July 2018

TACCOS

Toulouse Adhésion Cohésion Collage Structural

de la Chimie à la Mécanique

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WHAT IS IT?

TACCOS is an *informal* inter-laboratory team of teacher-researchers for the **multidisciplinary training** and **research** on **structural adhesive bonding** technology.

It was launched in 2017.

TACCOS is based on a collaboration between **transversal research axes** of 2 laboratories in Toulouse:

- "ADHÉRENCE" at CIRIMAT
- "ASSEMBLAGES" at ICA

CIRIMAT Toulouse

ADHÉRENCE

Toulouse Adhésion Cohésion

TAC de la Chimie à la Mécanique COS

Collage Structural

ICA

ASSEMBLAGES

CONTEXT

In order to **optimize the mechanical performances** of structures such as **the strength-to-mass ratio**, the use of various materials is common. Composite materials are then more and more used in aerospace structures.

As a result, there is a need to employ suitable technologies for the **multi-material joining**. The classical mechanical fastening is a solution. Nevertheless, this technology **deteriorates the properties** of structural parts, which **contradicts then the effort of optimization**.

1. Adhesive bonding is a **chemical joining** technology to ensure a **mechanical function** of the joining of two structural parts **without modifying / damaging their properties**.

2. Adhesive bonding (eventually in combination with other joining technologies) offers **higher mechanical performances** than those obtained with classical mechanical fastening.

3. Adhesive bonding is particularly suited to the joining of **thin parts possibly dissimilar**.

→ **Adhesive bonding appears then as a attractive candidate.**

CONTEXT

It exists a national roadmap called **MACS** (“Vers la Maîtrise des Assemblages Collés Structuraux”) which is coordinated by several “pôles de compétitivité” (Aerospace Valley, Astech, EMC2, Pegase), industrials (AIRBUS, SAFRAN, RENAULT, PSA, FAURECIA…) and technical centers or laboratories (CETIM, ParisTEch,…).

It was launched in 2009. It is expected that the results to be applied to various industrial sectors such as aerospace, rail, naval, automotive….

It aims at **better tailoring the structural adhesive bonding** by delivering **good practices guides** about **sizing**, **materials**, **processes** and **controls** in order to define the eligibility conditions of adhesive bonding:

- at the technico-economical level, compared to mechanical fastening
- at the **physisco-chemical** and **mechanical** levels

MOTIVATION

….. at the physisco-chemical and mechanical level

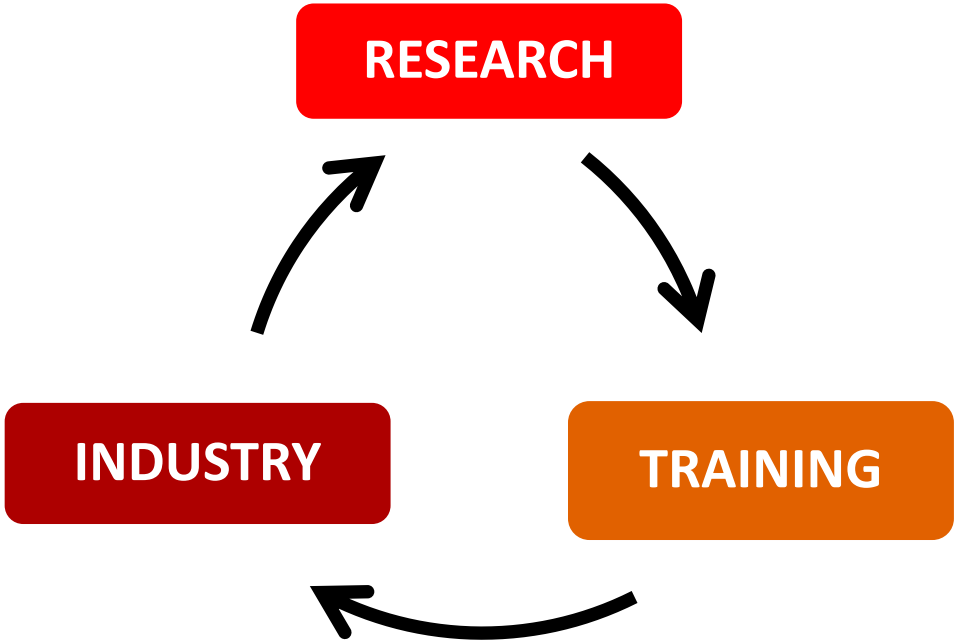
to address the questions raised by the structural adhesive, a multidisciplinary approach is required

