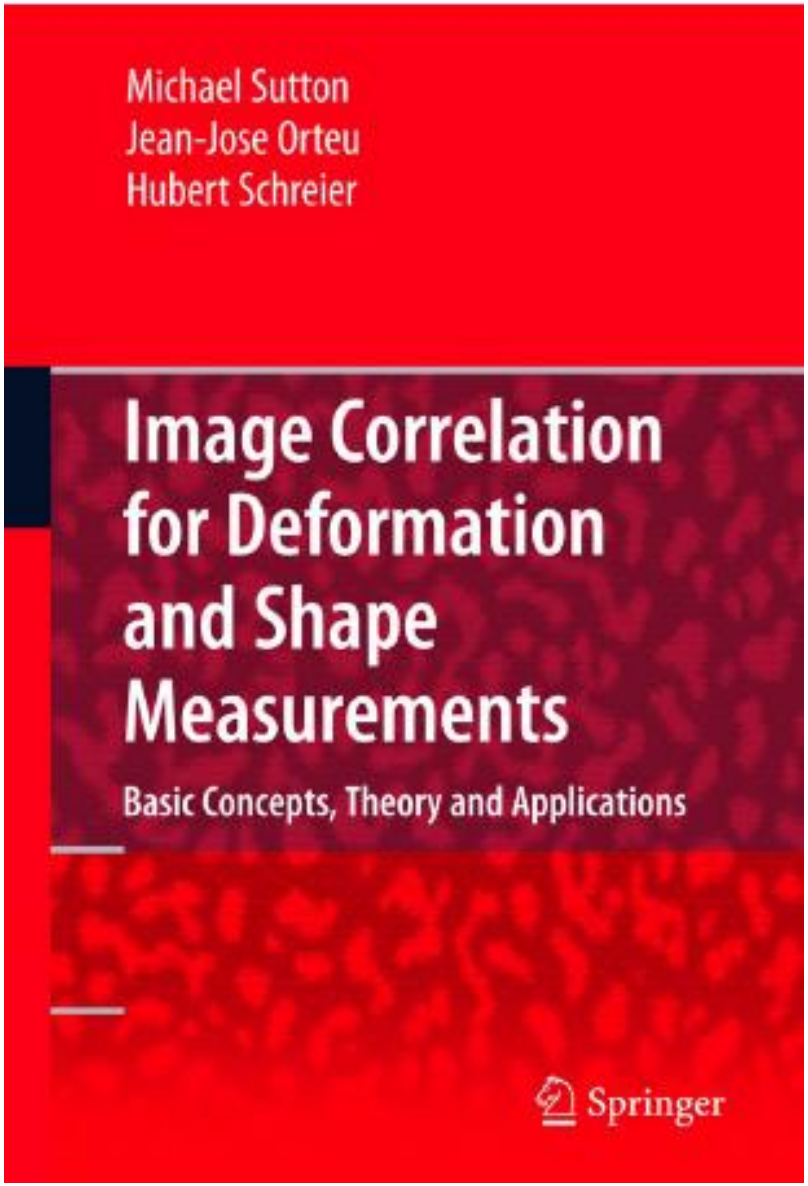
PYRO DYNAMICS

VIC-3D System



PYRO DYNAMICS

VIC-3D-HS, VIC-3D-UHS System


Michael Sutton
Jean-Jose Orteu
Hubert Schreier
Image Correlation for Deformation and Shape Measurements
Basic Concepts, Theory and Applications
Springer

PYRO DYNAMICS

Experiment	Validation of DIC Measurements – Comparison of Displacement Data obtained from DIC with the Micrometer Readings.
Organisation	Pyrodynamics – Bengaluru
System Used	VIC-3D, 3D Digital Image Correlation System.
Loading Conditions	Static Load
Camera Used	Point Grey Research Grasshopper 5MP Camera, 15fps
Image Frame Capture	One Image at every discrete load step.

PYRO DYNAMICS

A Speckle Pattern was applied On a Test Specimen of 100 x 100 mm using an Air Brush with a 0.2mm nozzle.

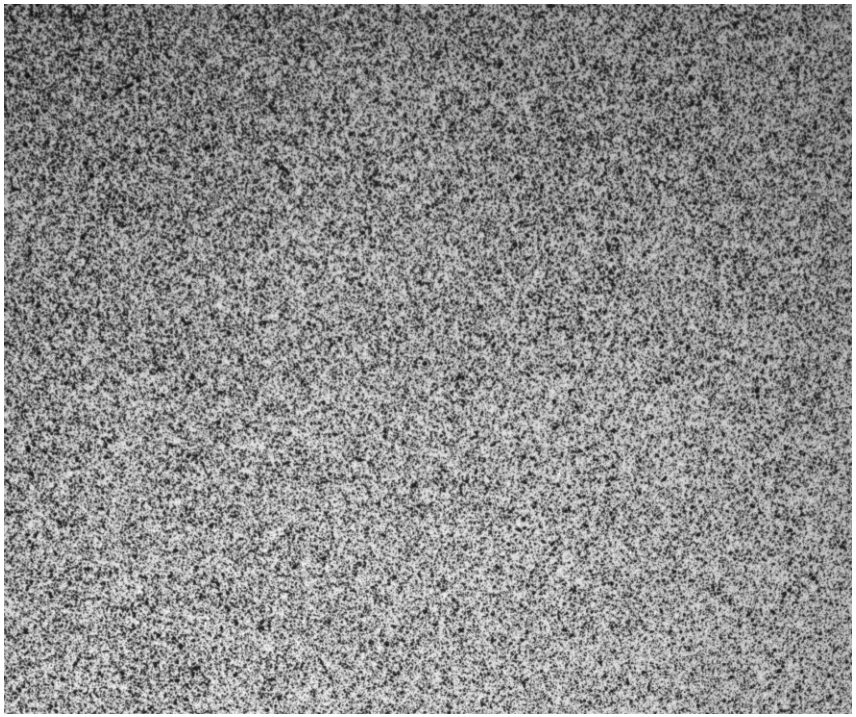
A displacement was provided by a micrometer in the V(Y) Direction

Each rotation of the micrometer provides 500 microns of displacement.

The displacements field showed very little gradients.

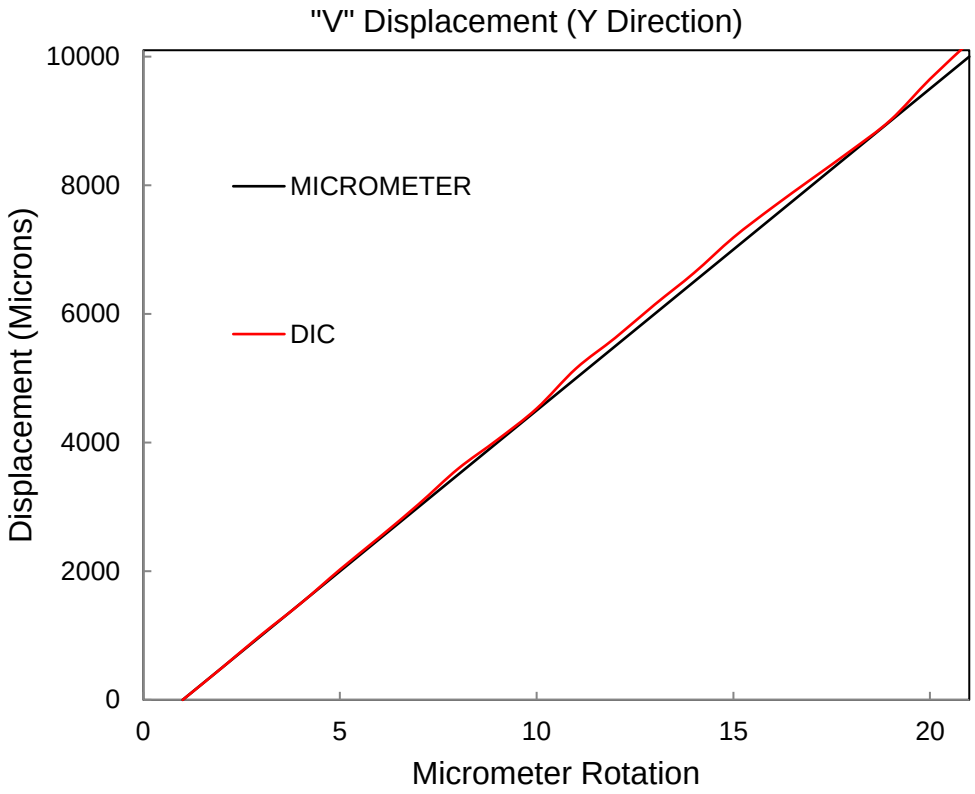
The mean of the DIC plot was taken for comparison with the micrometer readings

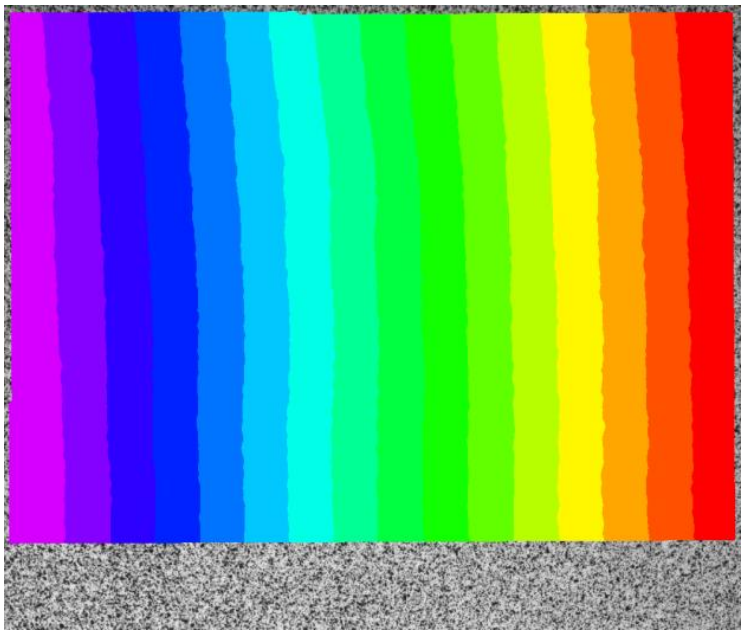
Displacement of the micrometer and DIC measurements matched perfectly.



STEP	MICRO METER	DIC
1	0	0
2	500	499.478
3	1000	1012.85
4	1500	1498.42
5	2000	2026.53
6	2500	2526.42
7	3000	3041.88
8	3500	3591.2
9	4000	4042.12
10	4500	4528.45
11	5000	5150.81
12	5500	5628.6
13	6000	6144
14	6500	6636.06
15	7000	7185.48
16	7500	7657.25
17	8000	8101.41
18	8500	8542.16
19	9000	9014.19
20	9500	9649.69
21	10000	10222.9

PYRO DYNAMICS





PYRO DYNAMICS

Experiment	Validation of DIC Measurements – Comparison of DIC Measurements with Photoelastic Fringe Pattern and Strain Gage.
Organisation	Pyrodynamics – Bengaluru
System Used	VIC-3D, 3D Digital Image Correlation System.
Loading Conditions	Static Load
Camera Used	Point Grey Research Grasshopper 5MP Camera, 15fps
Image Frame Capture	One Image at every discrete load step.

The Test Specimen is a Typical Photo elastic Model and is made out of Acrylic Sheet of 0.5 mm thick.

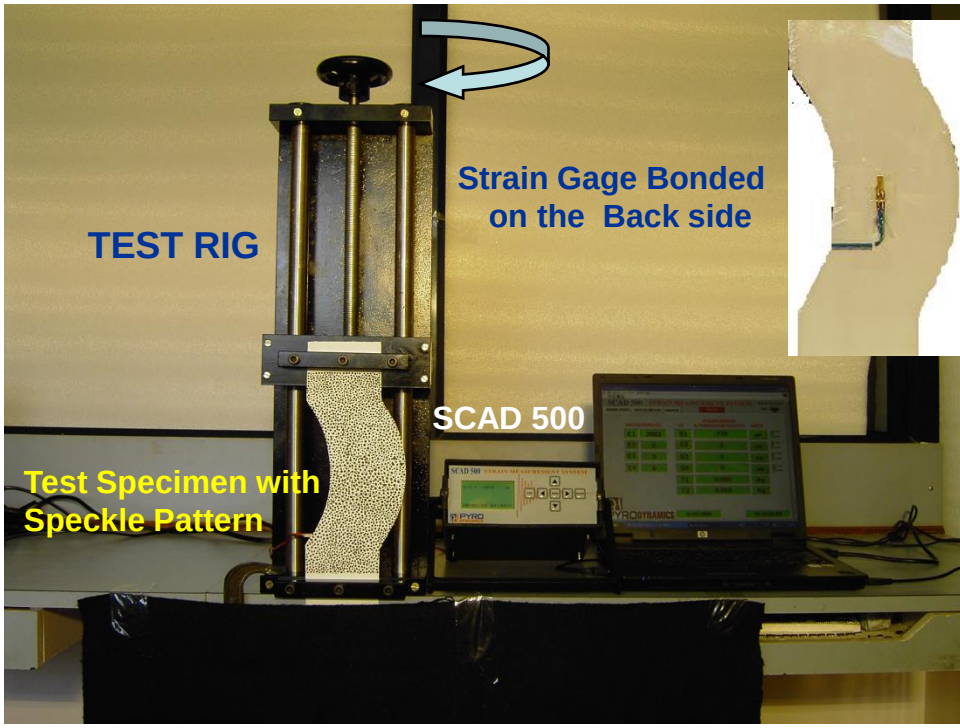
A speckle Pattern is Applied on the Test Specimen on the front side..

