Detecting and Monitoring the Development of Surface Cracks Using the Grid Method

Saksorn Fhaikhao

Michael R. Wisnom, Fabrice Pierron

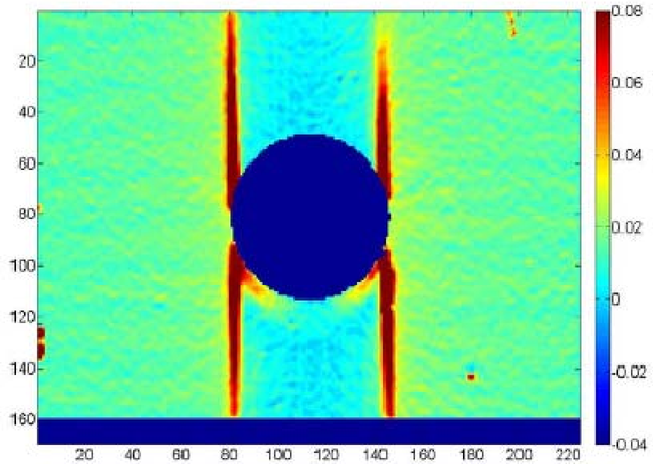
University of BRISTOL

ENSAM
Ecole Nationale Supérieure d'Arts et Métiers
Châlons en Champagne

accis
ADVANCED COMPOSITES CENTRE FOR INNOVATION & SCIENCE

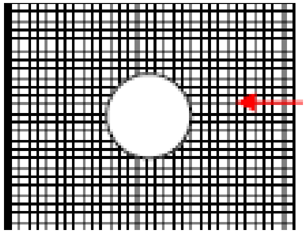
Background

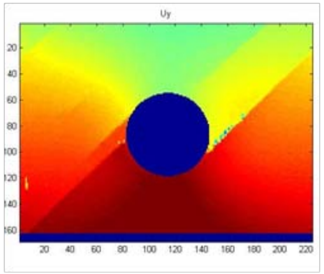
- Full field measurement techniques are developing rapidly and can provide a lot of information about the tests
- Cracks produce discontinuities in displacements that can easily be seen
- Manual processing of the data to give quantified information is very tedious
- The goal of this study was to develop an automated way to process full field displacements to identify the development of cracks during loading

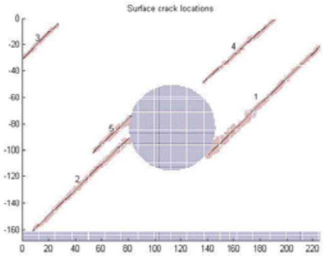


Outline

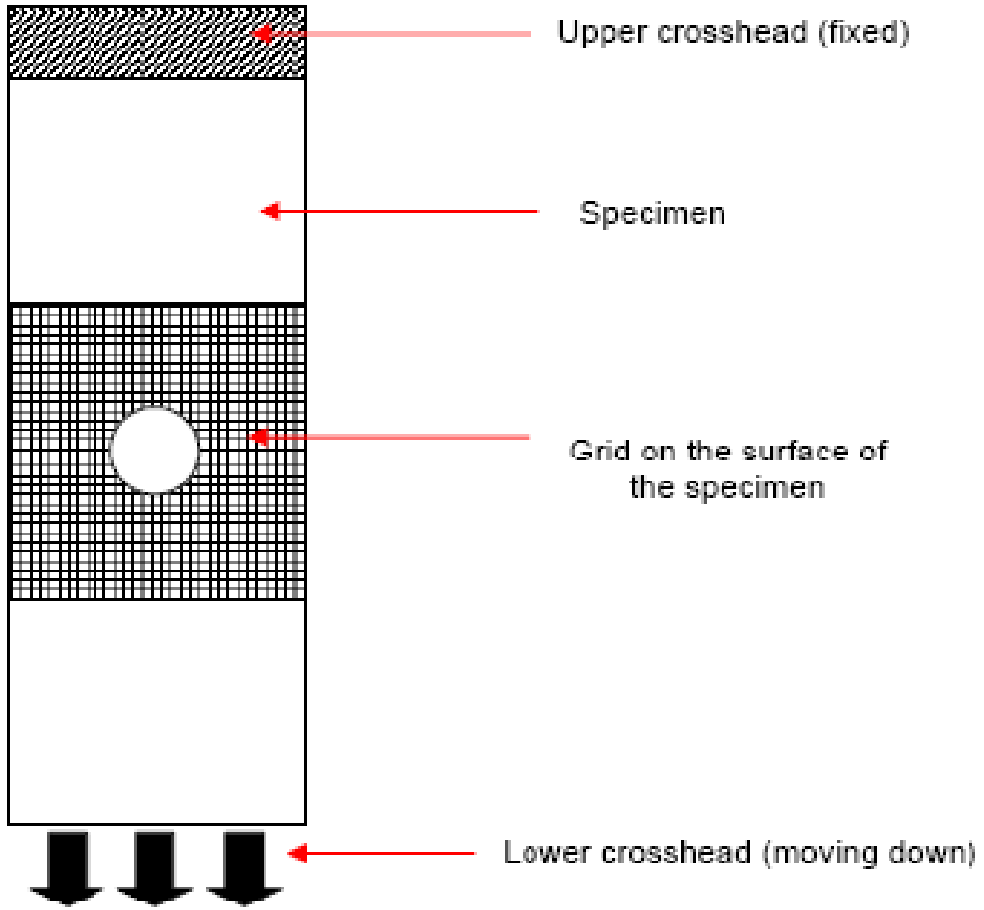
- Measurement of full-field surface strains using the grid method
- Development of an algorithm for automatically detecting surface cracks
- Application to open hole tension tests on glass-epoxy specimens
- Investigation of effect of blocked versus dispersed plies on crack development for cross-ply and quasi-isotropic laminates