2 worlds have to work together to progress on structural adhesive bonding

OBJECTIVES

TACCOS aims at promoting the **collaborations**:

- between the **disciplinaries**: Physico-Chemestry and Mechanics
- between **laboratories**: CIRIMAT+ICA, LGP Tarbes, I2M Bordeaux, University of Porto
- with **industrials**: SOCOMORE, ARKEMA/BOSTIK, CETIM



TRAINING

A need for **multi-disciplinary skilled engineers** is then emerging.

1. TACCOS will contribute to meet this requirement **by training students in a multi-disciplinary frame**.

2. In the frame **continuous training**, the TACCOS team is responsible for a training included in the **EUROSAE** training catalog. It is entitled “Technologie d’assemblage par collage structural”:

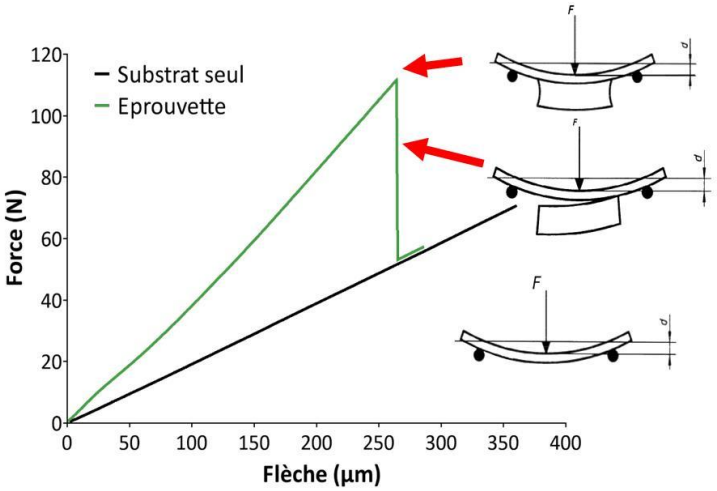
- multi-disciplinary training
- 50% theory / 50% practice
- a final application on repairs

http://www.eurosae.com/formation/?formation=535

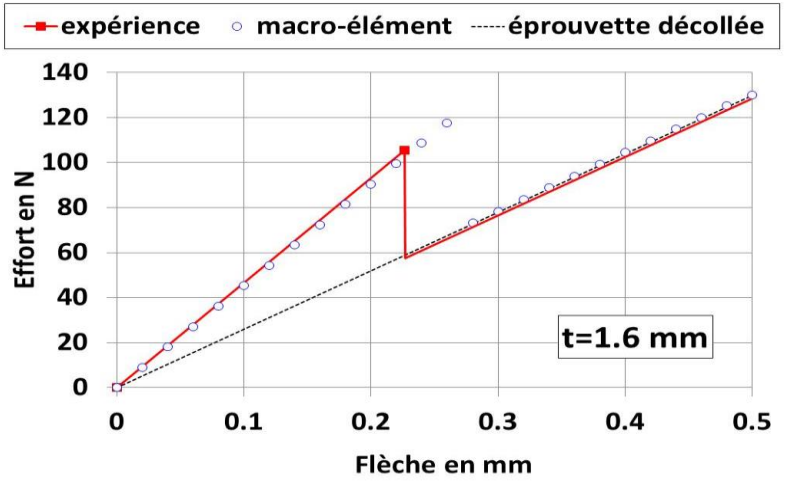
1st production in collaboration | **Poster presentation at JADH in October 2017 at Sainte-Maxime**