A strain Gage (350 Ohms, Quarter Bridge) is bonded at the center of on the back side of the specimen.

The Specimen is mounted on a test Rig (Designed By Pyrodynamics)

The Strain Gage output is connected to SCAD 500 – Strain Measurement System.

The strain data is viewed on the Front Panel LCD of SCAD 500 and also on the Host PC via RS 232 Interface.



The Test Rig has a Thumb wheel and rotation of the wheel in clockwise direction introduces tensile strain and anticlockwise rotation introduces compressive strain.

Loading Pattern:- The Test Specimen is mounted in the Test Rig.

A Tensile Load is applied by rotating the Thumb Wheel till the SCAD 500 shows a strain value of 2000 me. At this stage a image is captured. Subsequently images are captured in increments of 2000 με upto failure of the test specimen.

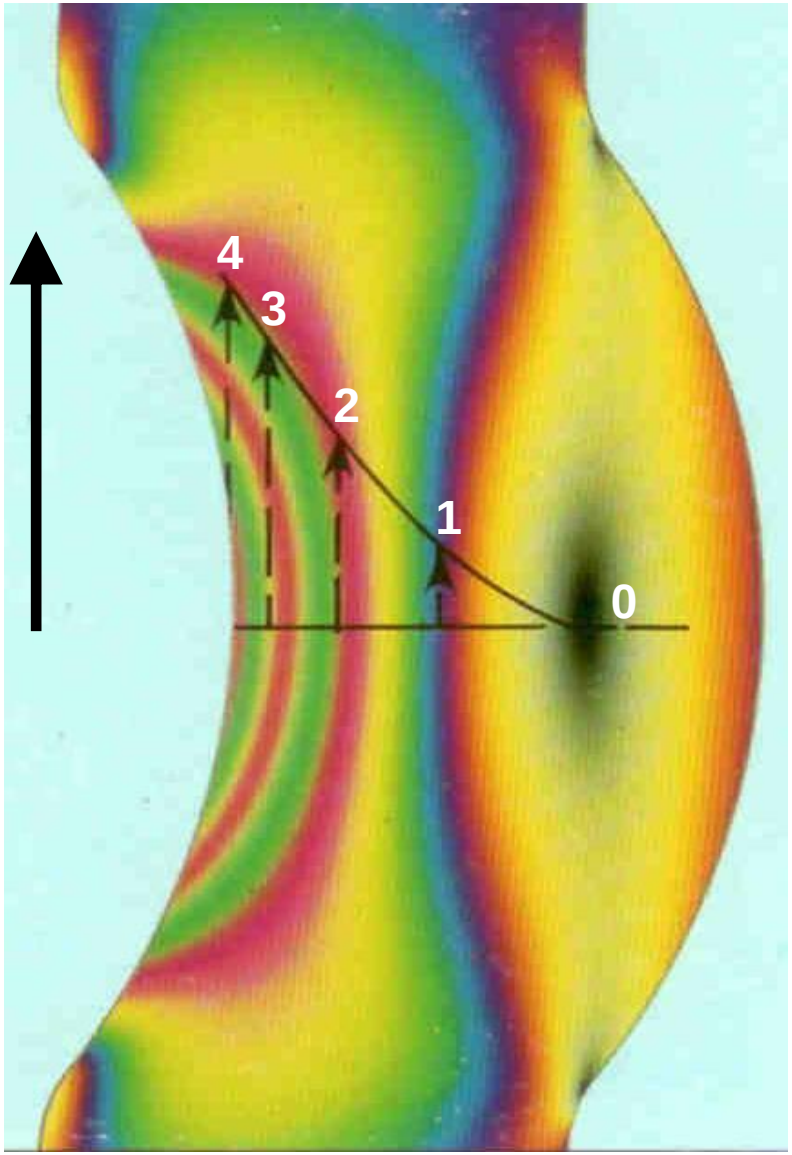
THE DIC MEASUREMENTS COMPARED EXTREMELY WELL WITH THE PHOTO ELASTIC FRINGE PATTERN

AND STRAIN GAGE MEASUREMENTS.

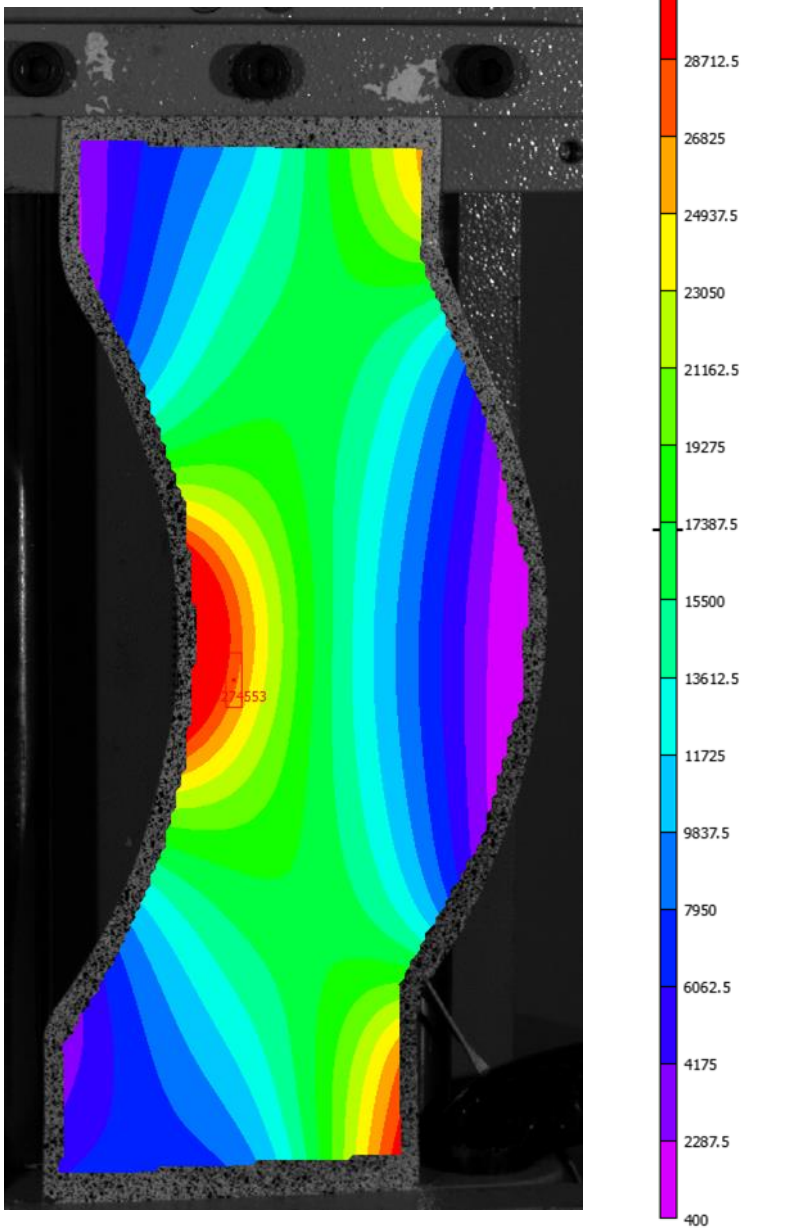
DIC RESULTS ALSO SHOWED EXCELLENT LINEARITY.

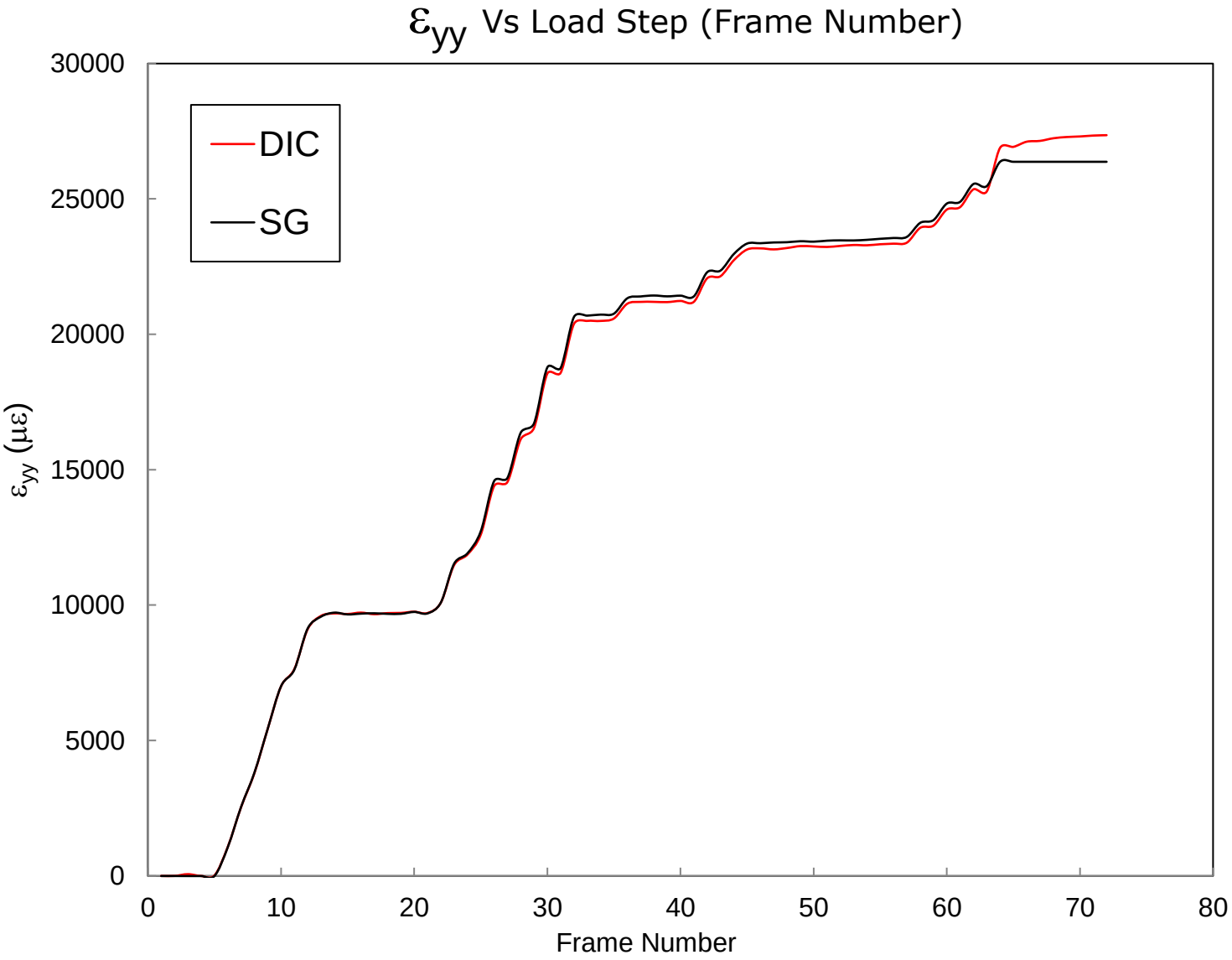
PYRO DYNAMICS

Photoelastic Fringe Pattern



ε_{yy} obtained from VIC-3D.At the final load

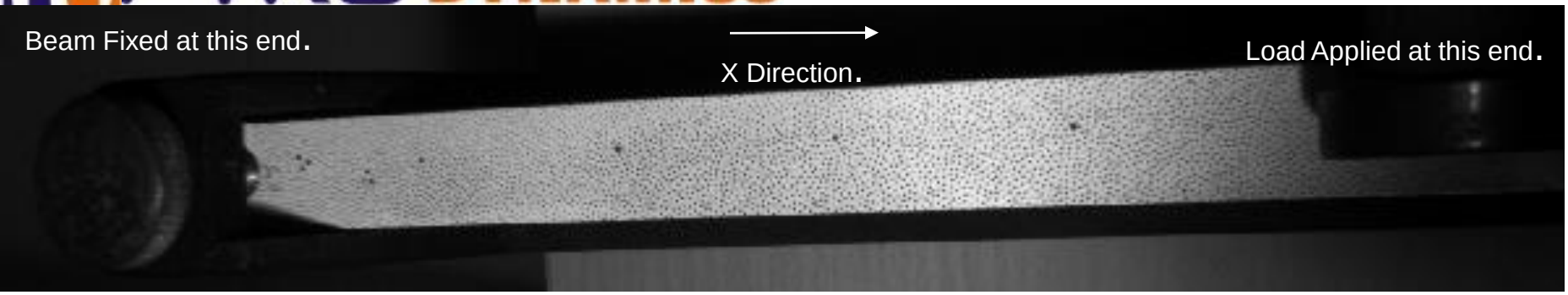



ε_{yy} Vs Load Step (Frame Number)
DIC
SG
ε_{yy} (με)
30000
25000
20000
15000
10000
5000
0
0
10
20
30
40
50
60
70
80
Frame Number

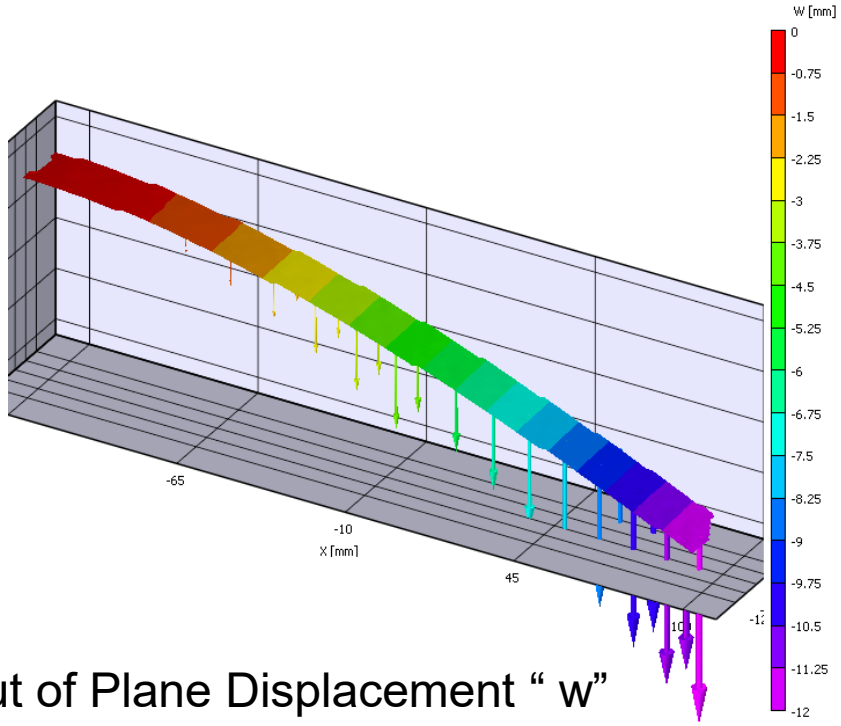
PYRO DYNAMICS

Experiment	Full Field Displacement and Strain Measurement on a Beam under Bending
Organisation	Indian Institute of Technology Department of Applied Mechanics Chennai.
System Used	VIC-3D, 3D Digital Image Correlation System.
Loading Conditions	Static Load
Camera Used	Point Grey Research Grasshopper 5MP Camera, 15fps
Image Frame Capture	One Image at every discrete load step.