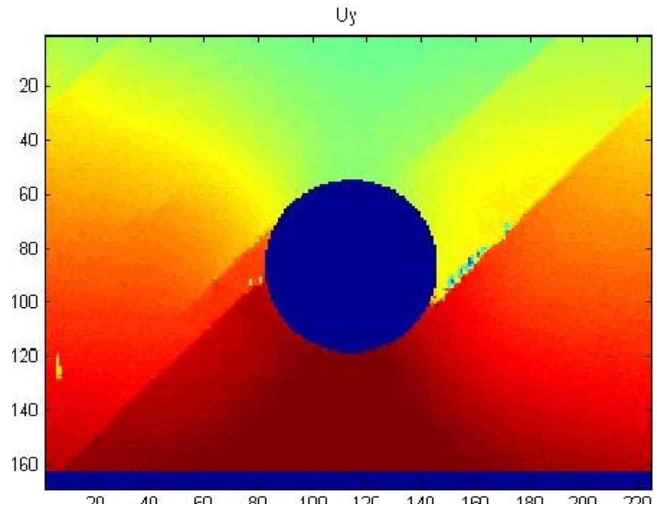
Procedure

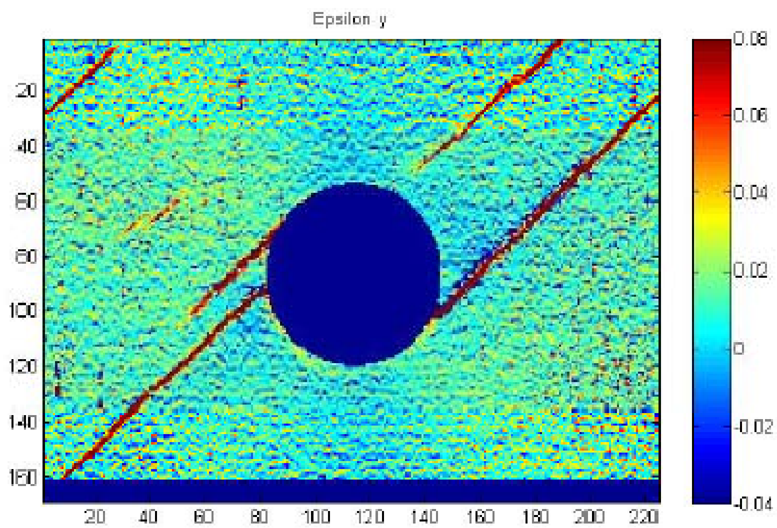


- Orthogonal grid printed on thin specialist photographic polymer film
- 0.1 mm pitch
- Grid carefully bonded to specimen
- Tested in tension

