Size effects in Unidirectional and Quasi-Isotropic Composites Loaded in Tension

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Introduction

- Strength of a material is dependent on the probability of finding a defect

- With increase in size the number of defects increase

Introduction

- Usually material property measurements are done on specific specimen dimensions

- What material strength data should we use for design of large structures?

Introduction

- Factors which influence size effects are:
  - -Material microstructure – flaws in fibre/matrix
  - -Free edge effects – off axis ply at free edges causes high interlaminar stresses
  - -Stress gradients – redistribution of stress with progressive failure
  - -Testing consideration - gripping stress/ stress concentrations

Introduction

- In the present work
  - **Waisted UD scaled specimens**
    - Dropped plies were interleaved between continuous plies
    - Chamfering the dropped plies suppresses delamination
  - **Uniform section scaled QI specimens**
    - Bonded end tabs

Size effects in UD Glass

Material:

E-Glass/913 pre-preg

Ply thickness: 0.125 mm

Specimens:

Specimen ID	No: - Continuous Plies	No:- dropped Plies	Gauge length (mm)	Width (mm)	Number of samples
G-4	4	3	30	10	11
G-8	8	6	60	20	12
G-16	16	12	120	40	11

Size effects in UD Carbon

Material:

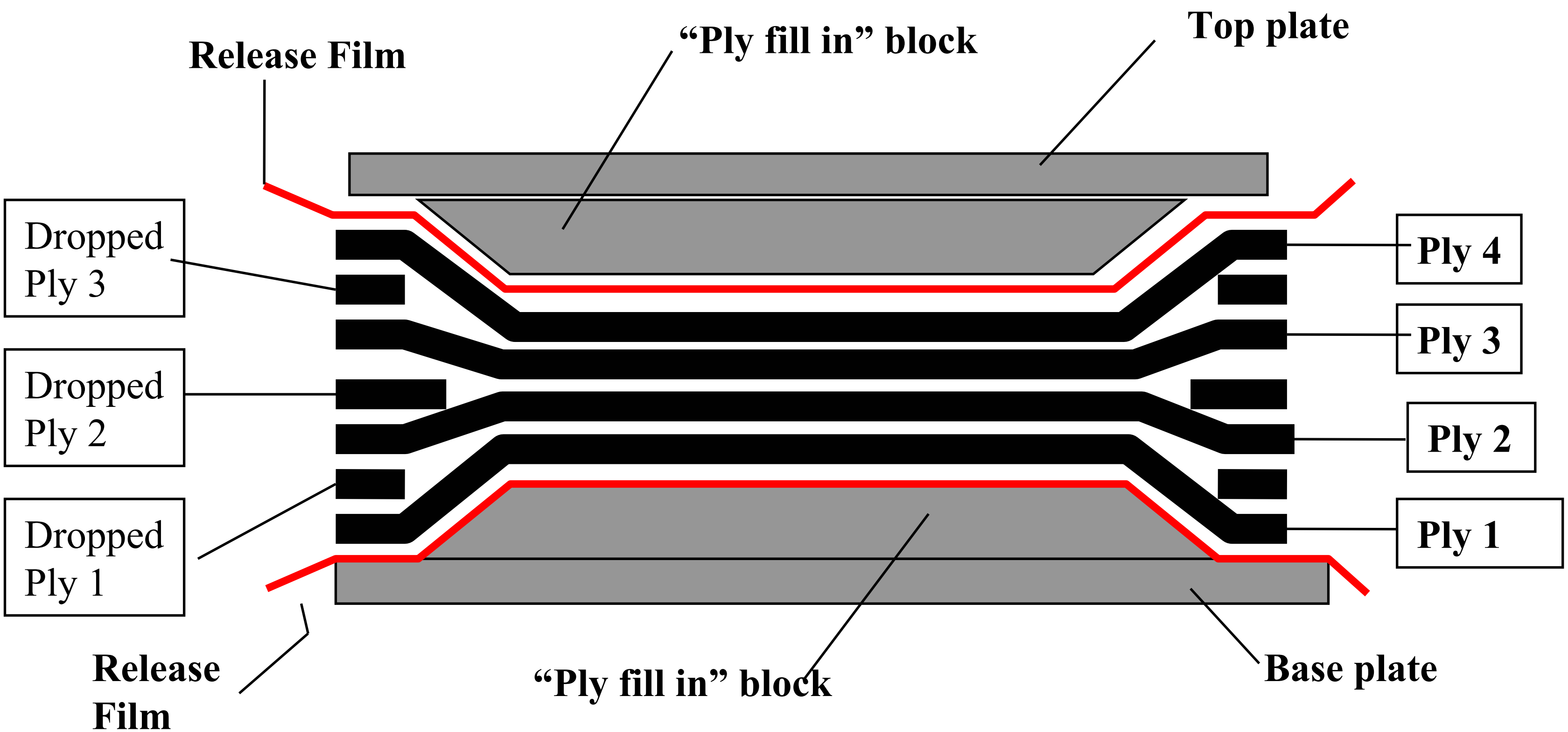
IM7/8552 pre-preg

Ply thickness: 0.125 mm

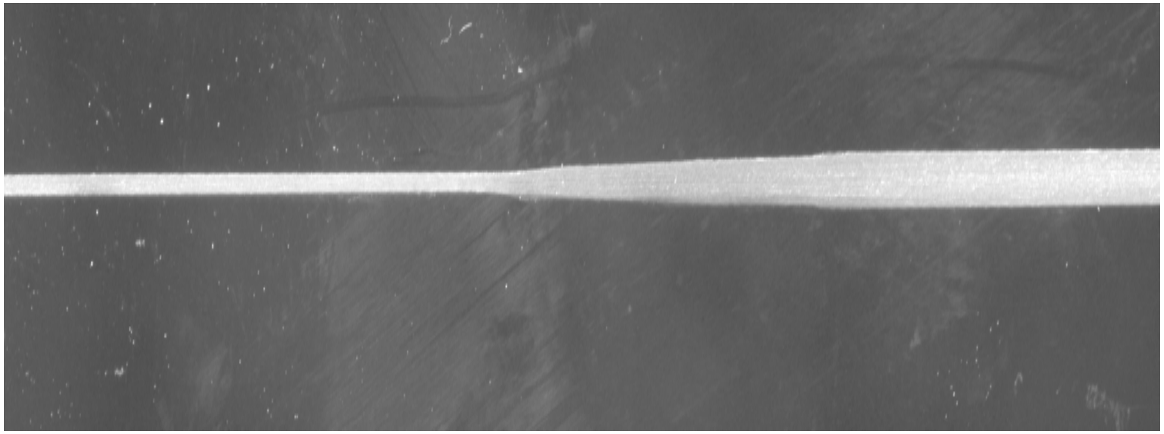
Specimens:

Specimen ID	No: - Continuous Plies	No:- dropped Plies	Gauge length (mm)	Width (mm)	Number of samples
C-4	4	3	30	5	12
C-8	8	6	60	10	12
C-16	16	12	120	20	9
C-32	32	24	240	40	11

