# WORKSHOP

# Measuring transverse strength and the factors affecting it.

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# Transverse strength vs along the fibres strength

In our first workshop, we defined strength as the maximum stress that the material can sustain under uniform uniaxial loading and in the absence of other stress components.

We have already devoted one WS to measuring UD tensile Strength and the factors affecting it as well as another devoted to measuring UD compression Strength and the factors affecting it, to determine respectively $X_T$ and $X_C$

Today we devote a WS to the determination of transverse strength properties ($Y_T$, $Y_C$). The reason for having a unique session for both cases is that the tests to obtain these properties present a series of difficulties that are common to those associated with the determination of $X_T$ and $X_C$, sharing the same type of features and difficulties: geometry, entrance of the loading into the specimen, presence of nominal singular values of the stress state, difficulty in getting uniform distribution of stresses, etc.

# Transverse strength properties

**Since almost the definition of the tests to determine $Y_T$ and $Y_C$, a phenomenon known as "scale effect" was observed and led to the concept of "in-situ strength". The representativity of the values obtained from the tests have been concentrating, since then, more attention than the problems associated with running the tests.**

**For this reason, we have tried to invite to this workshop some of the most significant authors that have been involved in the comprehension of this phenomenon, affording explanations.**

**How do we measure transverse strengths of composites and the factors affecting it?**

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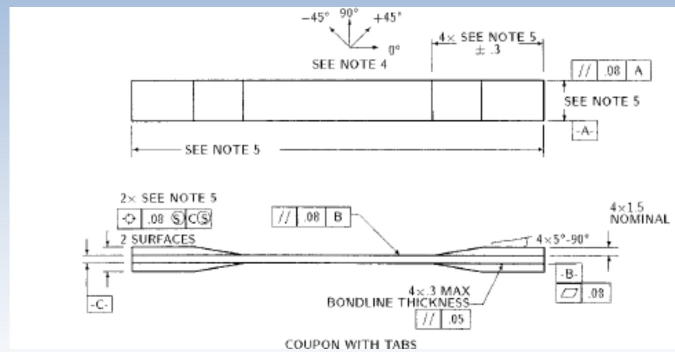
In our first workshop we defined strength as the maximum stress that the material can sustain under uniform uniaxial loading and in the absence of other stress components [1]. The second workshop discussed UD tensile strength [2], the third one dealt with UD compressive strength [3] and the fourth addressed UD composite strength under shear [4]. We now move to transverse strength under tension and compression and the factors affecting it. The main difficulty here is not associated with the determination of the property in a test, as the conditions associated with the aforementioned definition of strength can be reasonably accomplished, but the representativity of the values obtained to the actual performance of the material in a laminate.

# Tension tests in the transverse direction to the fibres to determine $Y_T$




Different Specimens in accordance with ASTM for 0 and 90 degrees orientation

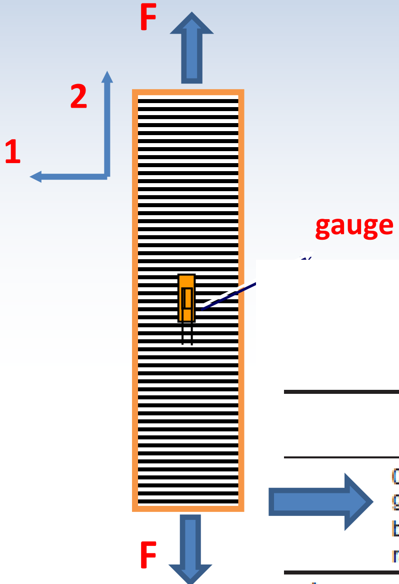



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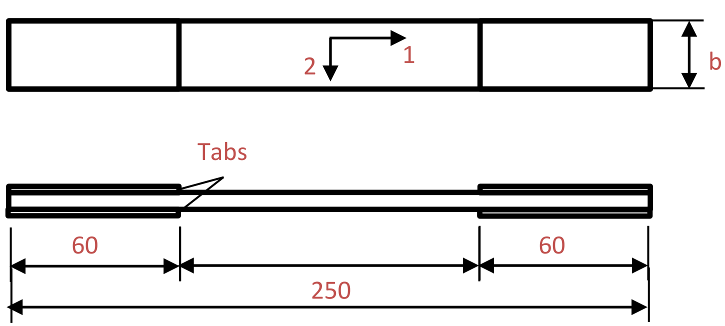
TABLE 2 Tensile Specimen Geometry Recommendations[A]