Experimental set-up

Determination of strains

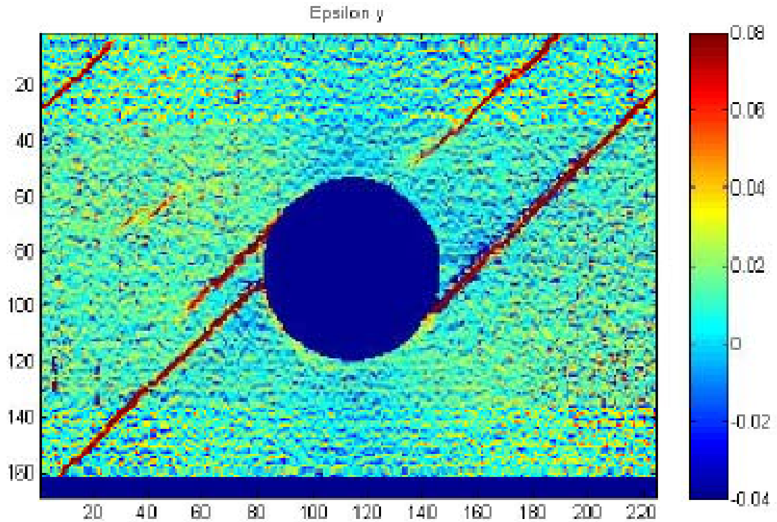




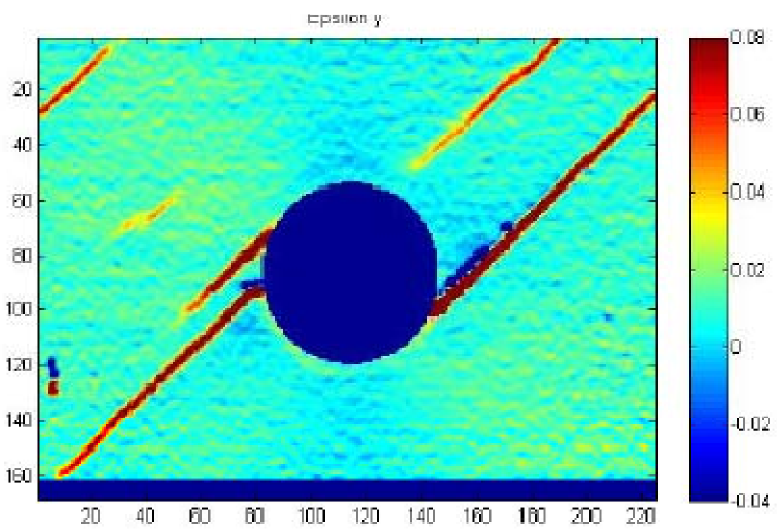
- Measure x and y displacements

- Local differentiation to calculate strains
- Note these are numerical strains

Noise filtering

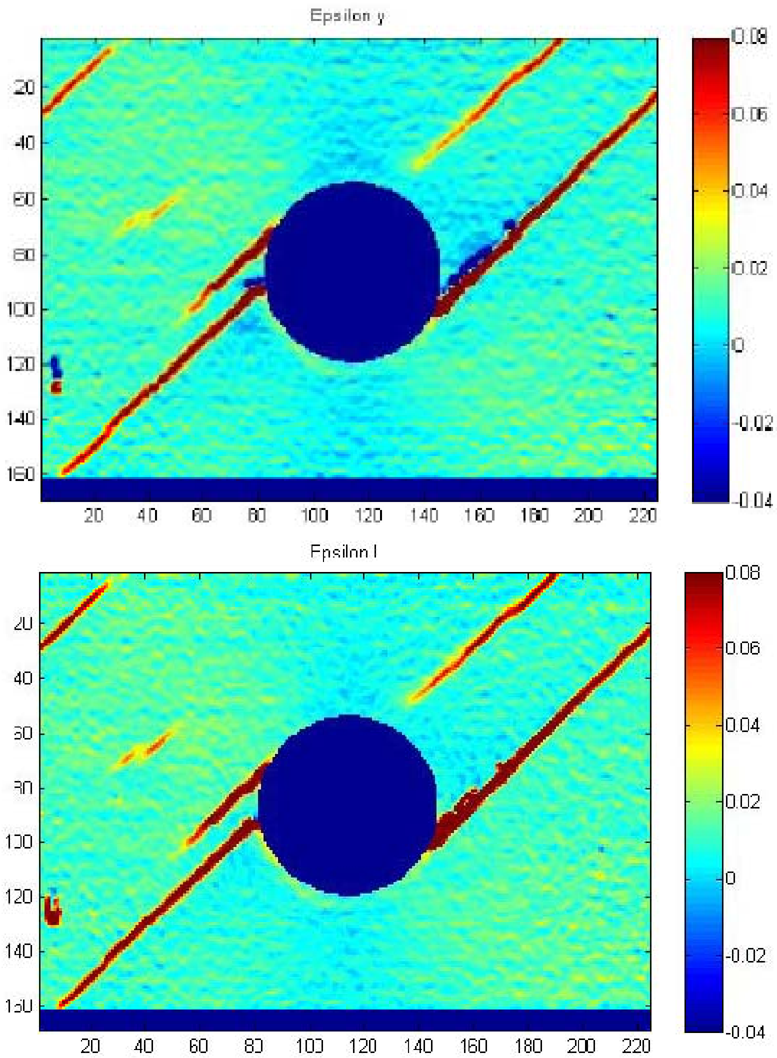


- 5 x 5 Gaussian filter
- Y strain before filtering



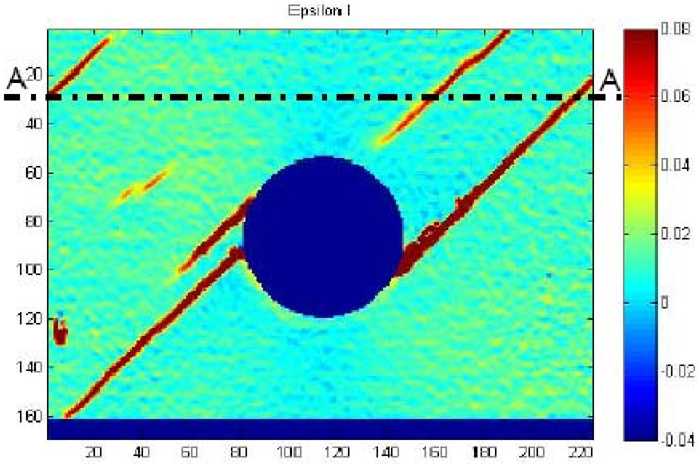
- Y strain after filtering

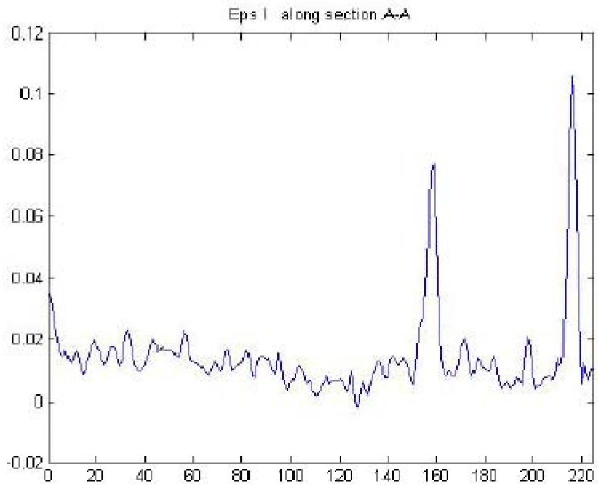
Choice of monitoring parameter



- Various possibilities – local, global strains, principal, max shear
- Maximum principal strain chosen
- Independent of crack orientation
- Works for mode I, II and mixed mode