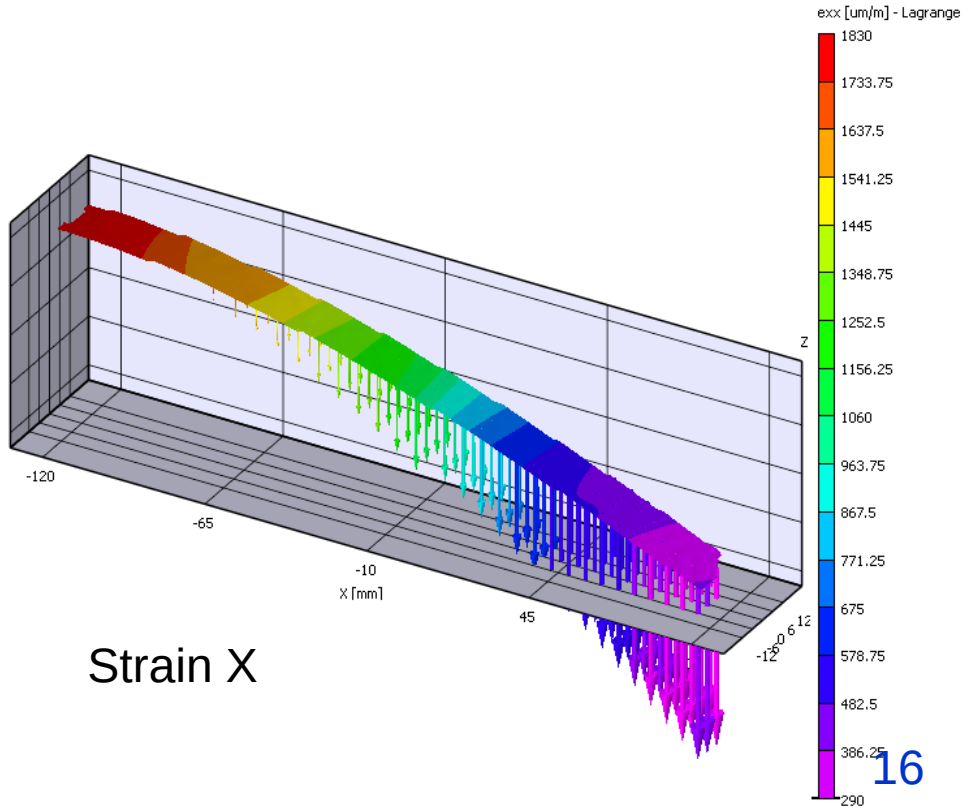
3D DIC Measurements on a Beam under Bending.



A speckle pattern was screen printed on the Test Specimen The beam was firmly fixed at one end and the beam was subject to a bending of 12mm at the other end. The fixed end will have a high strain and a low strain at the free end. This is clearly seen in the e_{xx} plot.. At the point of loading the displacement is the highest as seen in the "w



Out of Plane Displacement " w"



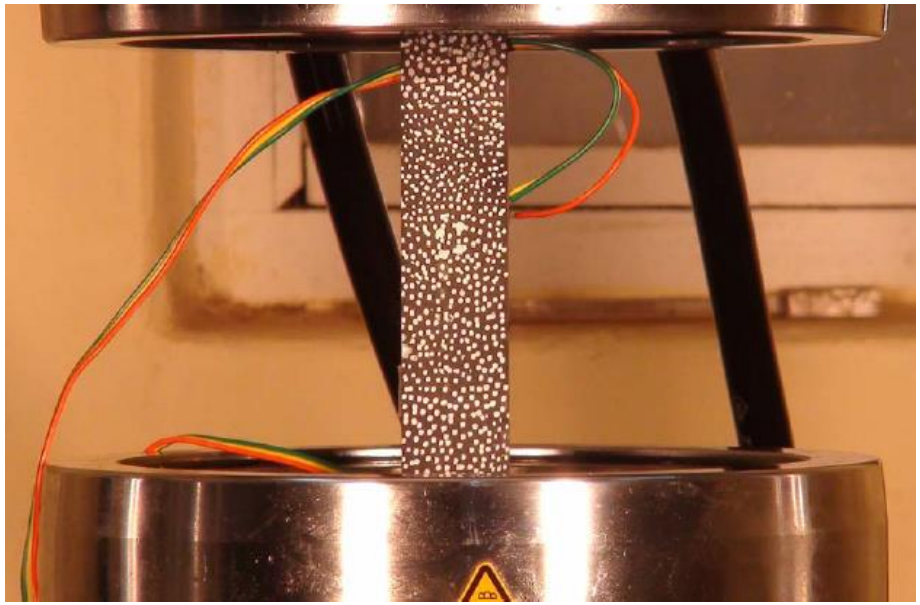
Strain X

PYRO DYNAMICS

Experiment	Full Field Displacement and Strain Measurement on a Tensile Composite Specimen
Organisation	Indian Institute of Science Structures Laboratory Department of Aerospace Engineering Bengaluru.
System Used	VIC-3D, 3D Digital Image Correlation System.
Loading Conditions	Static Load
Camera Used	Point Grey Research Grasshopper 5MP Camera, 15fps
Image Frame Capture	One Image at every discrete load step.

PYRO DYNAMICS

Experimental Set Up



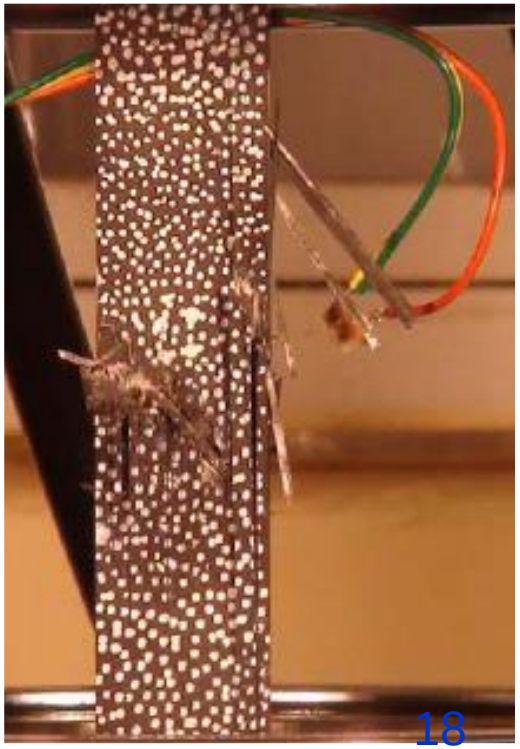
Test Specimen:- Composite Material.

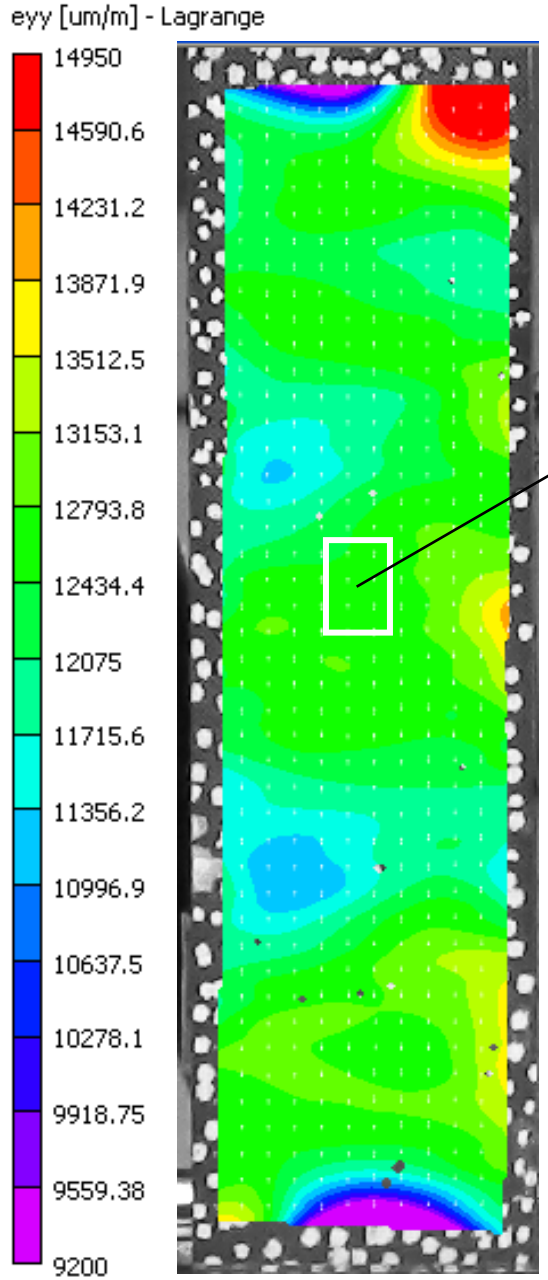
A speckle pattern was applied on the Composite Tensile Specimen.

Strain Gages were mounted on the back side of the specimen in the X and Y direction and the strain gages were interfaced to SCAD 500 Strain Measurement System.

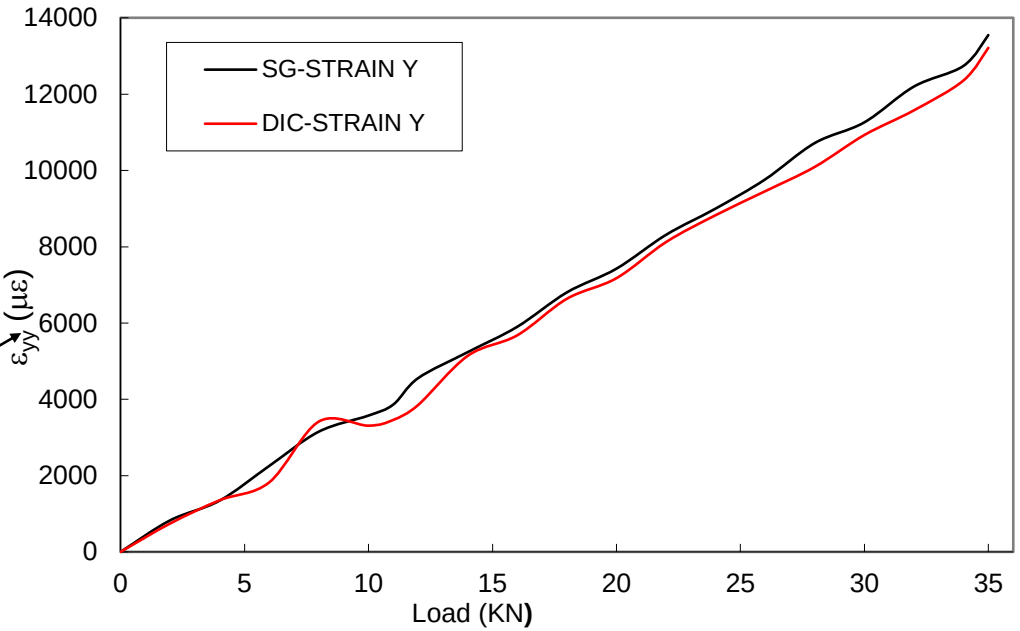
The load was applied in a UTM and images captured in steps of 2KN.

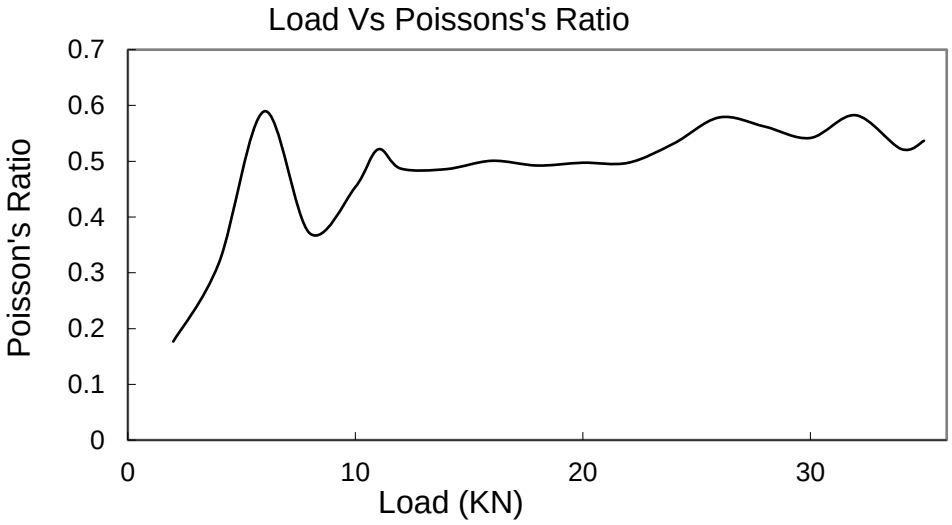
The Specimen failed at 36 KN.