| Fiber Orientation | Width, mm [in.] | Overall Length, mm [in.] | Thickness, mm [in.] | Tab Length, mm [in.] | Tab Thickness, mm [in.] | Tab Bevel Angle,° |
|---|---|---|---|---|---|---|
| 0° unidirectional | 15 [0.5] | 250 [10.0] | 1.0 [0.040] | 56 [2.25] | 1.5 [0.062] | 7 or 90 |
| 90° unidirectional | 25 [1.0] | 175 [ 7.0] | 2.0 [0.080] | 25 [1.0] | 1.5 [0.062] | 90 |
| balanced and symmetric | 25 [1.0] | 250 [10.0] | 2.5 [0.100] | emery cloth | — | — |
| random-discontinuous | 25 [1.0] | 250 [10.0] | 2.5 [0.100] | emery cloth | — | — |

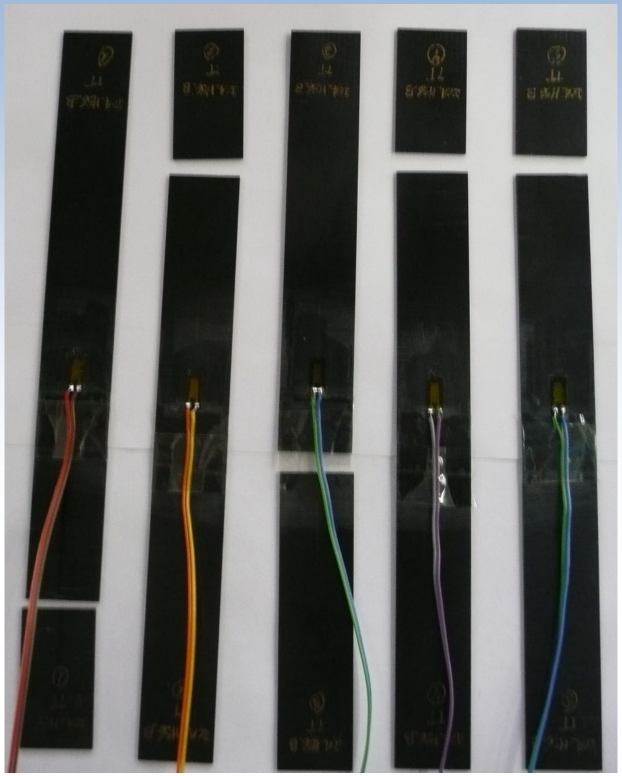
[A] Dimensions in this table and the tolerances of Fig. 2 or Fig. 3 are recommendations only and may be varied so long as the requirements of Table 1 are met.

Different Standards for longitudinal (EN 2650) and transverse test (EN 2597)




b = 25 mm for h = 2 mm

# Specimens for transverse strength under tension

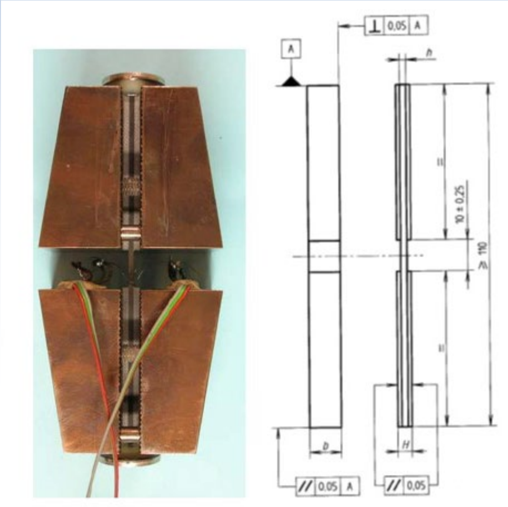


| Tensile RT/AR | TT | | | | |
|---|---|---|---|---|---|
| | Width (mm) | Thickness (mm) | Ultimate Load (N) | Tensile Strength (MPa) | Modulus[Gpa] |
| Coupon 1 | 25,13 | 1,09 | 948,04 | 34,72 | 8,40 |
| Coupon 2 | 25,11 | 1,09 | 984,92 | 35,88 | 8,38 |
| Coupon 3 | 25,08 | 1,10 | 1366,53 | 49,53 | 8,35 |
| Coupon 4 | 25,11 | 1,09 | 1053,59 | 38,50 | 8,34 |
| Coupon 5 | 25,09 | 1,09 | 1138,0 | 41,74 | 8,30 |
| Avg. | **25,10** | **1,09** | **1098,2** | **40,1** | **8,35** |
| Max. | **25,13** | **1,10** | **1366,5** | **49,5** | **8,40** |
| Min. | **25,08** | **1,09** | **948,0** | **34,7** | **8,30** |
| DST | 0,02 | 0,01 | 166,5 | 5,9 | 0,04 |
| CV(%) | 0,08 | 0,51 | 15,2 | 14,8 | 0,47 |