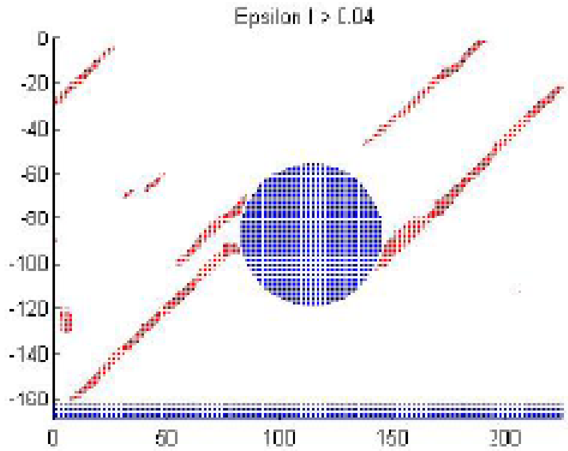
Maximum principal strains



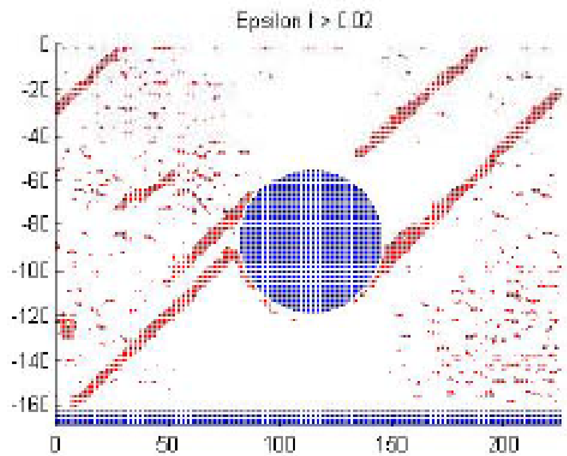


- Noise still present, but cracks do stand out
- Need a criterion to distinguish between real cracks and noise to use in detection algorithm