Size effects in UD Composites



Size effects in UD Composites

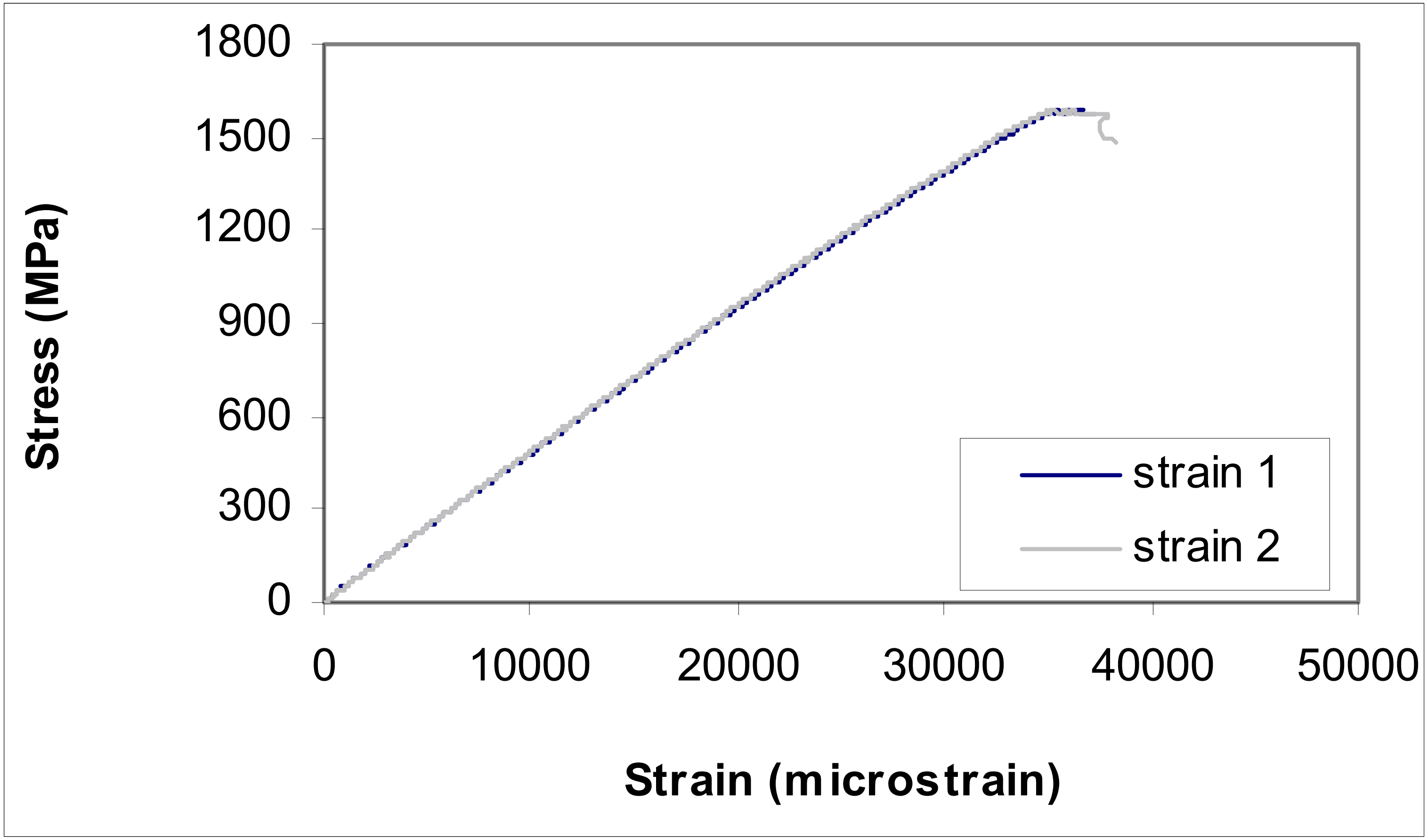


Specimen edge with chamfered dropped plies

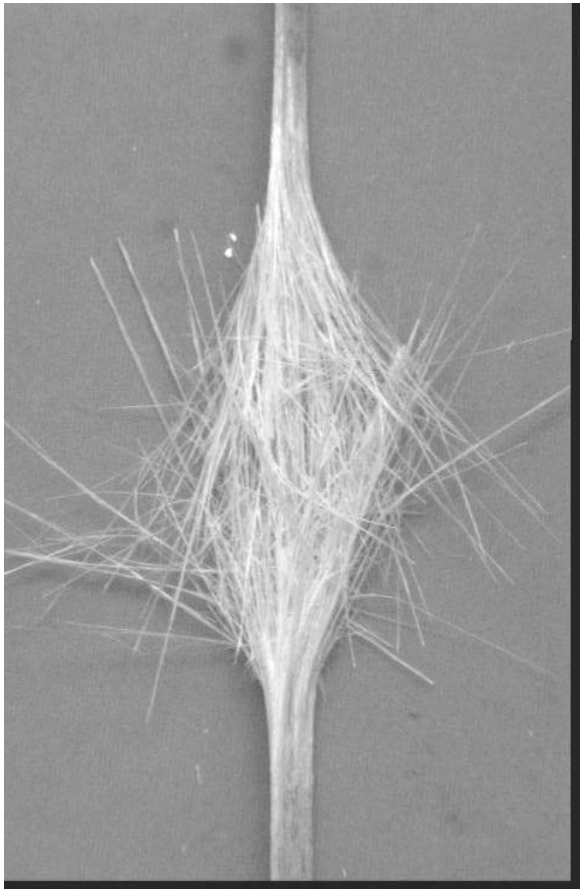
Chamfered Pre-preg (Top view)

Size effects in UD Glass

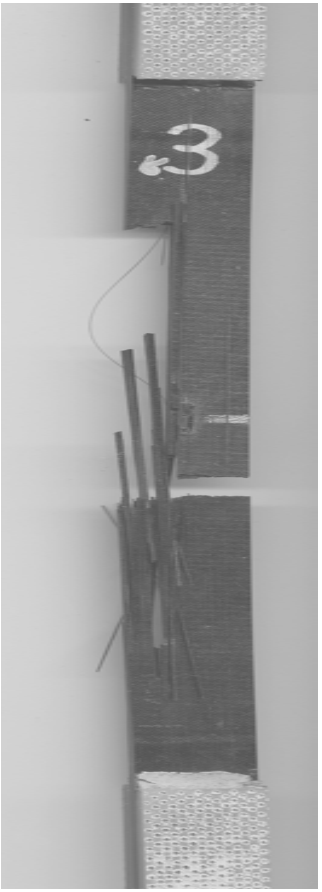
A typical stress-strain plot for the 4 ply specimen