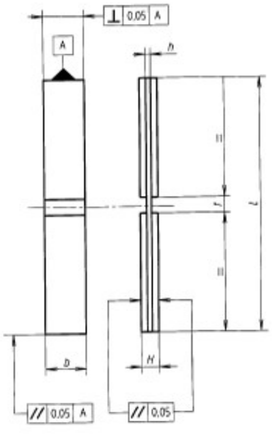
## Compression tests in the transverse direction to the fibres to determine $Y_C$

EN 2850 is for "parallel to fibre direction" but it is also used for transverse direction

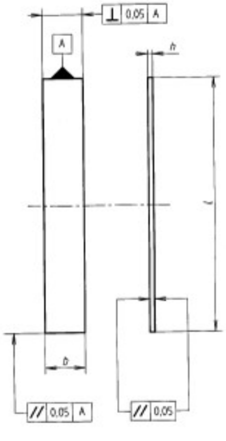
Compression test in accordance with EN 2850A




Compression test in accordance with EN 2850B




Type $B_1$ test piece for stress measurement

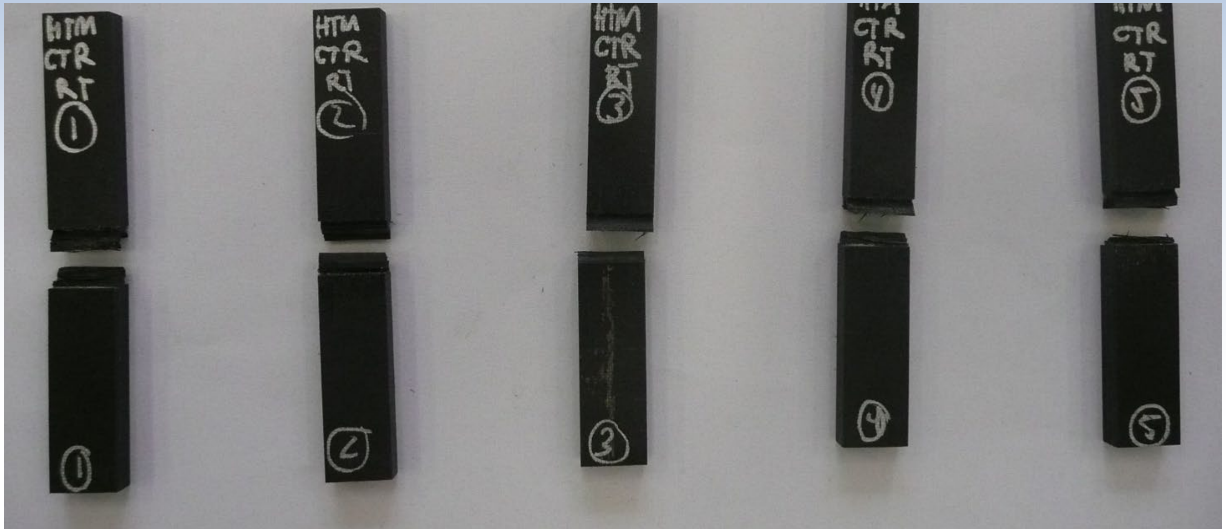



Type $B_2$ test piece for modulus measurement

Modulus (B2)

Strength (B1)

# Specimens for transverse strength under compression




| Compression RT/AR | | CTR | | | |
|---|---|---|---|---|---|
| | | Width (mm) | Thickness (mm) | Ultimate Load (N) | Compression Strength (Mpa) |
| Coupon 1 | | 12,5 | 2,23 | 4957 | 177,84 |
| Coupon 2 | | 12,5 | 2,28 | 4710 | 165,28 |
| Coupon 3 | | 12,54 | 2,37 | 4920 | 165,54 |
| Coupon 4 | | 12,5 | 2,22 | 4663 | 168,02 |
| Coupon 5 | | 12,51 | 2,34 | 4952 | 169,17 |
| | Avg. | **12,51** | **2,29** | **4840** | **169,2** |
| | Max. | **12,54** | **2,37** | **4957** | **177,8** |
| | Min. | **12,50** | **2,22** | **4663** | **165,3** |
| | DST | 0,02 | 0,07 | 142 | 5,1 |
| | CV(%) | 0,14 | 2,89 | 2,9 | 3,0 |

# Main features of the transverse tests

-Transverse tests present similar problems to those identified in previous workshops in the longitudinal direction.