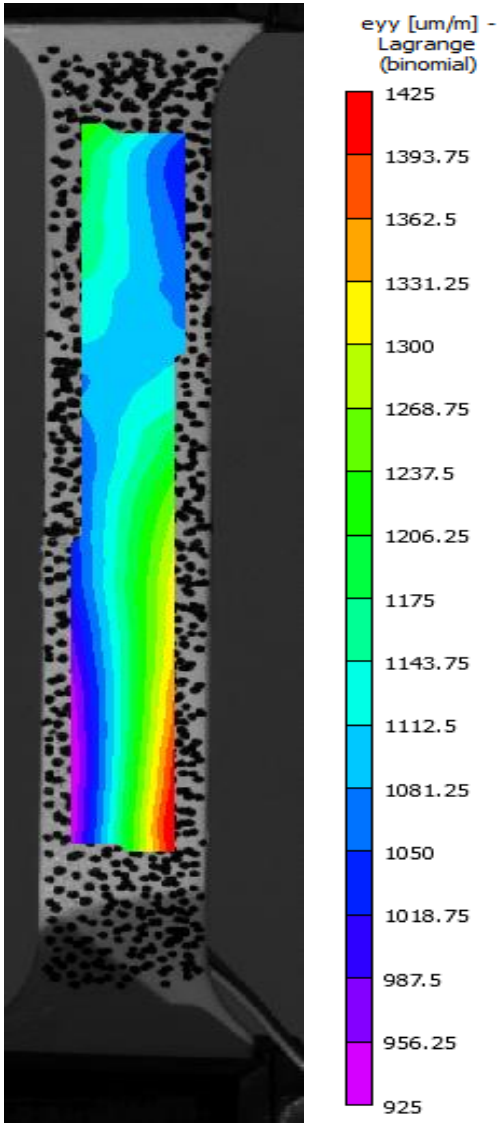
Plot of ε_{yy} At 34KN





PYRO DYNAMICS

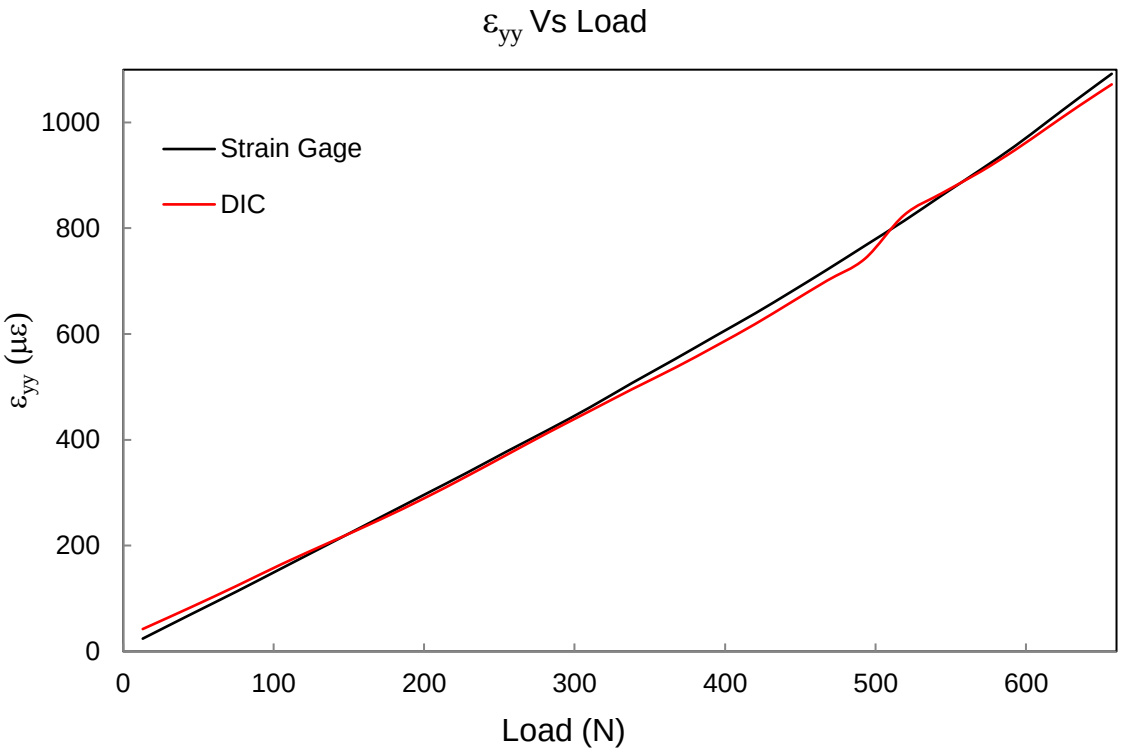
Experiment	Full Field Displacement and Strain Measurement on a Tensile Aluminum Specimen
Organisation	Pyrodynamics, Bangalore
System Used	VIC-3D, 3D Digital Image Correlation System.
Loading Conditions	Static Load
Camera Used	Point Grey Research Grasshopper 2MP Camera, 15fps
Image Frame Capture	One Image at every discrete load step.



Raw Image

Plot of ε_{yy} at final load

LOAD	Strain Gage (με)	DIC (με)	Difference (με)
13	24	42	-18
45	70	83	-13
76	114	125	-11
106	158	166	-8
138	205	207	-2
170	252	248	4
200	296	289	7
228	337	330	7
255	378	372	6
282	418	413	5
310	461	454	7
338	507	495	12
367	553	536	17
394	597	578	19
420	639	619	20
444	680	660	20
468	722	701	21
493	767	742	25
519	814	825	-11
544	862	866	-4
570	911	907	4
593	956	948	8
614	1001	990	11
635	1046	1031	15
657	1092	1072	20



PYRO DYNAMICS

Experiment	Full Field Displacement and Strain Measurement on a Tensile Aluminum Specimen
Organisation	NATIONAL AEROSPACE LABORATORIES
System Used	VIC-3D, 3D Digital Image Correlation System.
Loading Conditions	Static Load
Camera Used	Point Grey Research Grasshopper 5MP Camera, 15fps
Image Frame Capture	One Image at every discrete load step.

PYRO DYNAMICS

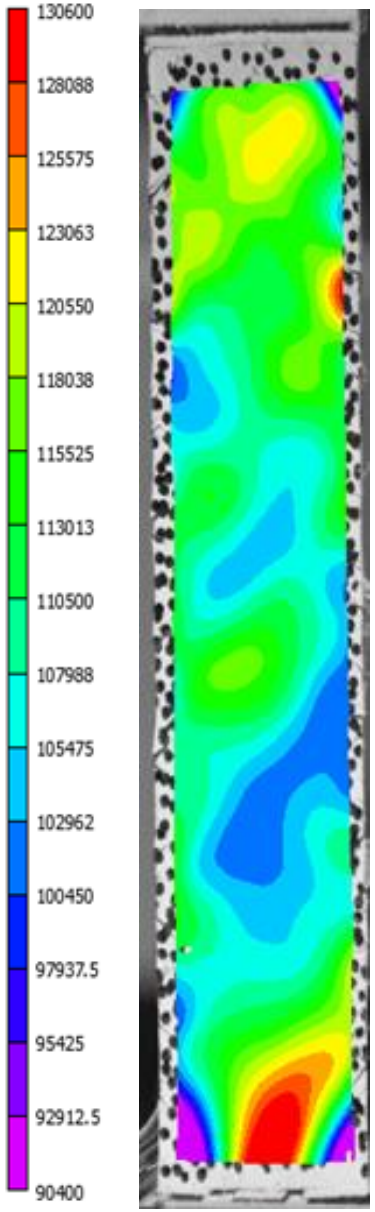
A speckle pattern was applied on the Tensile Specimen.

The specimen had strain gage bonded at the back of the specimen.

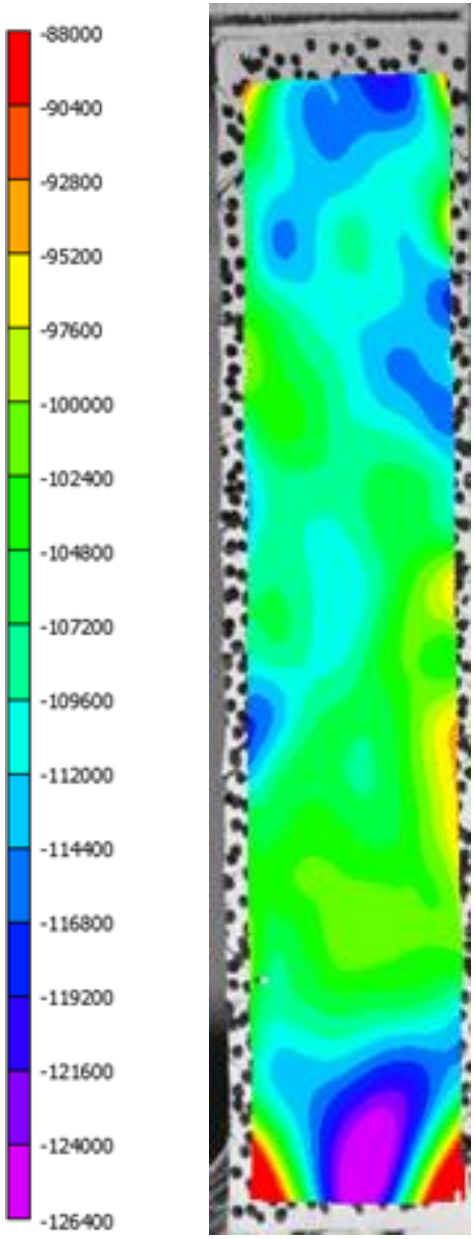
The specimen was loaded upto failure of 10500 Newtons. The image was captured at every 500N.

The Strain Gage was connected to SCAD 500 Strain Measurement System and the strains were recorded at every load step.