Size effects in UD Glass



"Bursting" failure observed for Glass specimens



Transverse and longitudinal cracks across the width in Carbon

Size effects in UD Glass

Test Results:

Specimen ID	Mean Failure Stress (MPa)	CV	Mean Failure Strain (μ strain)	CV
S-4	1512	3.4	35220	2.4
S-8	1516	2.7	34690	3.0
S-16	1471	3.0	34490	2.2

Size effects in UD Carbon

Test Results:

Specimen ID	Mean Failure Stress (MPa)	CV	Mean Failure Strain (μ strain)	CV
S-4	2806	4.2	15440	5.4
S-8	2687	2.5	14720	1.9
S-16	2553	3.8	14290	3.3
S-32	2347	6.5	13040	3.6

Size effects in UD Carbon

Weibull Modulus:

- Two parameter model expresses the probability of survival, P(s), of a specimen subjected to a strain field, ε, over a volume, V, as in eqn 1
- $P(s) = \exp[-\int(\varepsilon/\varepsilon_o)^m \, dV]$ (1)

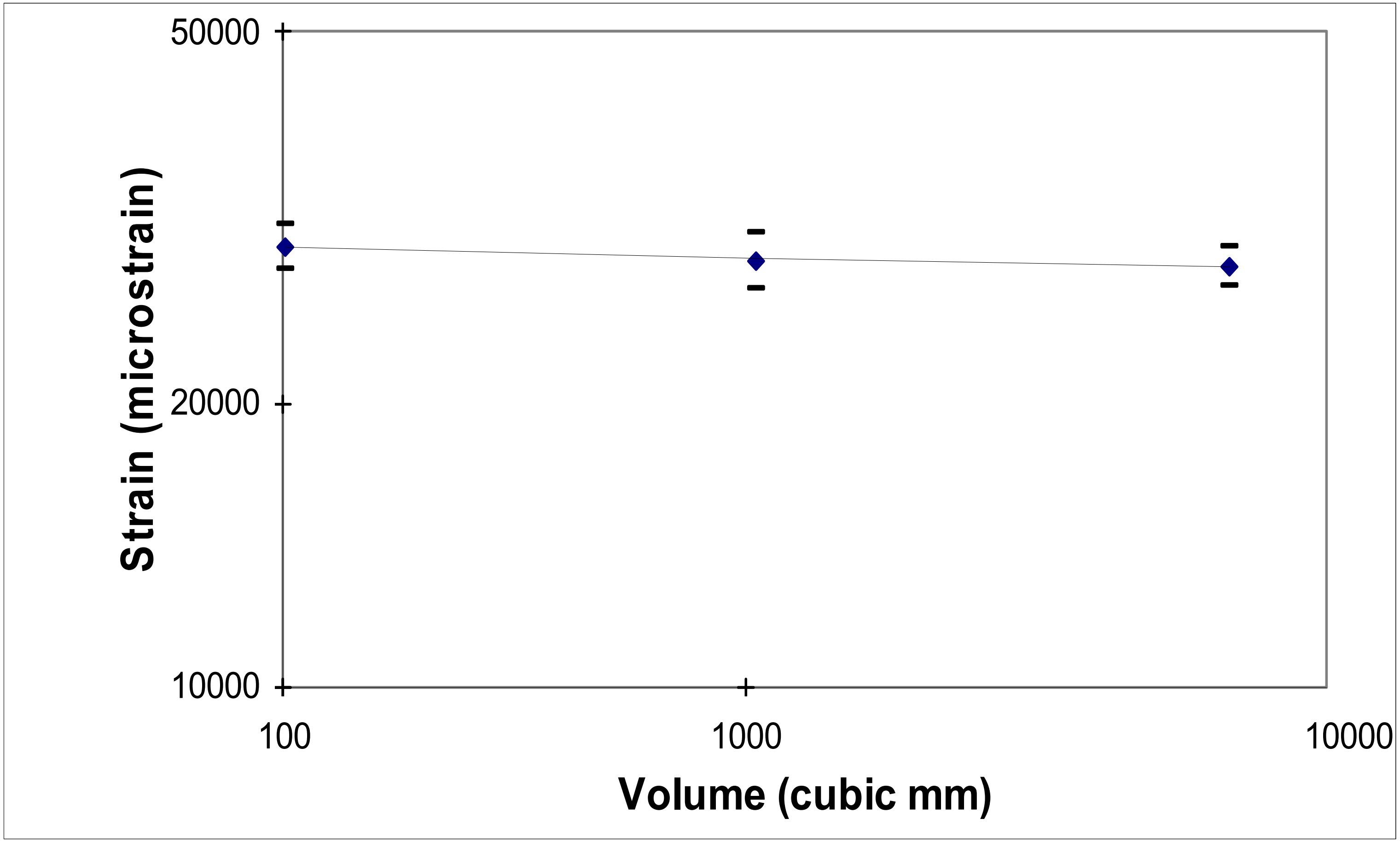
  ε_o is the characteristic strain

  m the Weibull modulus
- When two different sizes of specimen with equal probability of survival are compared eqn 1 can be expressed as in eqn 2
- $\varepsilon_1/\varepsilon_2 = (V_2/V_1)^{1/m}$ (2)