Threshold parameter

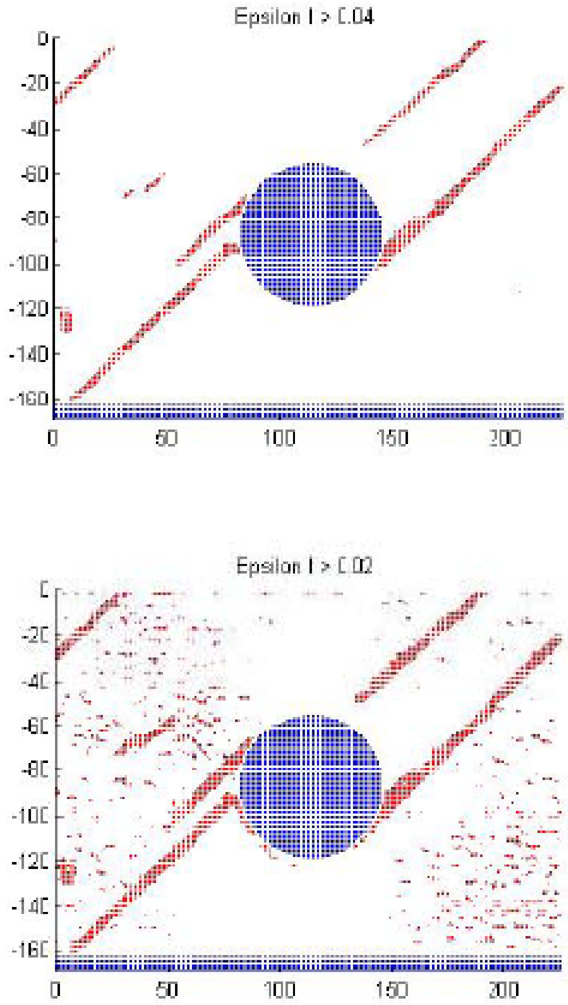


- Points with max principal strain above 0.04



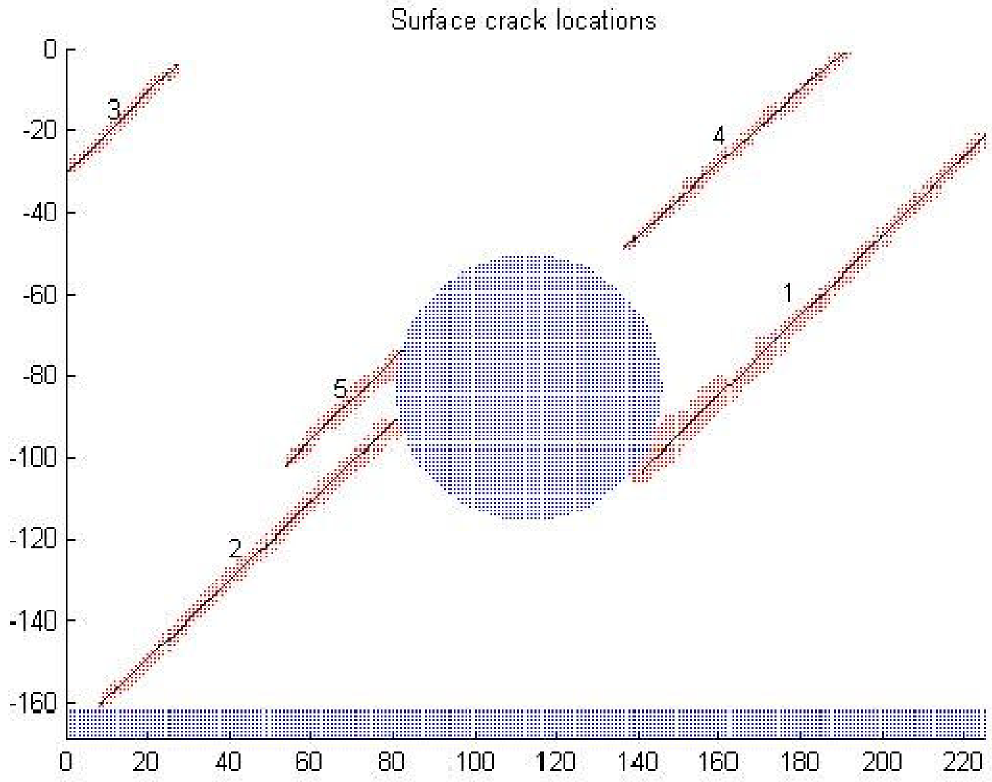
- Points with max principal strain above 0.02

Double threshold algorithm



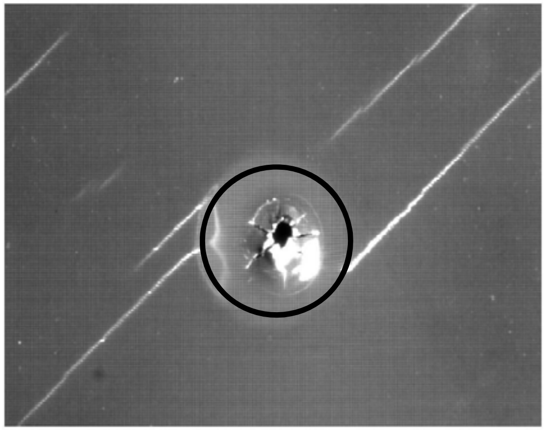
- Any points above 0.04 threshold marked
- Other points above a second lower threshold of 0.02 marked if one of the adjacent points is also above the threshold
- Reduces noise whilst capturing full length of cracks

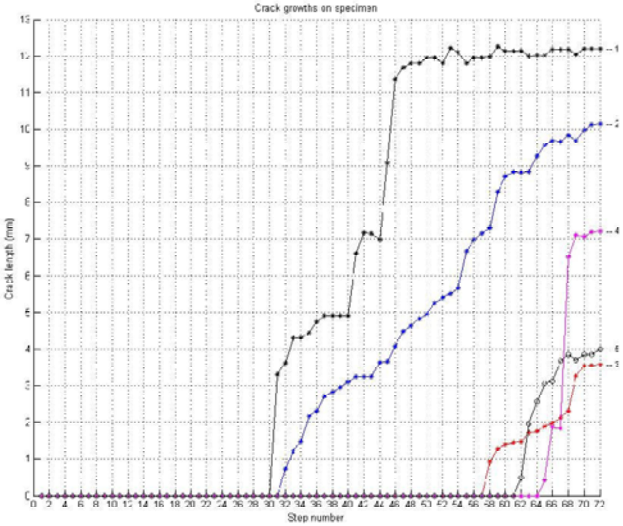
Crack identification



- Least squares fitting through clusters of detected points
- Cracks assumed straight
- No assumption on orientation

Multiple cracks





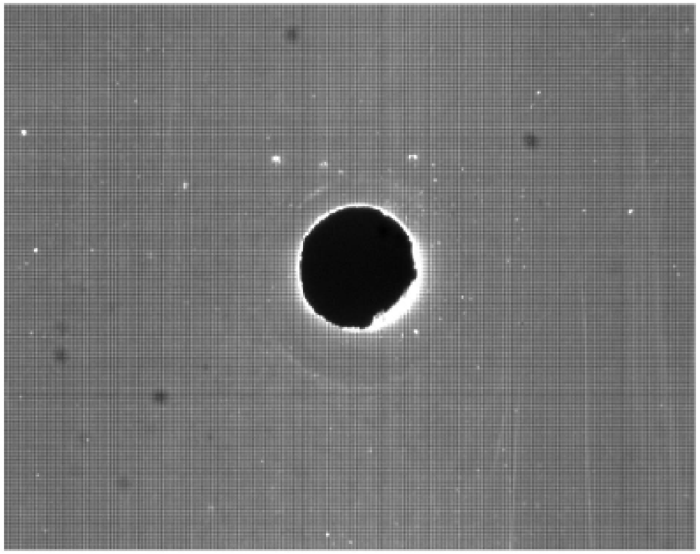
- Define cracks by windowing last image on test
- Can then automatically process to get length of each crack as a function of load