-In the case of compression, premature failure may appear due to the gripping system that produces local stress concentrations very near to the gauge zone.

-The response in tension is linear and brittle whereas a certain non-linearity may appear under compression where an inclination of the plane of failure of about 53-55 degrees is observed.

-In both tension and compression cases, a certain dependence of the properties on the thickness of the specimens has been observed.

-Finally, also in both cases, the typical scatter associated with loading in a direction normal to the fibres appears, this scatter being more noticeable under tension that under compression.

# The view point of the industry

In spite of the similarity of these transverse tests to determine $Y_T$ and $Y_C$ compared with those to determine $X_T$ and $X_C$ along the direction of the fibres, they are not performed as commonly.

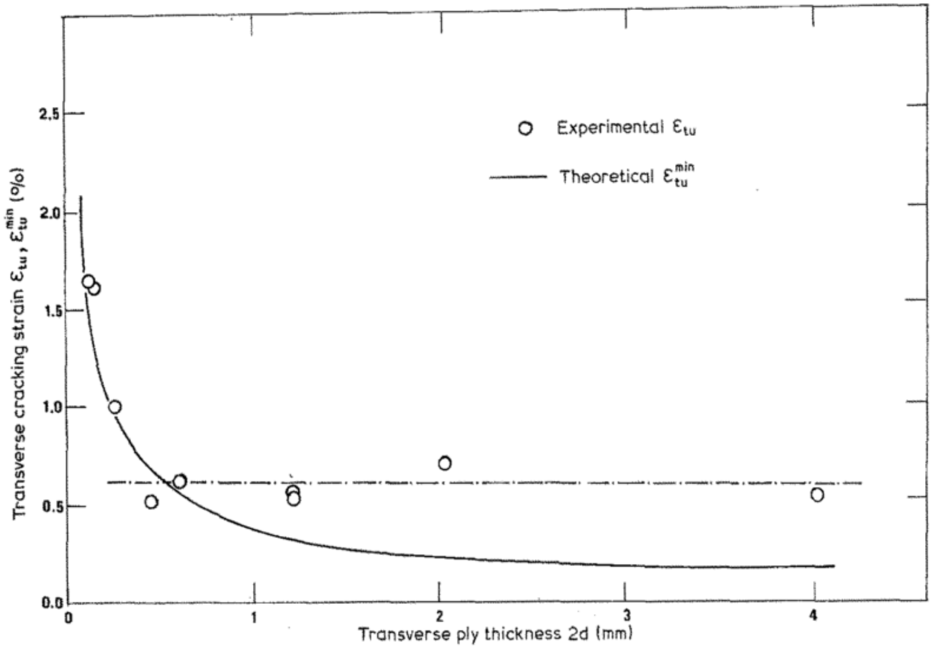
In fact, the list of material acceptance tests of major aeronautic manufacturers only considers tests along the direction of the fibres as a requisite to consider the material “flight worthy”.

**Number of tests performed in the transverse direction and in the longitudinal direction in the same period of time (Courtesy of ELEMENT-Seville)**

| | Transverse | longitudinal |
|---|---|---|
| Tension | 523 | 1296 |
| Compression | 149 | 1444 |