PYRO DYNAMICS



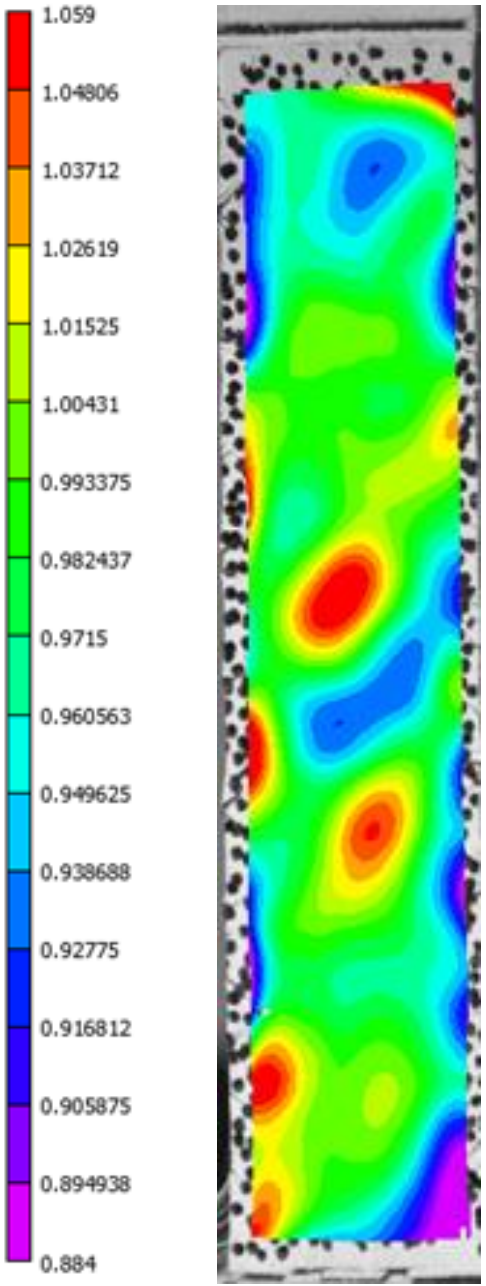
Strain Y ar 10500 N



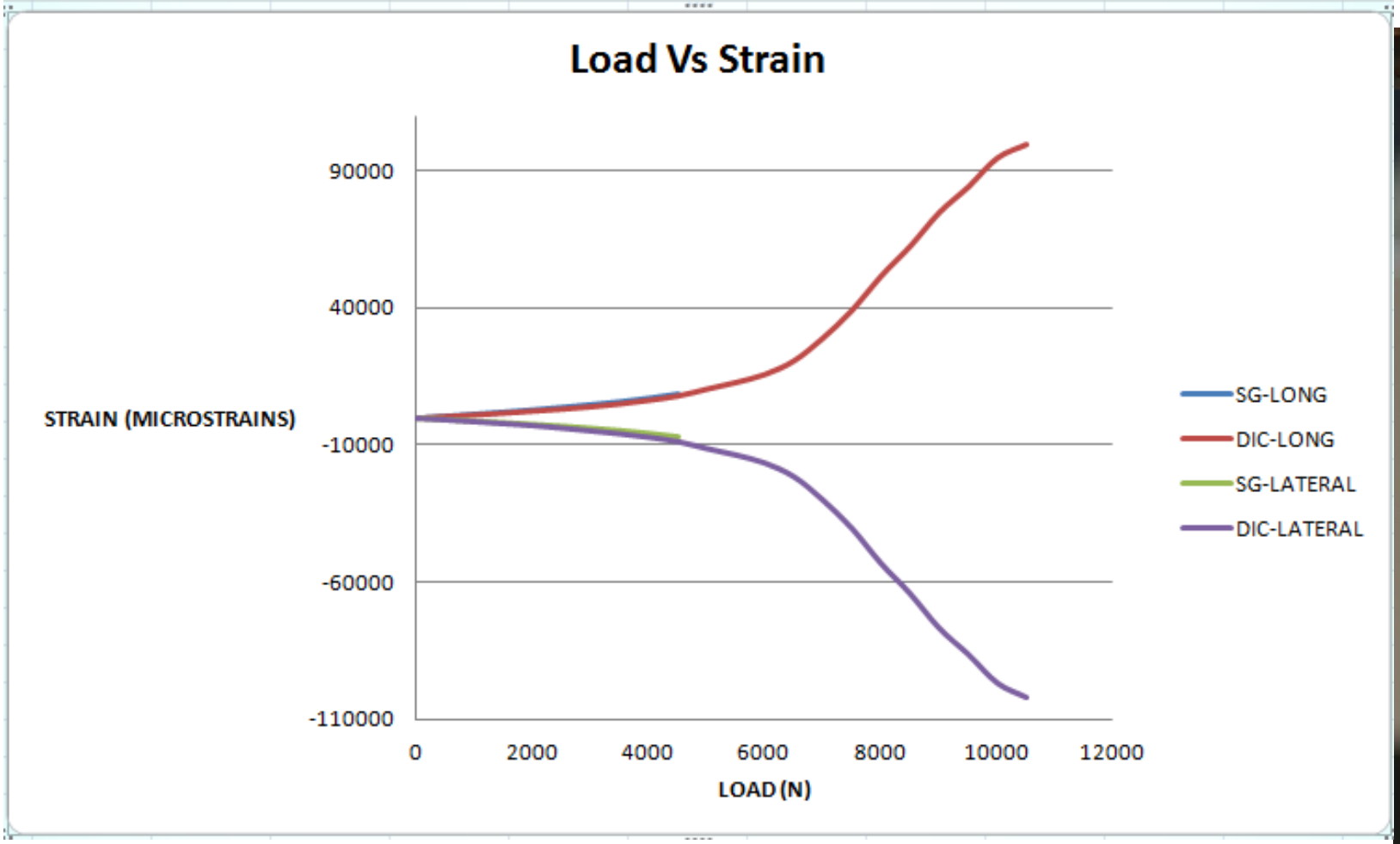
Strain X at 10500 N

Poisson's Ration

Mean Value
0.908975



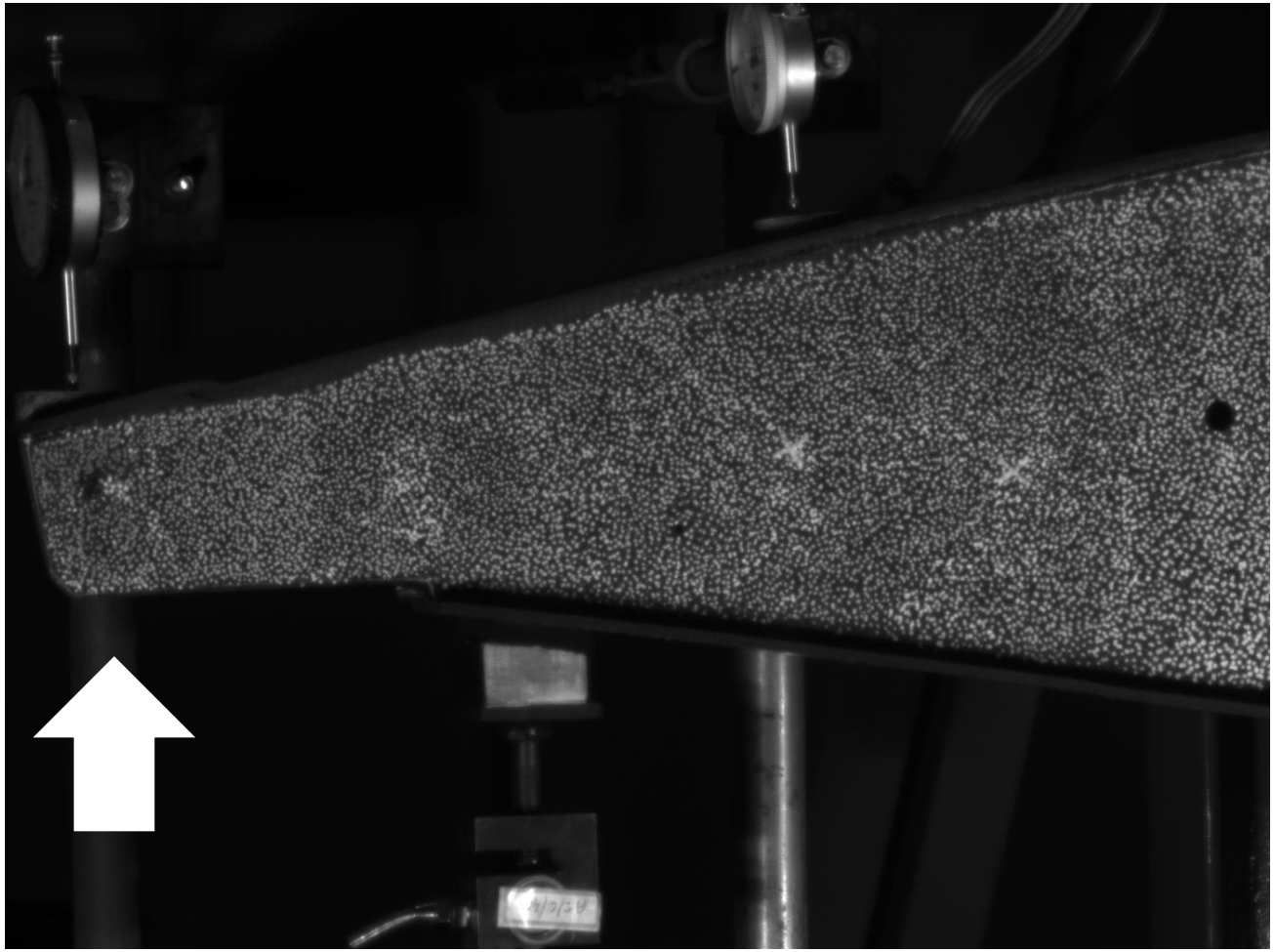
PYRO DYNAMICS



Specimen at Failure

PYRO DYNAMICS

Experiment	Full Field Displacement and Strain Measurement on the AFT Rib of a Wing of a Plane.
Organisation	National Aerospace Laboratories Bengaluru.
System Used	VIC-3D, 3D Digital Image Correlation System.
Loading Conditions	Static Load
Camera Used	Point Grey Research Grasshopper 5MP Camera, 15fps
Image Frame Capture	One Image at every discrete load step.

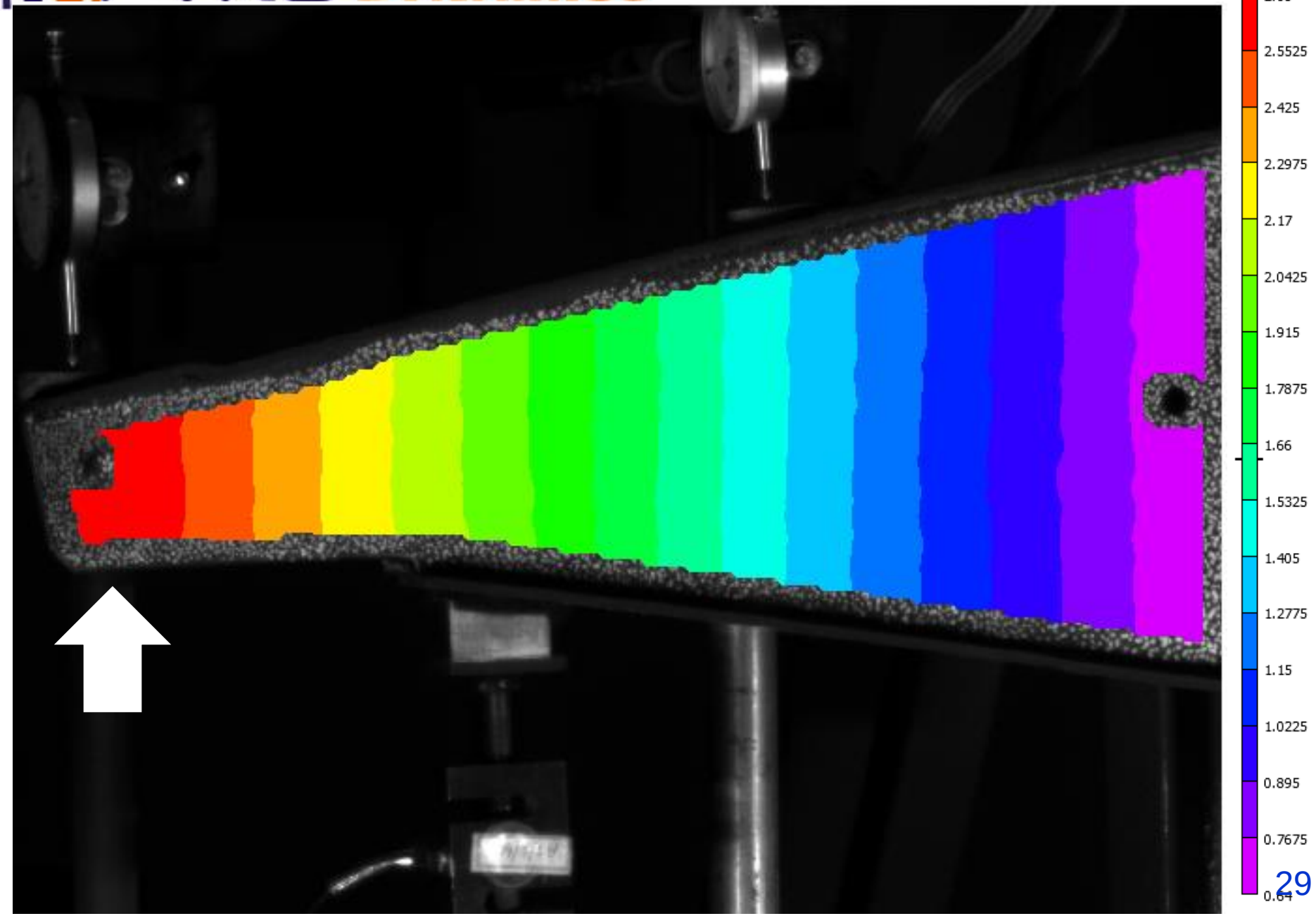


The Specimen was fixed at one end and load applied at the other end. Load was applied in steps of 100 Kgs upto 500 Kgs.

2 Dial Gages were mounted to record the displacements. Strain Gages were mounted at the back of the specimen and interfaced to SCAD 500 System. The locations are marked **X**

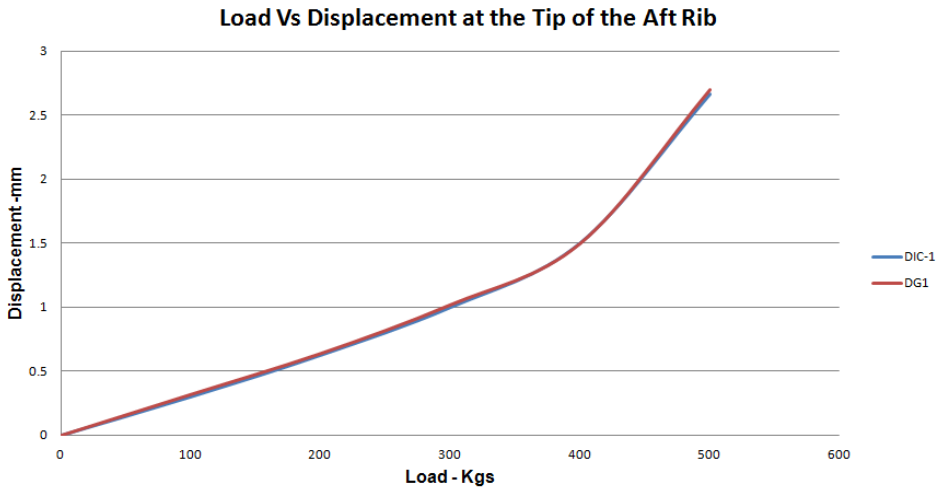
PYRO DYNAMICS

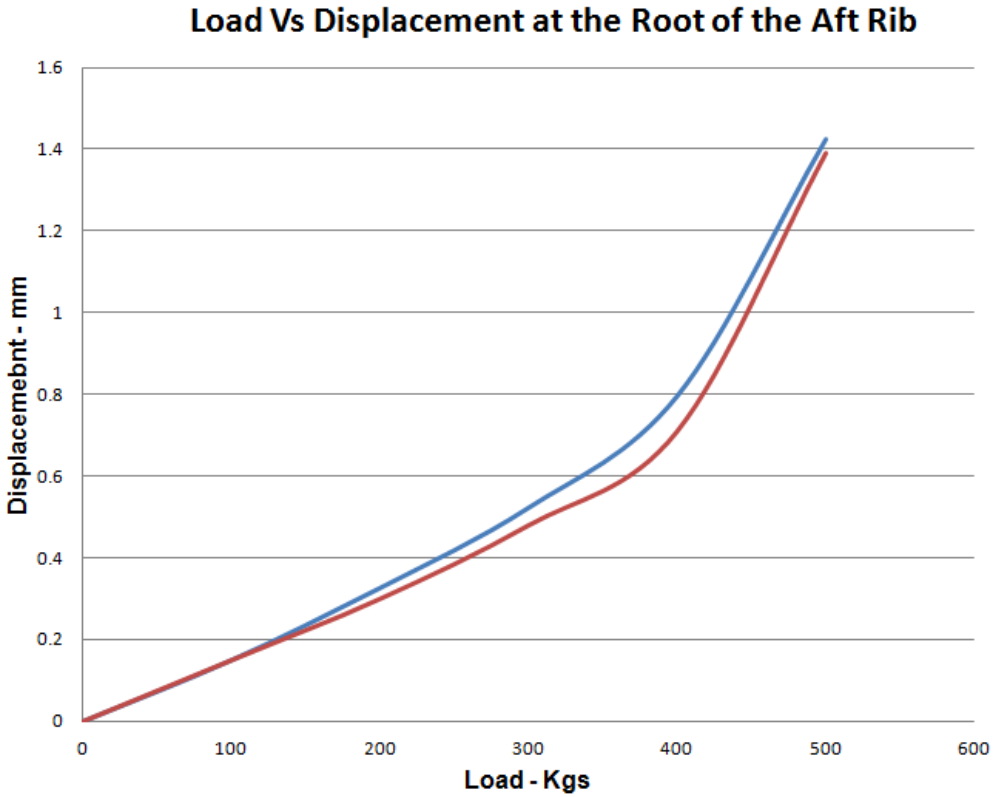
" V " Displacement



PYRO DYNAMICS

Displacement Data of Dial Gage 1 and "V" Displacement obtained from VIC-3D.