Validation

- Crack lengths compared against directly measured values
- Accuracy of +/- 0.2 mm
- Consistent with 0.1 mm grid pitch

Surface crack no.	Crack length (mm)		Difference (mm)	% error
	Measured directly	From the routines		
1	12.0	12.20	0.20	1.67
2	10.3	10.12	-0.18	-1.75
3	3.5	3.58	0.08	2.29
4	7.0	7.21	0.21	3.00
5	3.8	3.99	0.19	4.76

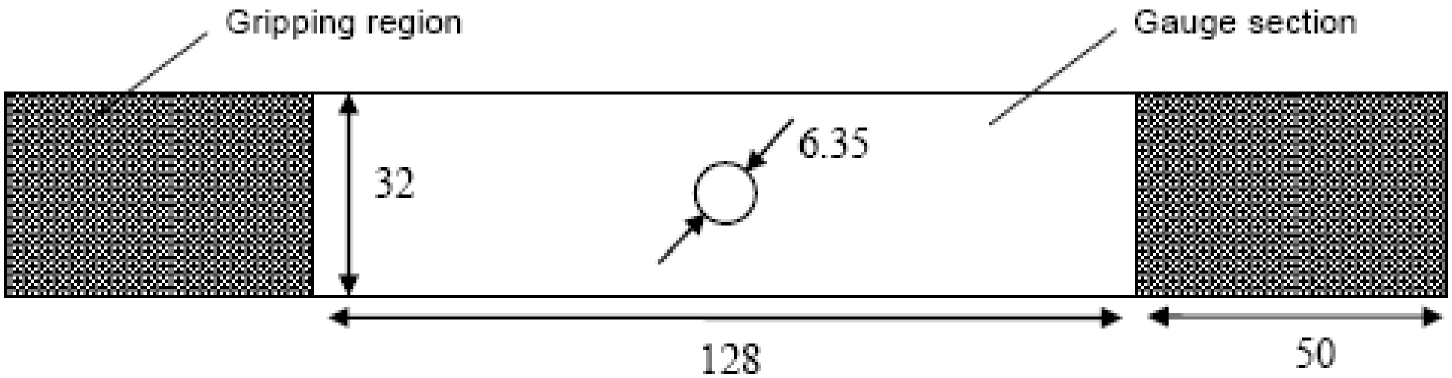
Limitations



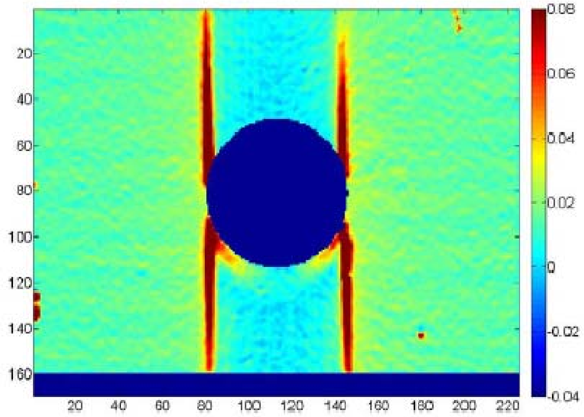
- Quality of grid, transfer to specimen, air bubbles
- Grid debonding
- Cannot distinguish between grid debonding and specimen cracking

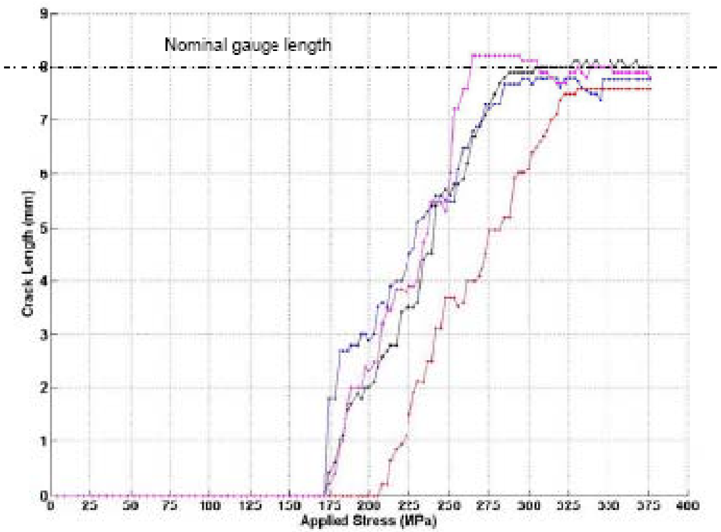
Application

- Open hole tension of glass/epoxy
- Cross-ply and quasi-isotropic layups
- Blocked and dispersed plies