ε_1 and ε_2 are the strains in the two specimens

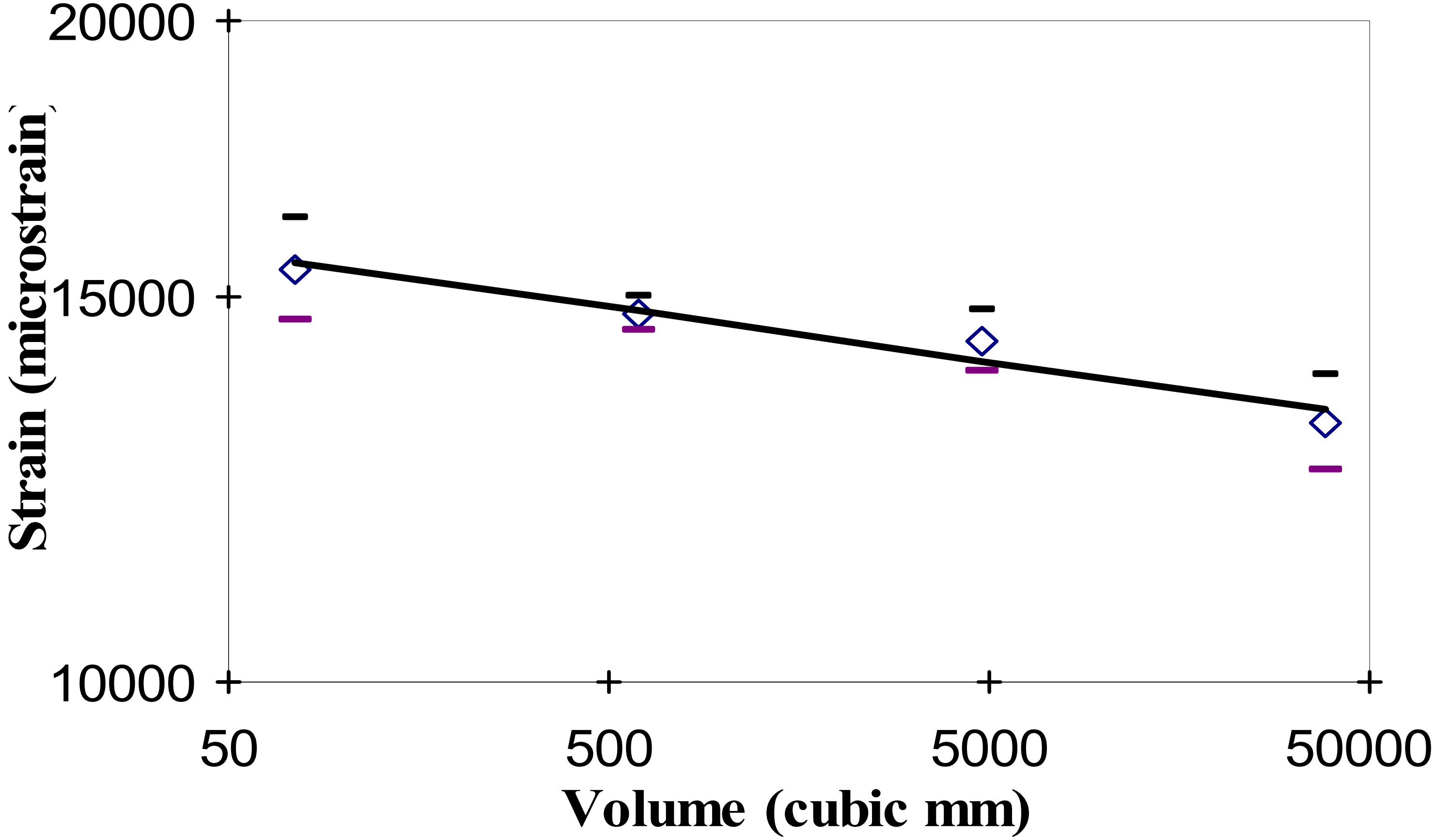
V_1 and V_2 are the volumes

Size effects in UD Glass



Variation of strength with size for Glass

Size effects in UD Composites



Weibull modulus for Carbon is 40

Size effects in Quasi-Isotropic laminates

- Material:

  IM7/8552 pre-preg

- Specimen:

  Lay up sequence of $(+45_m/90_m/-45_m/0_m)_{ns}$

  Sub-laminate scaled : m fixed at 1 and n scaled