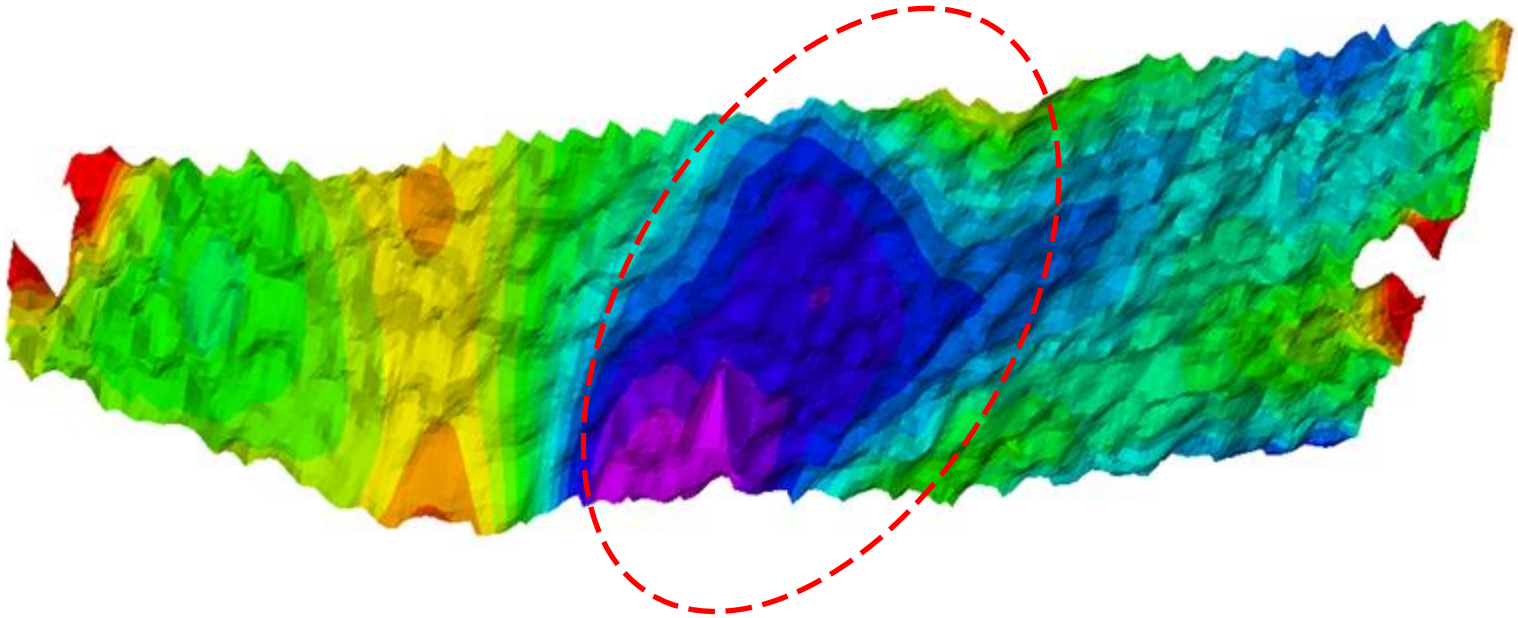




Displacement Data of Dial Gage 2 and "V" Displacement obtained from VIC-3D.

PYRO DYNAMICS

Shear Strain

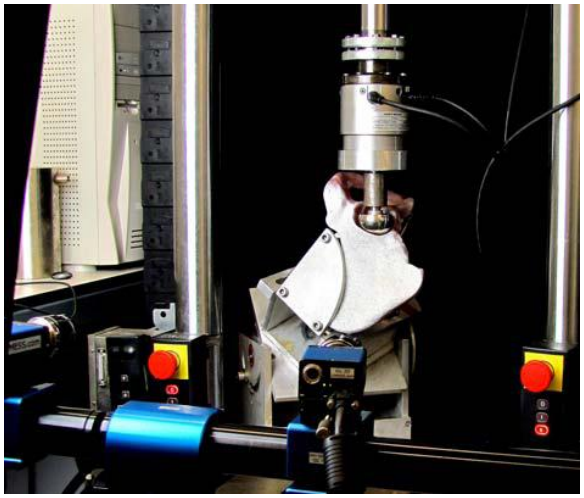


The Shear Strain Pattern Shows a Significant Strain Concentration.

The full scale strain measured was -222 με. Low Strain measurement is very much possible with the VIC-3D system with a resolution of 20 με.

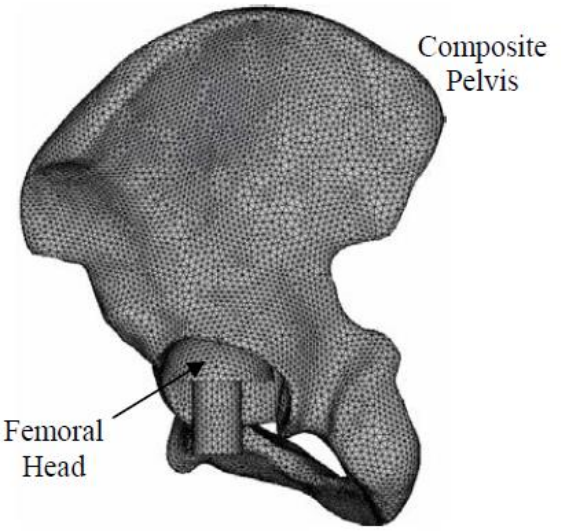
PYRO DYNAMICS

EXPERIMENTAL VALIDATION OF A FINITE ELEMENT MODEL OF THE COMPOSITE PELVIS USING DIGITAL IMAGE CORRELATION



Experimental setup for DIC

FE Model of the Composite Pelvis.



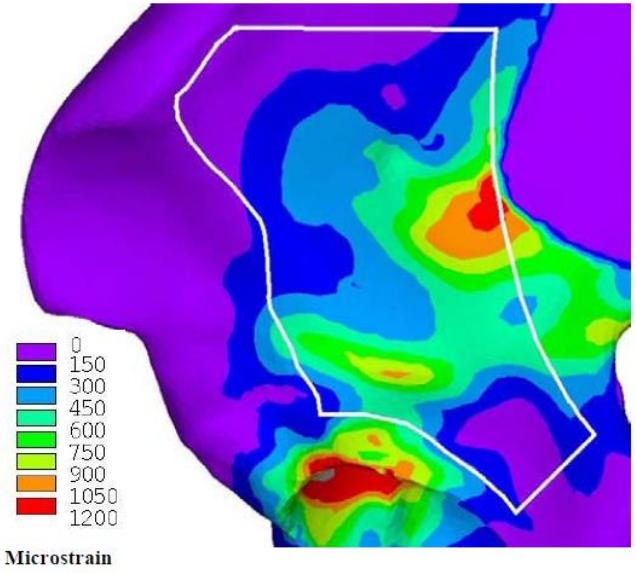


Figure 4. Distribution of von Mises strain in the equivalent FE model of the composite pelvis.

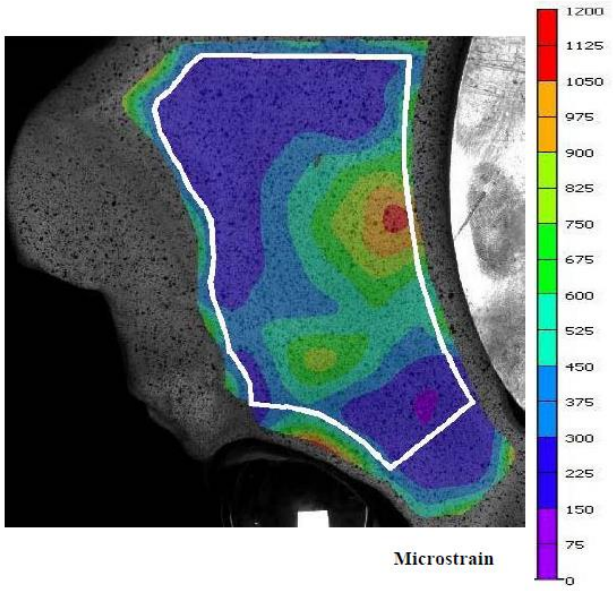


Figure 3. Experimental measurement of von Mises strain pattern using DIC technique.

EXPERIMENTAL VALIDATION OF A FINITE ELEMENT MODEL OF THE COMPOSITE PELVIS USING DIGITAL IMAGE CORRELATION

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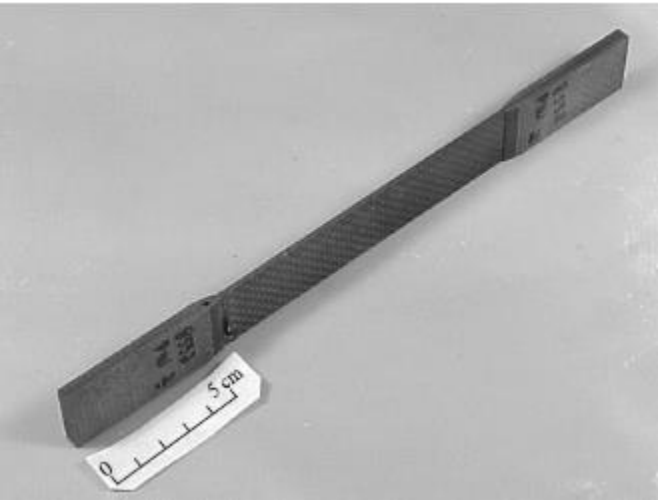
PYRO DYNAMICS

Experiment	Fatigue Measurements of a Composite Specimen
Organisation	Indian Institute of Technology. Department of Aerospace Engineering. Chennai.
System Used	VIC-2D, 2D Digital Image Correlation System.
Loading Conditions	1 Hz Cyclic Loading upto failure. Measurements carried out in the front and back of the specimen using Two VIC-2D Systems.
Camera Used	Prosilica 2MP Camera, 63fps
Image Frame Capture	60 images in one second and a hold period of 100 seconds. This image capture is looped.

PYRO DYNAMICS



A speckle Pattern was applied on the Composite Specimen. Measurements are made on the width of the specimen.

To study the failure measurements were made both on the front and back side of the specimen.

The failure mode is different in the front and back of the specimen

Image of the Front of the Specimen

At No Load and After Failure.