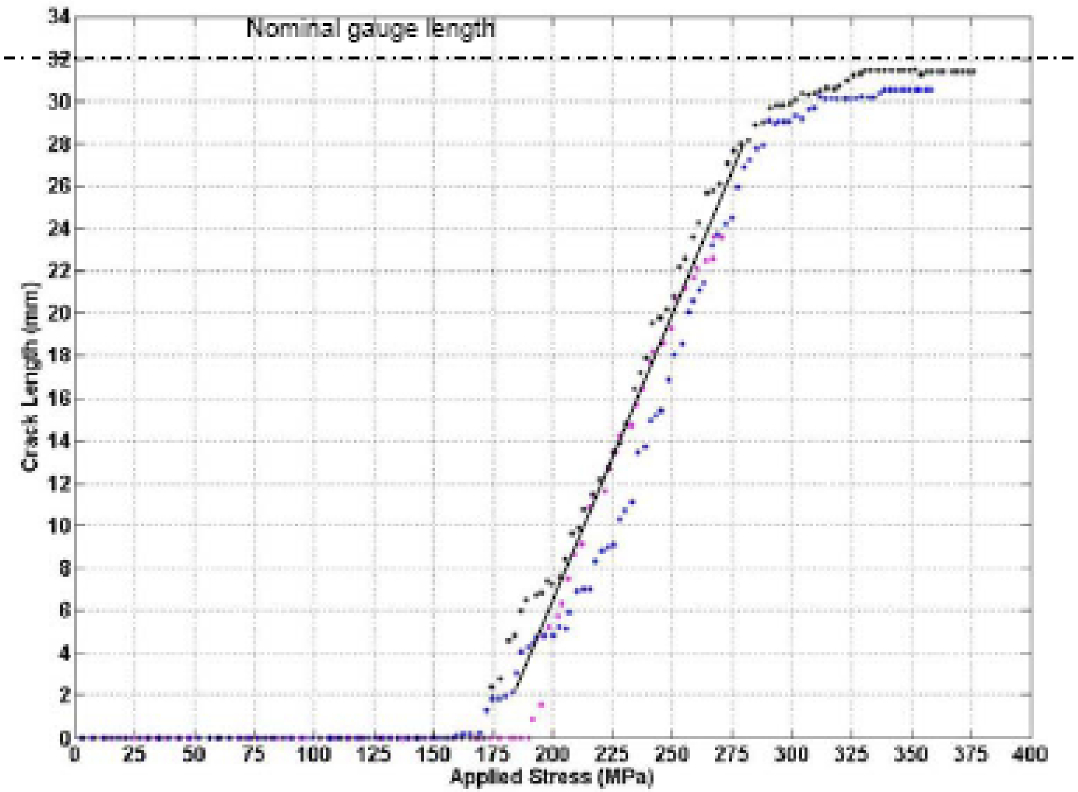
Growth of splits in cross-ply





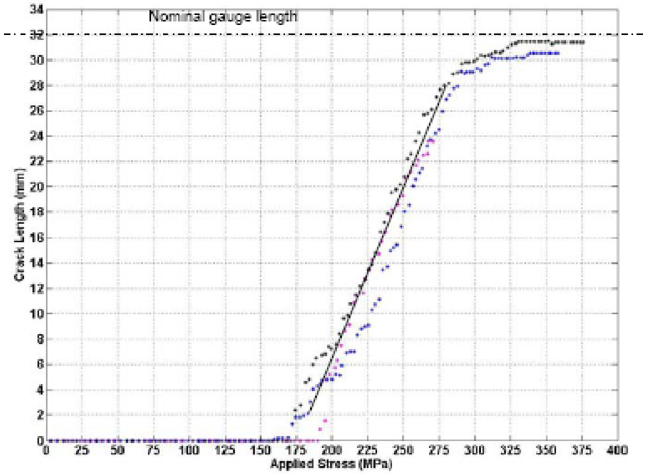
- $(0_4/90_4)_s$ layup
- Max principal strains
- Growth of 4 splits very similar

Repeatability

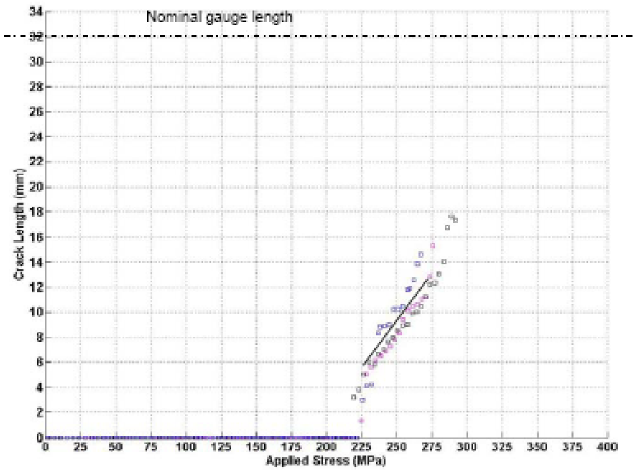


- Total split lengths compared
- Consistent results between 3 different specimens