  Ply-level scaled: n fixed at 1 and m scaled

  Uniform section QI laminates

  End tabbed

Size effects in Quasi-Isotropic laminates

Specimens:

Specimen ID	**Scaling m or n =**	**Gauge length (mm)**	**Width (mm)**	**Thickness (mm)**
1(m or n)-QI	1	30	8	1
2(m or n)-QI	2	60	16	2
4(m or n)-QI	4	120	32	4
8(m or n)-QI	8	240	64	8

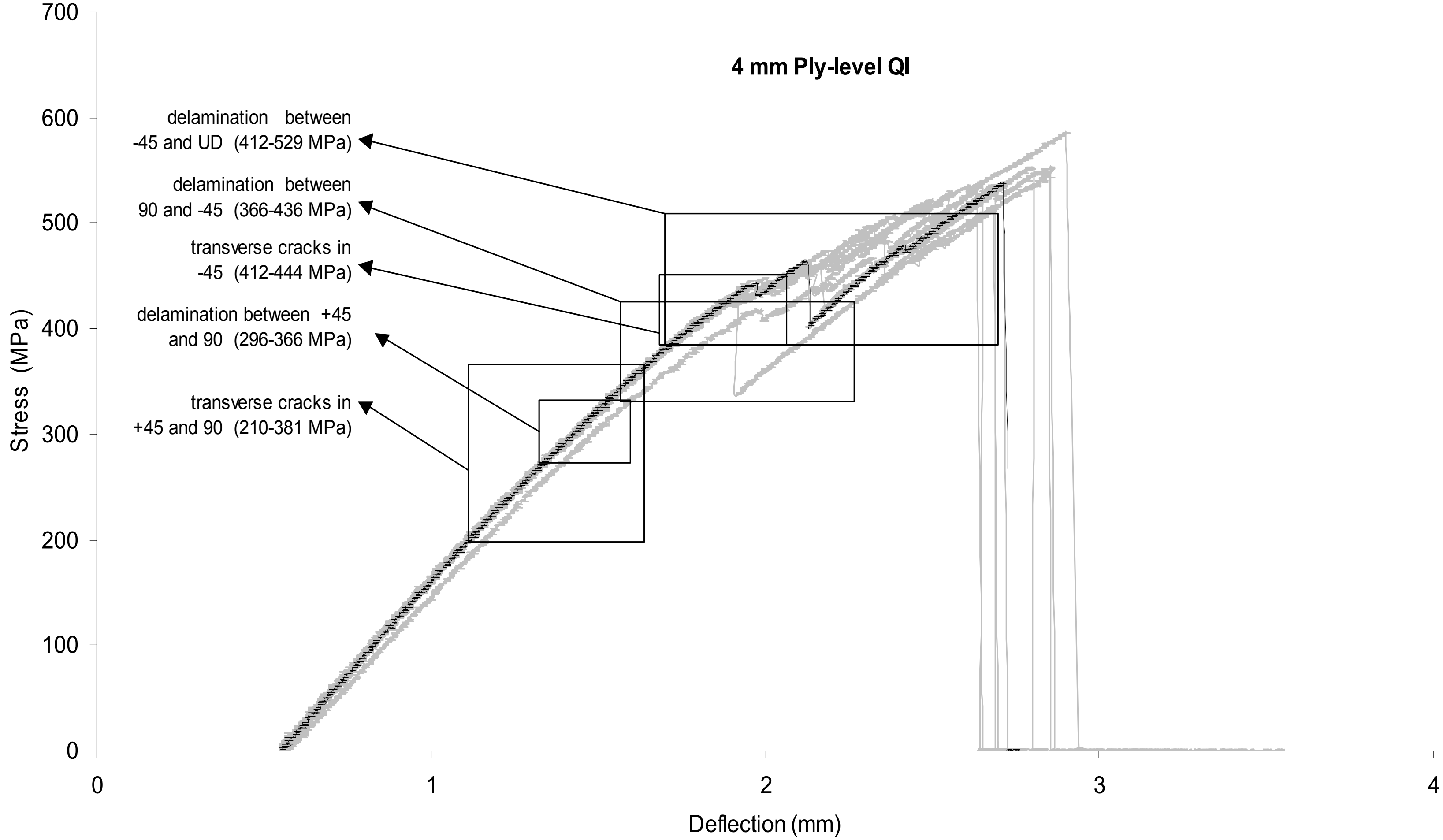
Size effects in Quasi-Isotropic laminates