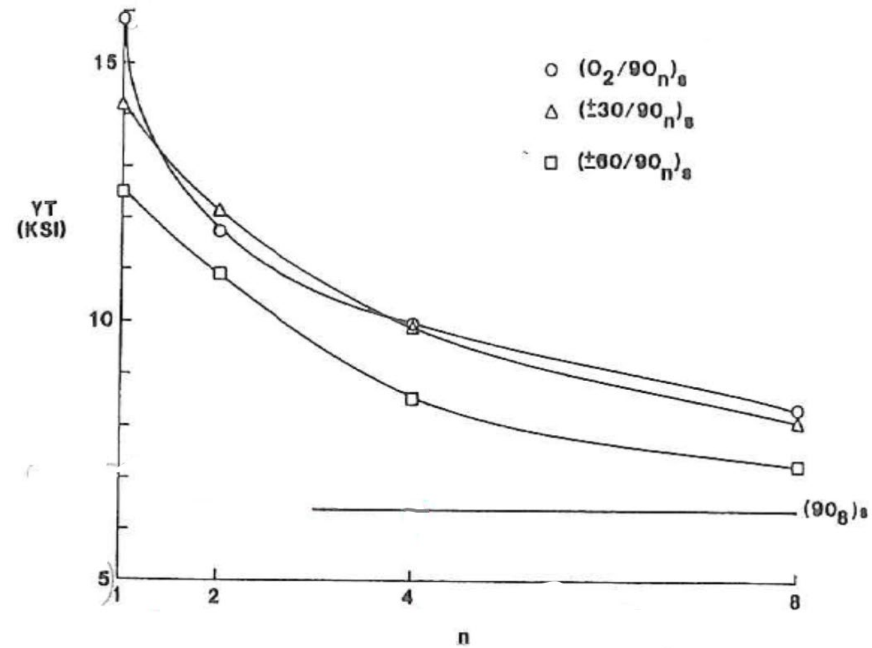
# Scale effect in Laminates

**Parvizi et al** (1978)




Values of $\varepsilon_{tu}$ as a function of ply thickness and experimental values of $\varepsilon_{tu}$ for various ply thicknesses

**Flaggs and Kural** (1981)




In situ transverse strengths as a function of thickness and the orientations of the adjacent laminae.

**The scale effect questions the representativity of the values obtained for $Y_T$ in a test**

# The scale effect/The in-situ Strength


-A. Parvizi, K. V. Garret, J. E. Bailey, Constrained cracking in glass fibre-reinforced epoxy cross-ply laminates, J. Mat. Sci. 13 (1978) 195–201.
-D.L. Flaggs, M.H. Kural, Experimental Determination of the In Situ Transverse Lamina Strength in Graphite/Epoxy Laminates, J. Com. Mat. 16 (1982)103-116.

-K. W. Garret, J.E. Bailey, ... ss fibre ...

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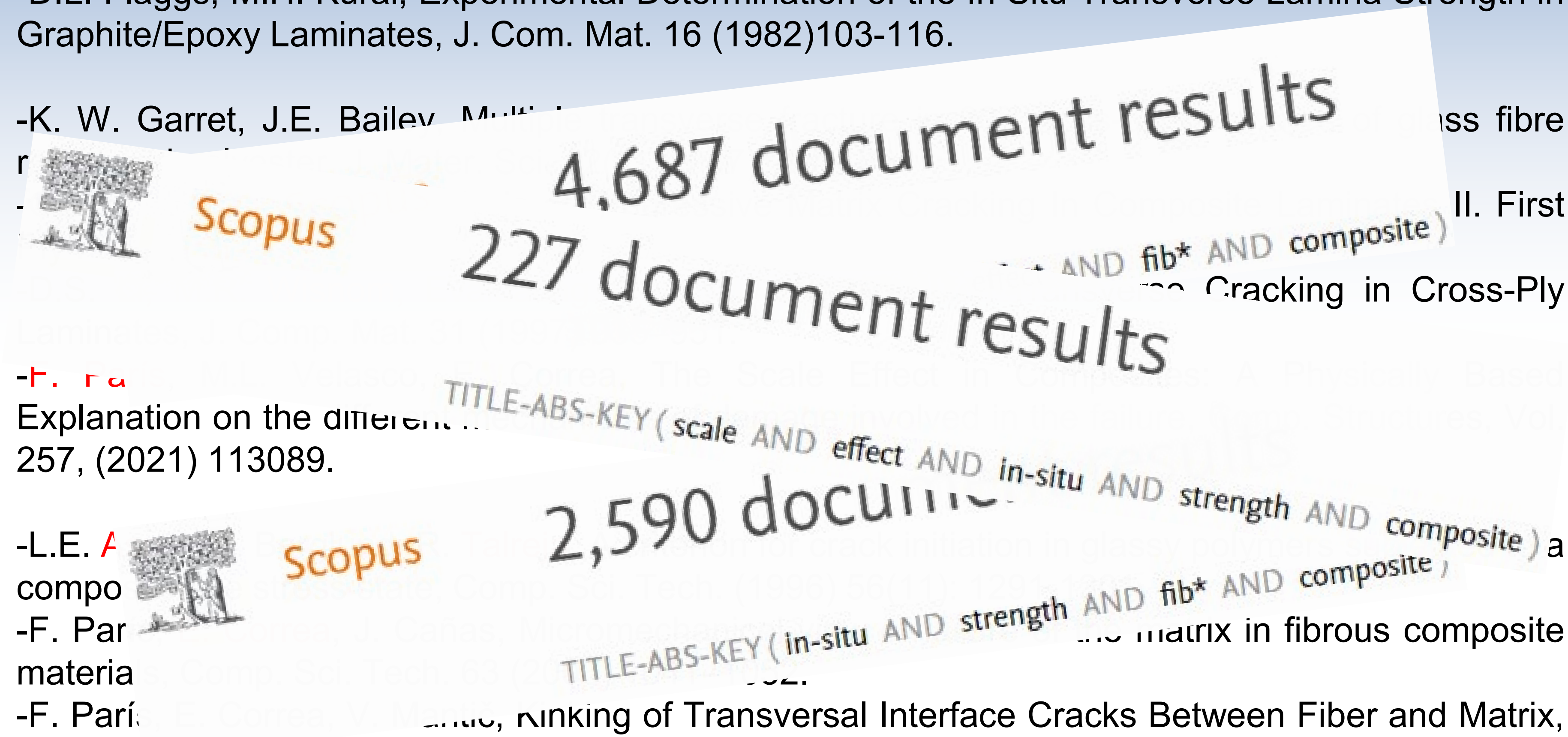
257, (2021) 113089.