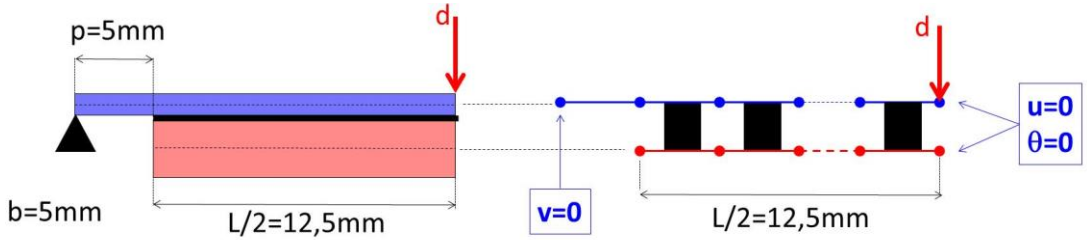
This poster was the result from previous works led **independently** on:

- the prediction of adhesion failure based on **3-point bending test**;
- the simplified stress analysis of bonded joints using the **macro-element technique**.



Épaisseur	3 mm	1,6 mm	1 mm
Chargement	445 N	123 N	70 N
Énergie d'initiation	4 mJ	4 mJ	4 mJ

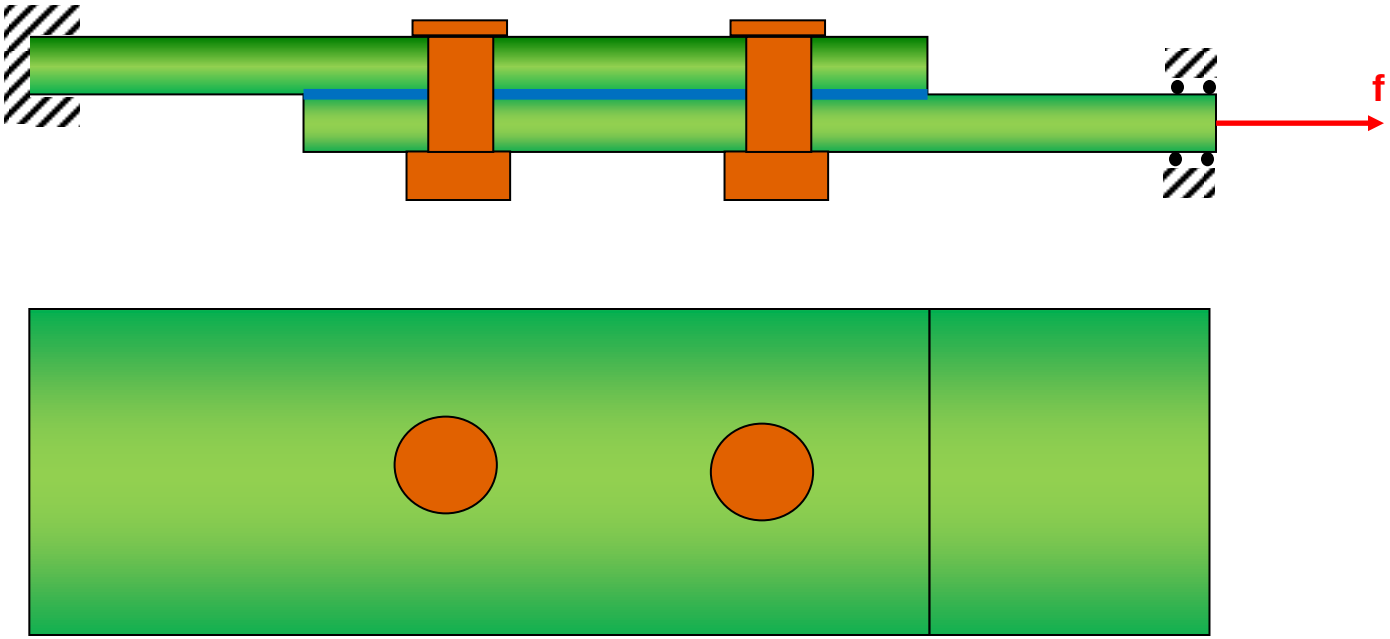




M. Aufray, E. Paroissien, J.B. Sauvage, D. Poquillon, F. Lachaud. Modélisation numérique et expérimentale de l'essai de flexion trois points. Poster presentation, JADH2017, 11-13 October 2017, Sainte-Maxime (FR)