- Test data - failure stress (MPa):

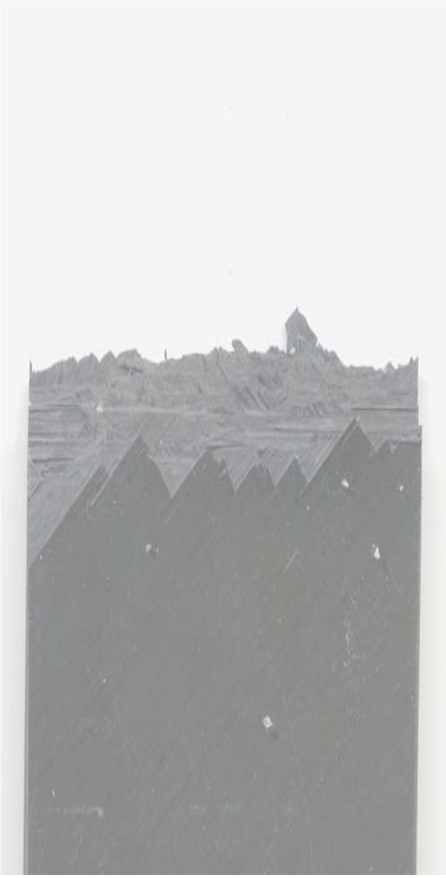
m or **n**	Sub laminate level m=1, n	Ply level n=1, m
1	842	
2	911	660
4	929	541
8	--	458

Size effects in Quasi-Isotropic laminates

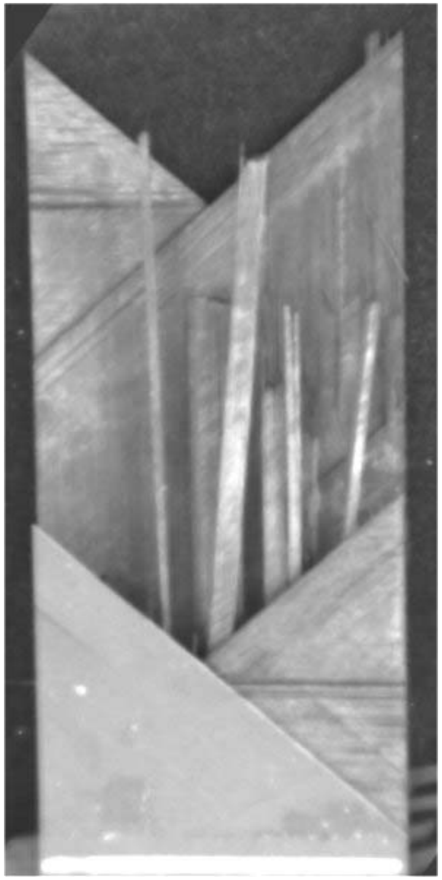
- Typical sequence of events in the failure of Ply level scaled specimen