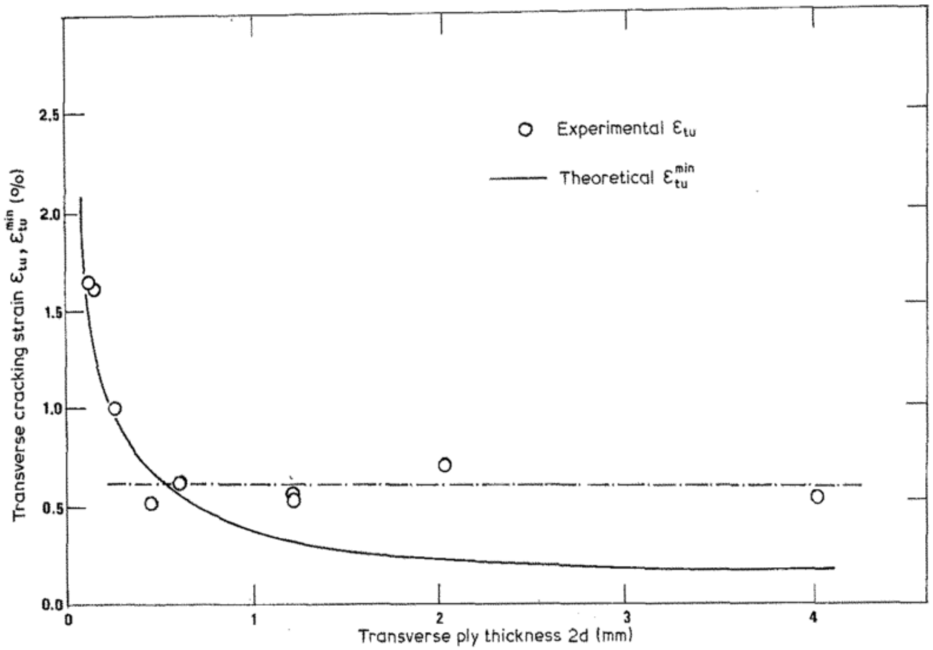


-L.E. A... a
compo...
-F. Par... matrix in fibrous composite
materia...
-F. Parí... Kinking of Transversal Interface Cracks Between Fiber and Matrix,
J. Appl. Mech. 74 (2007) 703–716.

-W.V. Liebig, C. Leopold, T. Hobbiebrunken, B. Fiedler, New test approach to determine the transverse tensile strength of CFRP with regard to the size effect, Comp. Communications, 1, (2016) 54-59.