Macro-Element technique	Simplified stress analysis of bonded and/or bolted joints

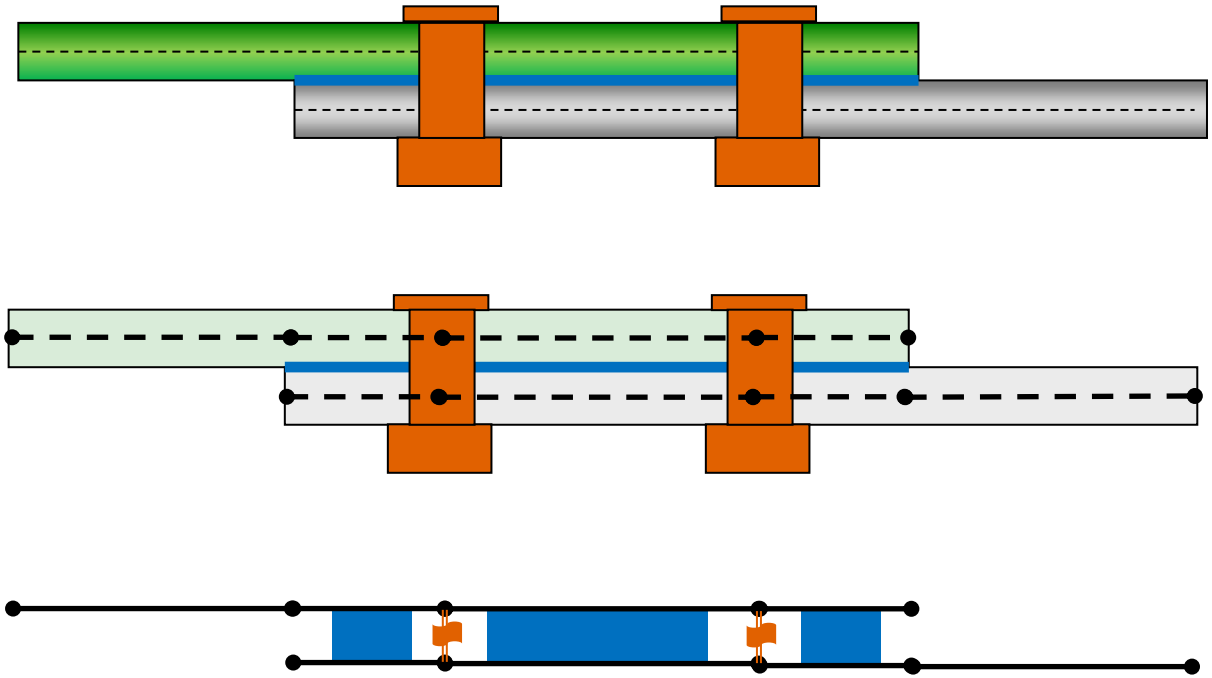
Which **simplified model** to **quickly and accurately** assess the load transfer within a **hybrid (bolted / bonded) joint** in-plane loaded?



Macro-Element technique

Simplified stress analysis of bonded and/or bolted joints

[1]**Marc Sartor** suggested to model the joints with special elements, termed macro-elements (**ME**).