Effect of ply blocking – cross-ply



Blocked plies $(0_4/90_4)_s$

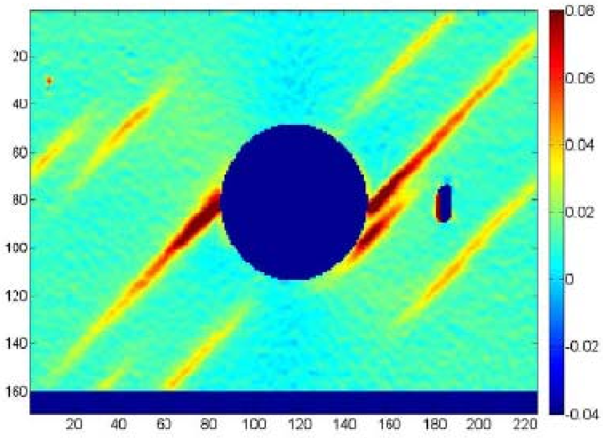


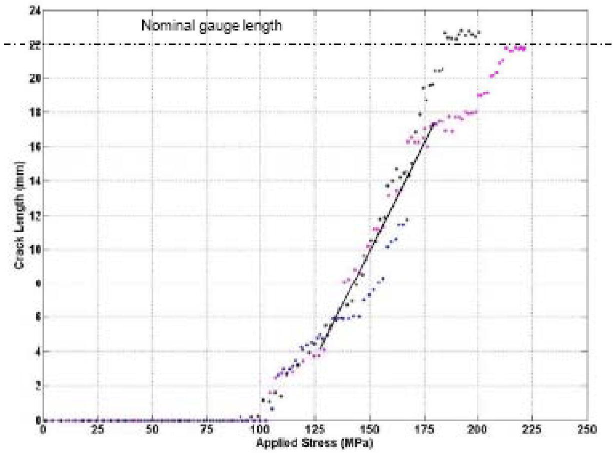
Dispersed plies $(0/90)_{4s}$

Layup	Initial cracking stress (MPa)	Final failure stress (MPa)
Dispersed plies $(0/90)_{4s}$	227	280
Blocked plies $(0_4/90_4)_s$	177	424

- Failure initiates earlier with blocked plies
- Ultimate strength higher
- Crack length/load slope doubled

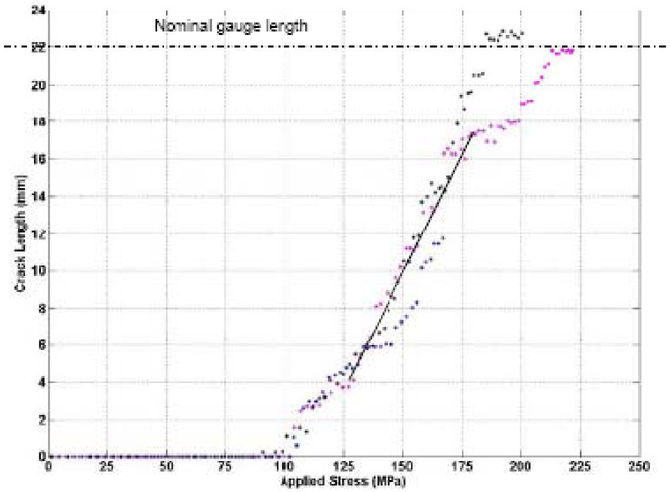
Quasi-isotropic



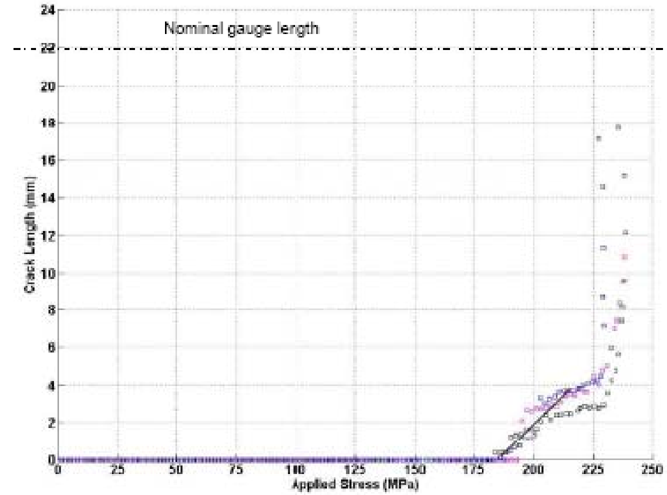


- $(45_4/90_4/-45_4/0_4)_s$ layup
- Max principal strains
- Results consistent between specimens

Effect of ply blocking – quasi-isotropic



Blocked plies $(45_4/90_4/-45_4/0_4)_s$



Dispersed plies $(45/90/-45/0)_{4s}$

Layup	Initial cracking stress (MPa)	Final failure stress (MPa)
Dispersed plies $(45/90/-45/0)_{4s}$	**194**	**235**
Blocked plies $(45_4/90_4/-45_4/0_4)_s$	**103**	**205**

- Failure again initiates earlier with blocked plies
- But ultimate strength lower
- Crack length/load slope doubled, as for cross-ply

Conclusions

- Surface crack detection technique successfully developed
- Grid method captures surface strains very well
- Maximum principal strain criterion with double threshold enables cracks to be detected satisfactorily
- Crack length / load plots produced automatically for multiple cracks
- Detected crack lengths were within +/- 0.2 mm of directly measured values
- Showed the different behaviour of cross-ply and quasi-isotropic specimens with blocked and dispersed plies
- Scope to extend method to measuring crack opening displacements, and investigate effect of internal cracks via influence on surface strain fields

ICCM17 Edinburgh

27 – 31 July 2009

University of BRISTOL

www.iccm17.org

accis
ADVANCED COMPOSITES CENTRE FOR INNOVATION & SCIENCE