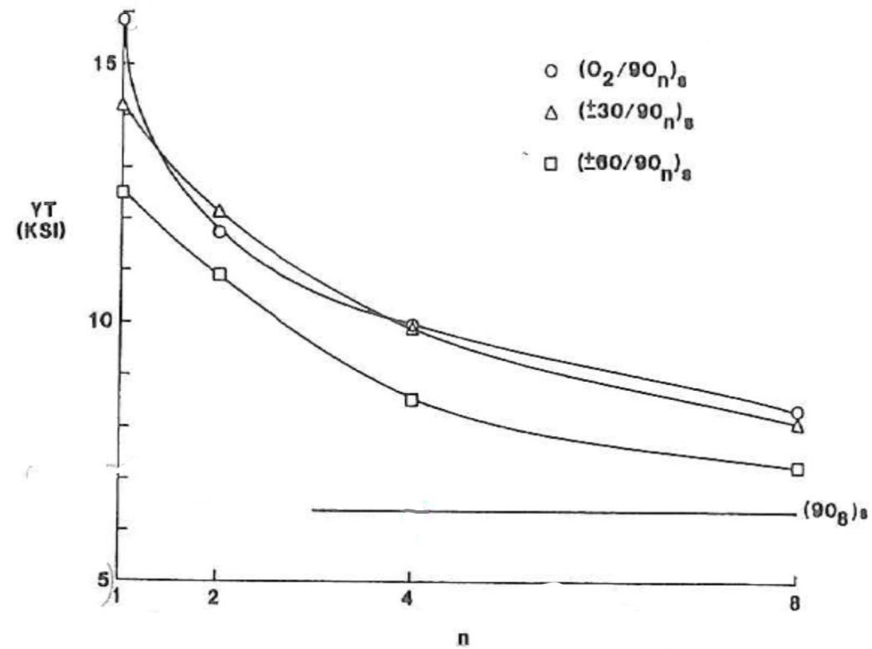
# Scale effect in Laminates

**Parvizi et al** (1978)




Values of $\varepsilon_{tu}$ as a function of ply thickness and experimental values of $\varepsilon_{tu}$ for various ply thicknesses

**Flaggs and Kural** (1981)

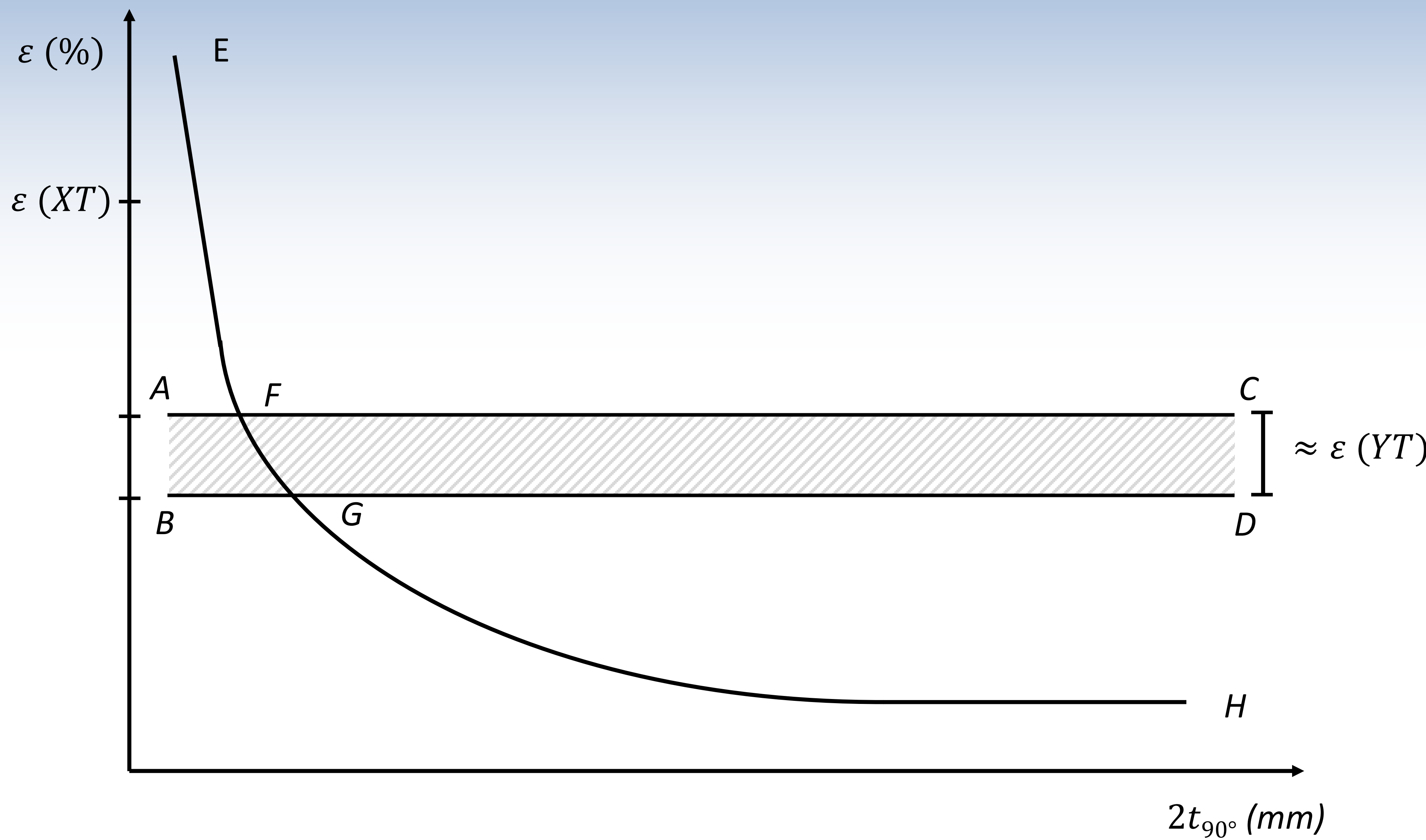



In situ transverse strengths as a function of thickness and the orientations of the adjacent laminae.