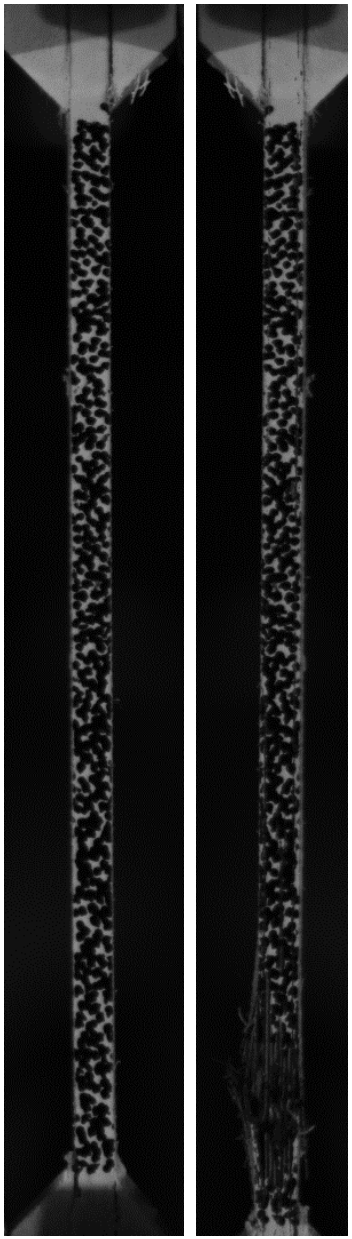
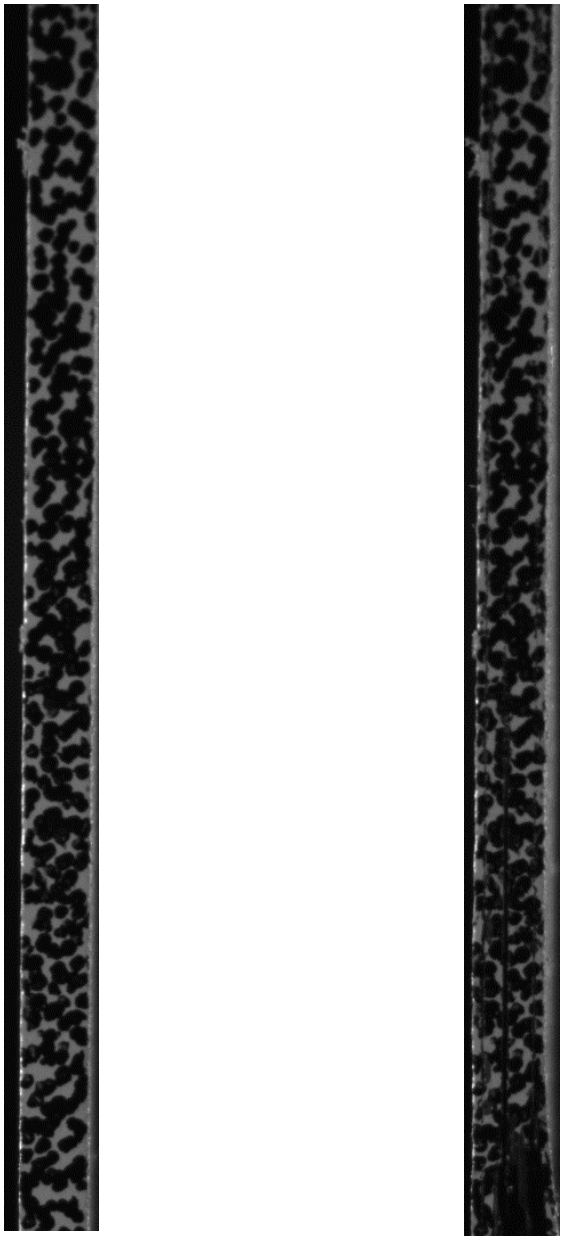


Image of the Back of the Specimen

At No Load and After Failure.



PYRO DYNAMICS

System Set Up.

Two Prosilica GX Series were used for Measurements.

These cameras are interfaced to the GigE Dual Port of the PC.

Each camera can capture images at 63 fps simultaneously.

The analog output of the Load cell from the UTM was interfaced to the Daq.

So whenever an image was captured the analog output was also recorded.

The specimen was subject to a cyclic load from 24 to 48KN. Frequency – 1 Hz

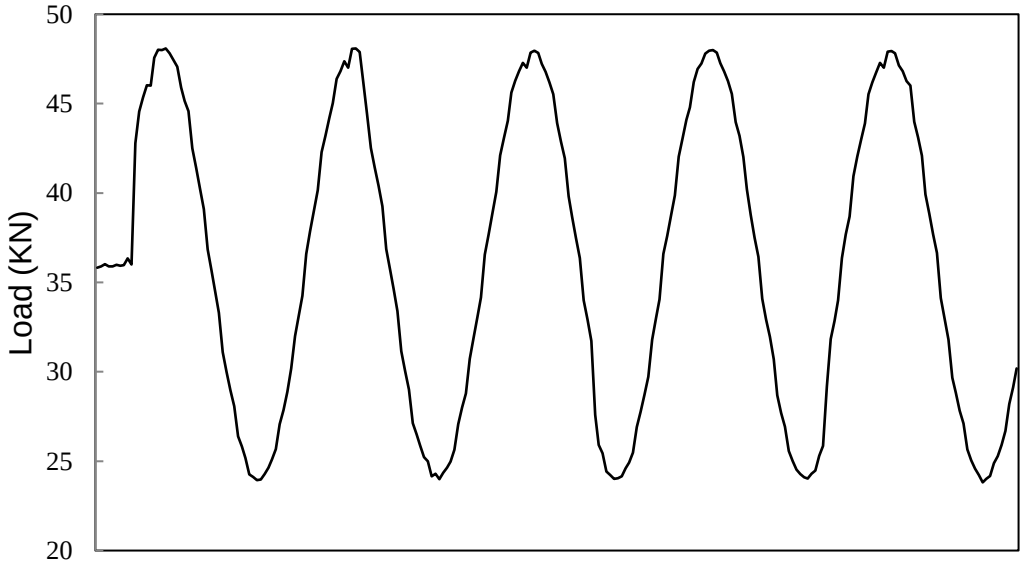
The specimen failed after 8558 cycles.

The VIC-SNAP software was programmed to capture 60 images in one second and a hold period of 100 seconds.

This cycle of image capture was looped until failure.

Duration of the Test:- 3 Hours.

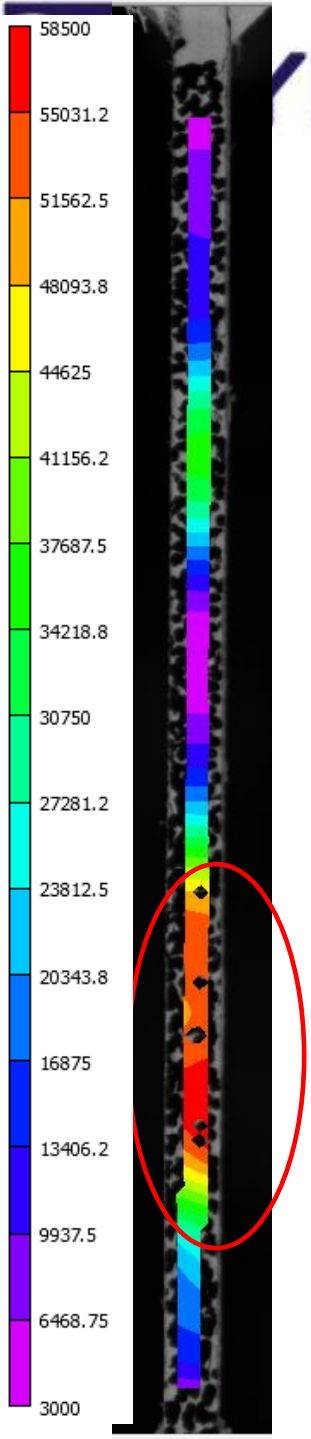
Loading Cycle



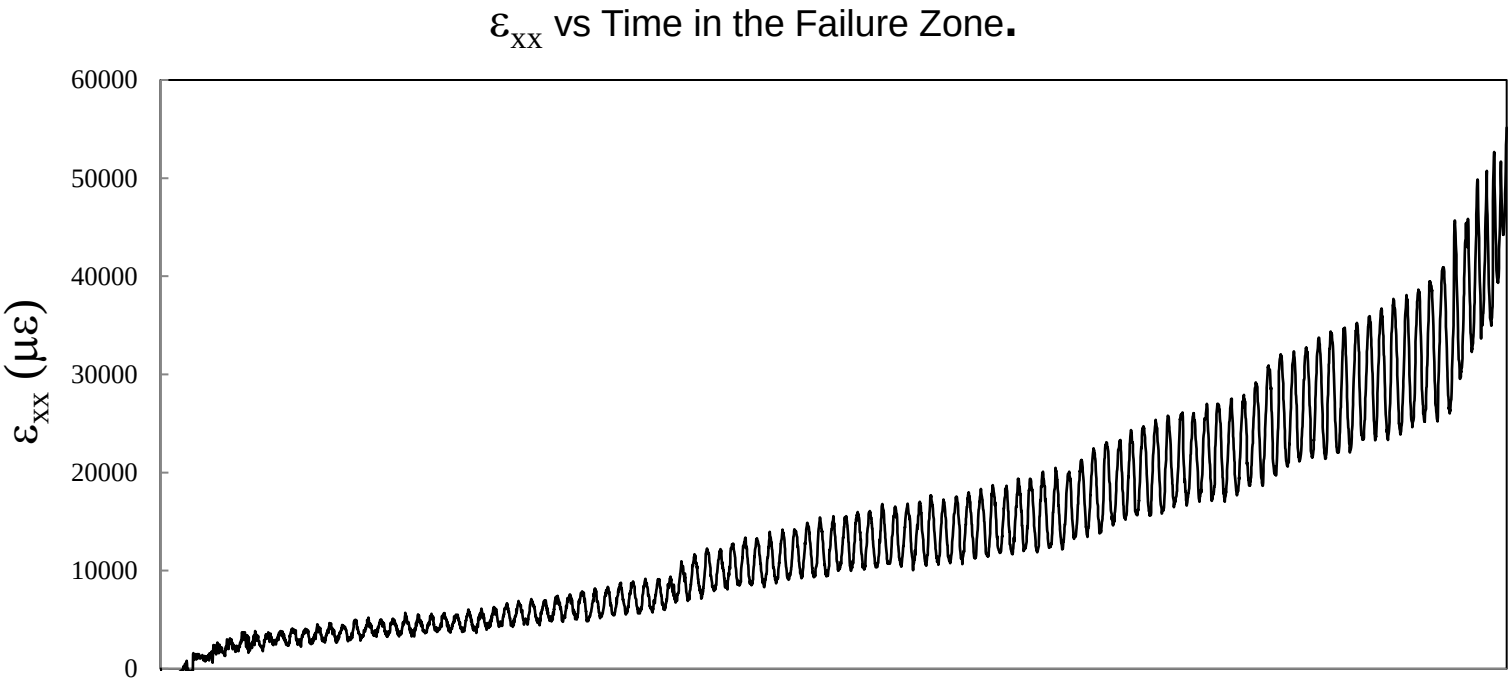
Measurements were made on the Front and Back of the Specimen Simultaneously. So the setup Included 2 Simultaneous Measurements in 2D DIC.

VIC-2D Software was used for Analysis.

Strain Plots – Front of the Specimen - Strain - X

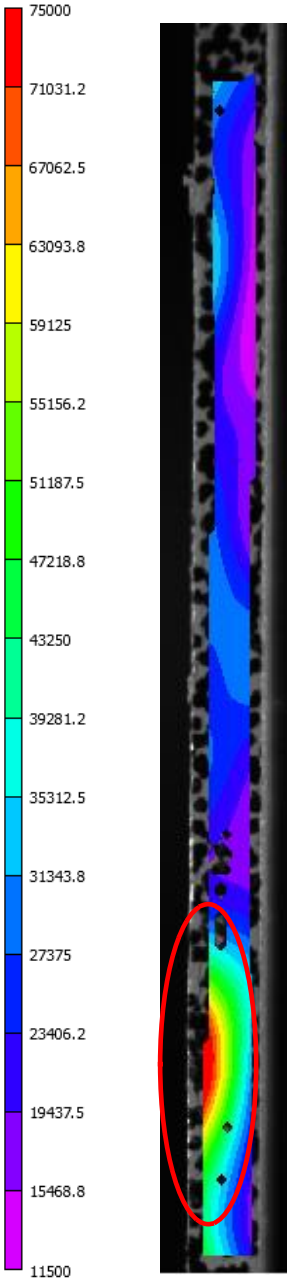


Failure Zone

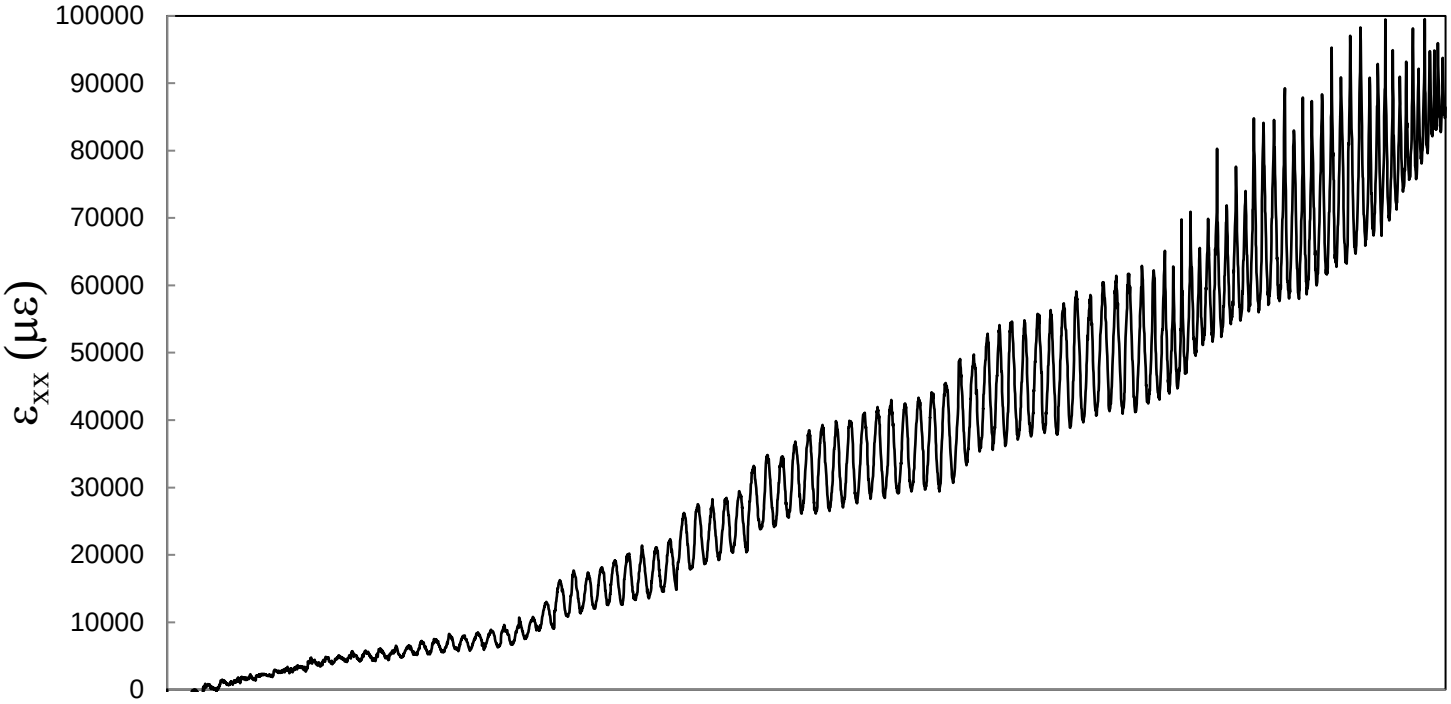


PYRO DYNAMICS

Strain Plots – Back of the Specimen – Strain X.