Size effects in Quasi-Isotropic laminates



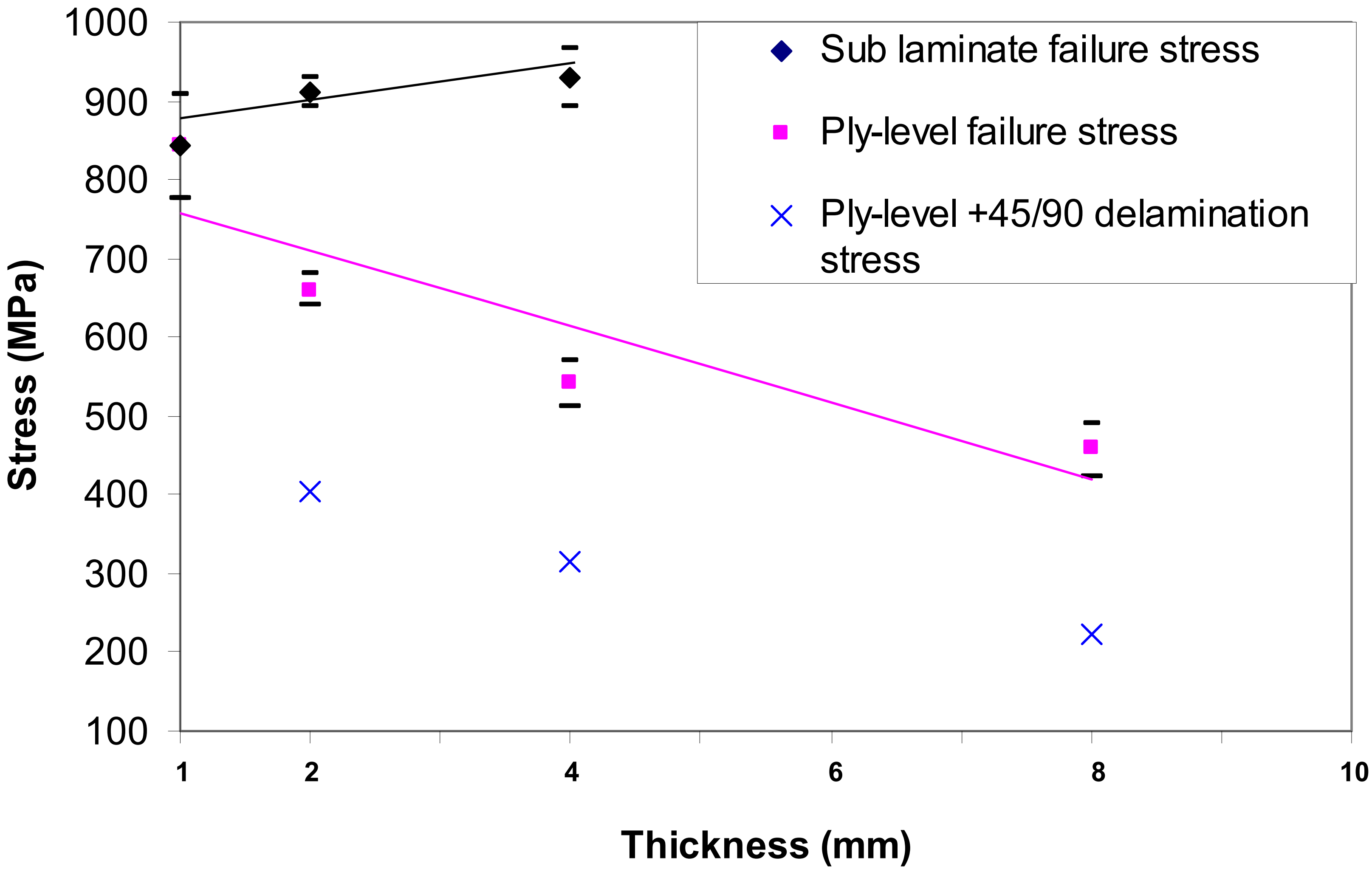
Sub laminate scaled



Ply level scaled

Failure pattern observed in the 4 mm thick QI specimen

Size effects in Quasi-Isotropic laminates



Variation of the strength with increasing specimen thickness

Conclusion

- Tests on UD Laminates:
  - The failure stress and strains tend to decrease with increasing size
  - Failure in Glass is progressive with multiple fibre failure occurring at different sites
  - Failure in Carbon is sudden with longitudinal and transverse cracks running across the sample width
  - The reduction in stress/strain with volume is more in Carbon than in Glass
  - A Weibull modulus of 40 is derived for Carbon laminates

Conclusion

- Tests on QI laminates:
  - The strength of the QI laminates decreases with increase in ply block thickness
  - The failure modes of the ply level scaled samples are similar and essentially by transverse cracking followed by extensive delamination
  - A reduction of 45% in failure stress is observed for the Ply-level scaled samples
  - Sub-laminate level scaled specimen show higher resistance to delamination and the fracture is essentially by fibre failure
  - Small increase in strength is seen in the Sub-laminate scaled specimens