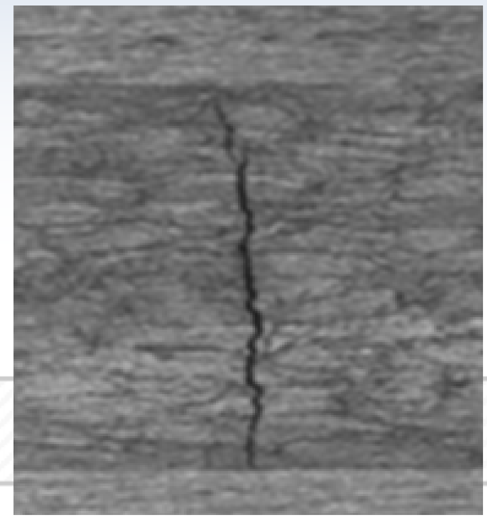
**The points in the graphs represent the values of a deformation/stress associated with the detection of the first damage.**

**Do all experimental points in the graphs represent the same damage in the 90 degrees lamina?**

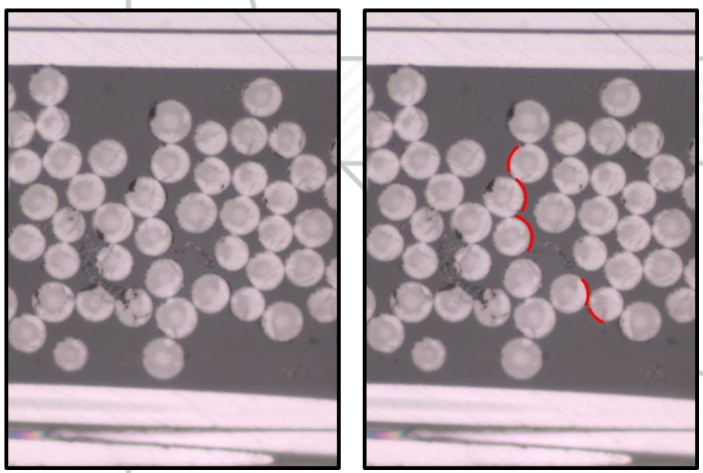
# Identification of the damage



# Identification of the damage



Full transverse crack in a conventional 90 degrees lamina of 190 microns of thickness



Isolated debondings in a ultrathin 90 degrees lamina of 50 microns of thickness

# Final Comments

The determination of $Y_T$ and $Y_C$ presents similar types of difficulties than the determination of $X_T$ and $X_C$

Why industry uses these transverse values less than those associated with longitudinal direction ?

The appearance of ultra-thin plies has attracted again the attention on the concept of scale effect and in-situ strength due to the apparent delay in the appearance of damage in the 90 weakest lamina of a laminate

The use of thick plies to save the manufacturing cost opens the question of the negative incidence of the damage in these laminas in the performance of the laminates under different loadings

It would be possible to design a laminate in order to make coincident in terms of loading the failure of the 90 degrees lamina and the appearance of transverse cracks in the 90 degrees lamina?

# WORKSHOP

# Measuring transverse strength and the factors affecting it.


**Federico París** — Universidad de Sevilla

**Michael Wisnom** — University of Bristol

**Yentl Swolfs** — KU Leuven


October 20, 2022

# 5 minutes presentations

| Title | Presenter | Affiliation |
|---|---|---|
| **Cavitation on a thermoplastic matrix for a UD composite subject to transverse compression (Brazilian test)** | **Lucien Laiarinandrasana** | **Mines Paris PSL** |
| Transverse biaxial tests on long fibre reinforced composites | Elena Correa | University of Seville |
| Size effects in transverse tensile strength | Michael Wisnom | University of Bristol |
| New test approach to determine the transverse tensile strength of CFRP with regard to the size effect | Bodo Fiedler | Hamburg University of Technology |
| Experimental analysis of polymer matrix composite microstructures under transverse compression loading | Mark Flores | Air Force Research Laboratory |
| Transverse failure initiation – a dilatational stress controlled failure event in the glassy polymer matrix | Leif Asp | Chalmers University of Technology |
| The importance of micromechanics in the understanding of transverse strength concept in composites | Federico París | University of Seville |
| The role of local stress triaxiality in determining the transverse tensile strength of UD composites | Ramesh Talreja | Texas A&M |