ε_{xx} vs Time in the failure zone



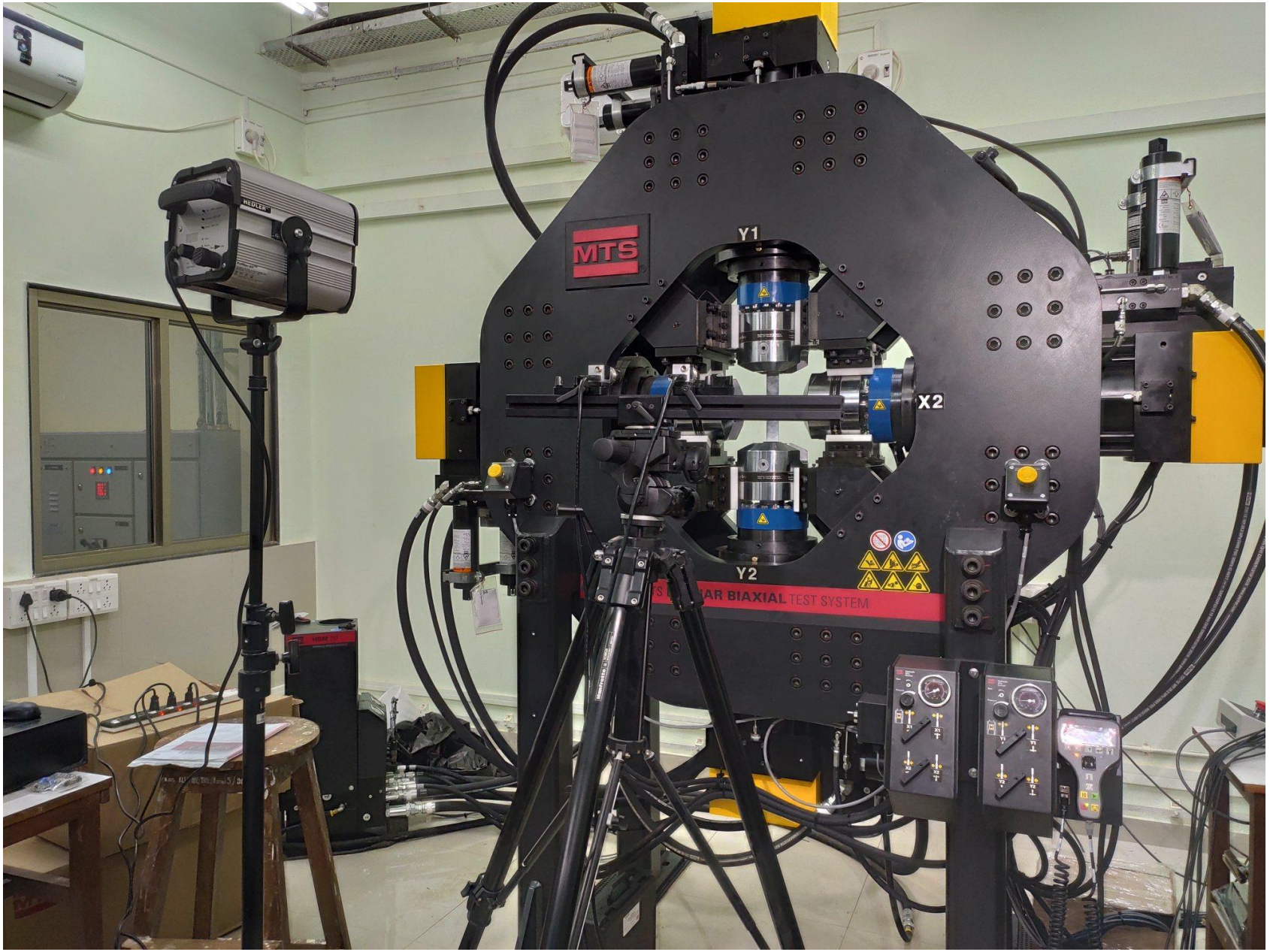
Failure Zone

From the plots its clear the failure mode and the strain profile are different on the back and front of the specimen.

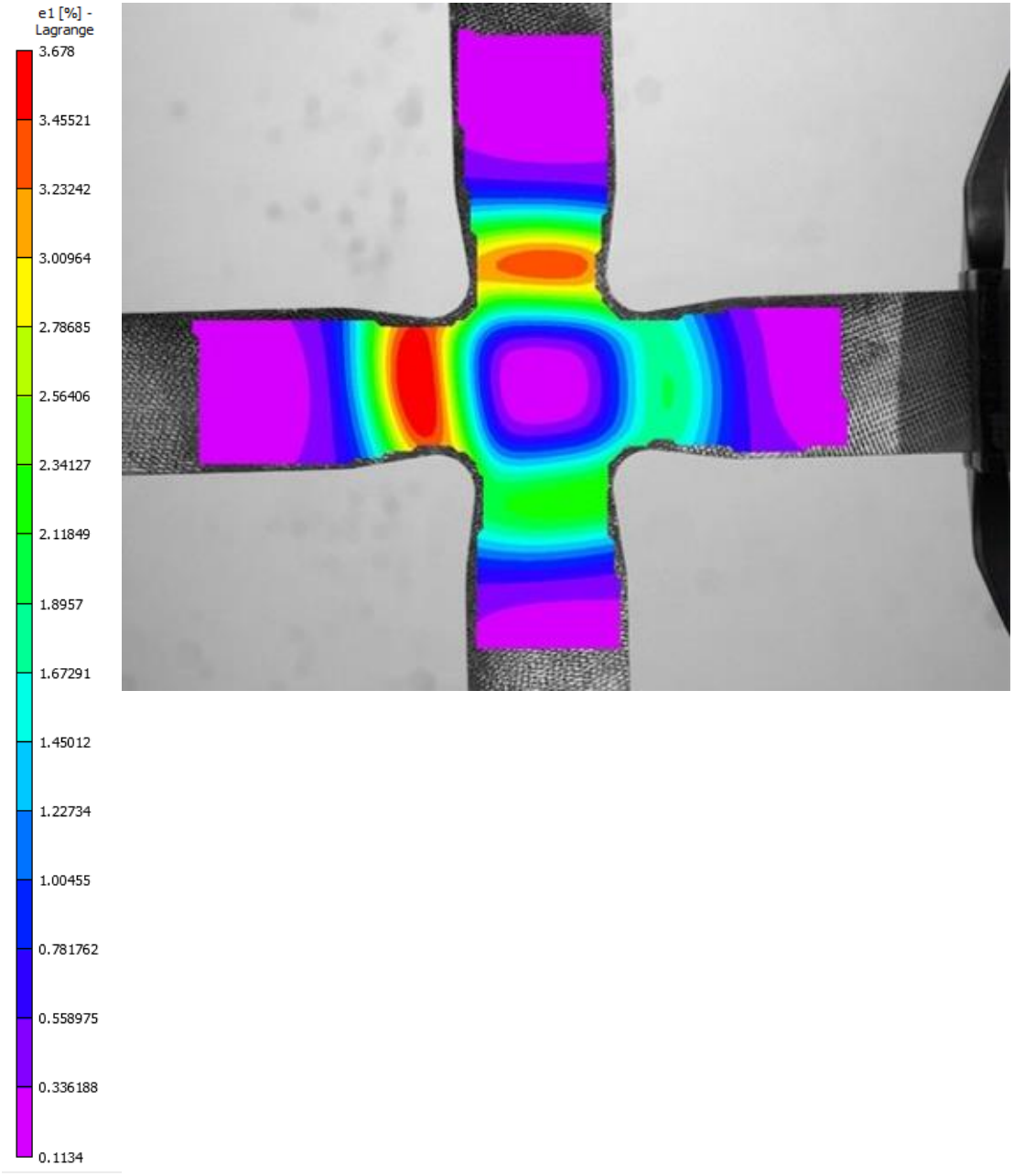
PYRO DYNAMICS

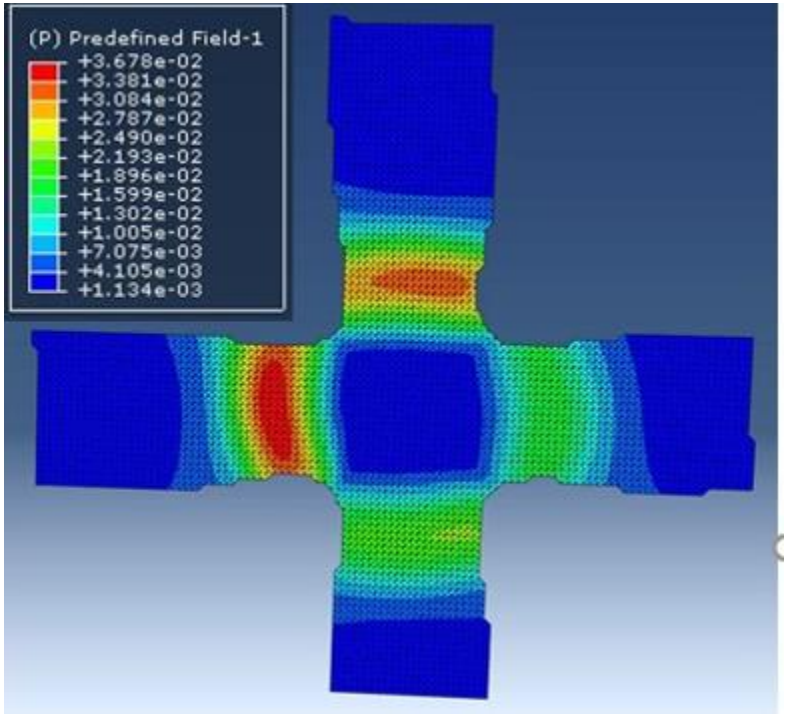
Experiment	Bi Axial Test of a Aluminum Cruciform Specimen.
Organisation	Indian Institute of Technology. AMTF - Department of Mechanical Engineering. Chennai.
System Used	VIC-3D, 3D Digital Image Correlation System.
Loading Conditions	Static.
Camera	5MP, 75 fps USB 3.0 CMOS Camera.

PYRO DYNAMICS



Principal Strain 1





Principal Strain 1 Data obtained from VIC-3D and Plotted in Abaqus.

PYRO DYNAMICS

Advantages of Digital Image Correlation

- ✓ Non Contact and Full Field.
- ✓ Setup time is less.
- ✓ Easy to use.
- ✓ Provides Full Field Displacement & Strain Fields.
- ✓ Full Field Modal analysis and Full Field Acceleration Measurement.
- ✓ Strain Resolution of 25 to 50 με or better.
- ✓ Displacement Resolution:- A few Microns to Sub Microns depending on the Field of View.

In Plane Displacement Resolution = 1/100000 of the Field of View.

Out of Plane Displacement Resolution = 1/50000 of the Field of View.

Field of View is defined as the Diagonal Distance of the Area of Interest.

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- ✓ DIC Measurements can be made on any material:- Concrete, Metal, Plastics, Composites, Rubber, Human Skin…etc
- ✓ Validation of FEM Data can be done easily.
- ✓ Direct interface to Matlab to Compare DIC and FEM Data.
- ✓ High Speed DIC and Modal Analysis.
- ✓ Area of Measurement:- mm^2 to a few m^2
- ✓ Strain Range:- Upto 100's of % Strain.
- ✓ High Strain Zones easily identified.
- ✓ Generally 5MP USB cameras with 75fps are used for DIC Measurements.
- ✓ However the recent trend is to use Cameras with a resolution of 8.9 to 12.3 Mega Pixels to carry out Strain Measurements on Large Structures Like Wind Turbine Blades, Wing of Air Craft, Space Craft Shells…etc. This way DIC Measurements are carried out with a good displacement and strain resolutions.

PYRO DYNAMICS

✓ Cameras with 2 MP Resolution and frame rates of 162 fps are Available for Dynamic Measurements.

✓ Recent Trend is to use High Speed Cameras (10,000 fps upwards with 1 MP Resolution) to carry out High Strain Rate, Impact Measurements, Shock Tube Applications, Hopkinson Bar Tests…etc

✓ Recent Trend is that DIC has been successfully used for Non Contact Full Field Modal Analysis

✓ Recent Trend is DIC has been successfully used for measurements of Microscopic Images (In AFM or SEM), MEMS…etc.

✓ The future is to use Volumetric Digital Image Correlation. VDIC has the promise and capability to carry out DIC Measurements insitu of the structure (Something that was carried out so far only through Fiber Optic Sensors).

This technique is still in the University Research and will be commercially available soon.

Limitations of DIC

× Optical Access of The Test Object is a must.

PYRO DYNAMICS

Lets Think Collectively

Thank You

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