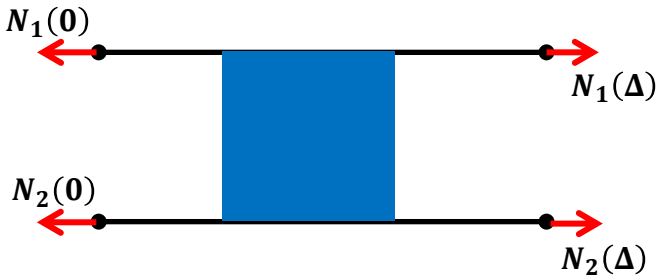
[1]*Institut Clément Ader (ICA), Université de Toulouse, ISAE-SUPAERO, INSA, IMT MINES ALBI, UTIII, CNRS, France*

Paroissien, E., 2006. Contribution aux Assemblages Hybrides (Boulonnés/Collés) – Application aux Jonctions Aéronautiques. PhD Dissertation, Université de Toulouse III.

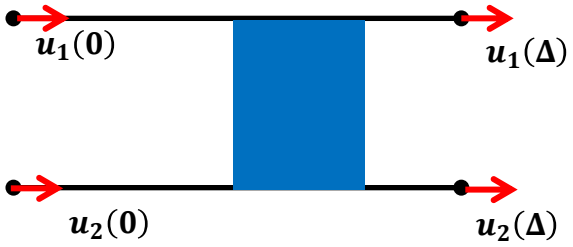
Macro-Element technique | **Simplified stress analysis of bonded and/or bolted joints**

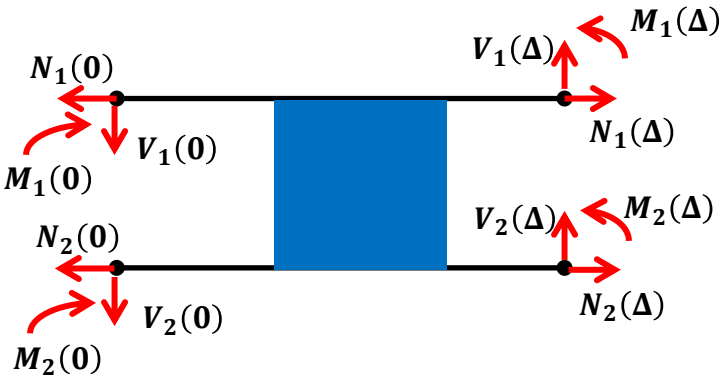
ELEMENTARY STIFFNESS MATRIX

The elementary stiffness matrix for a bonded overlap expresses the relationships between the nodal displacements and the nodal forces.

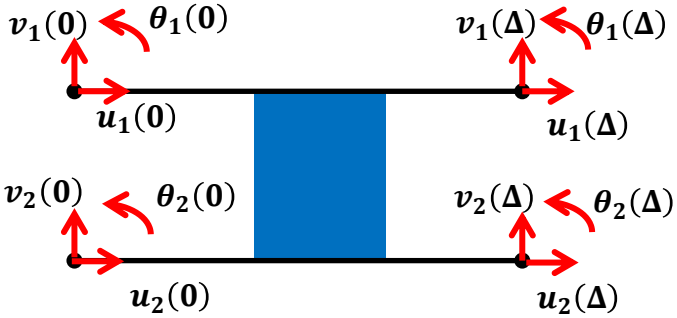


$$\begin{pmatrix} -N_1(0) \\ -N_2(0) \\ N_1(\Delta) \\ N_2(\Delta) \end{pmatrix} = K_{BC} \begin{pmatrix} u_1(0) \\ u_2(0) \\ u_1(\Delta) \\ u_2(\Delta) \end{pmatrix}$$





$$\begin{pmatrix} -N_1(0) \\ -N_2(0) \\ N_1(\Delta) \\ N_2(\Delta) \\ -V_1(0) \\ -V_2(0) \\ V_1(\Delta) \\ V_2(\Delta) \\ -M_1(0) \\ -M_2(0) \\ M_1(\Delta) \\ M_2(\Delta) \end{pmatrix} = K_{PC} \begin{pmatrix} u_1(0) \\ u_2(0) \\ u_1(\Delta) \\ u_2(\Delta) \\ v_1(0) \\ v_2(0) \\ v_1(\Delta) \\ v_2(\Delta) \\ \theta_1(0) \\ \theta_2(0) \\ \theta_1(\Delta) \\ \theta_2(\Delta) \end{pmatrix}$$

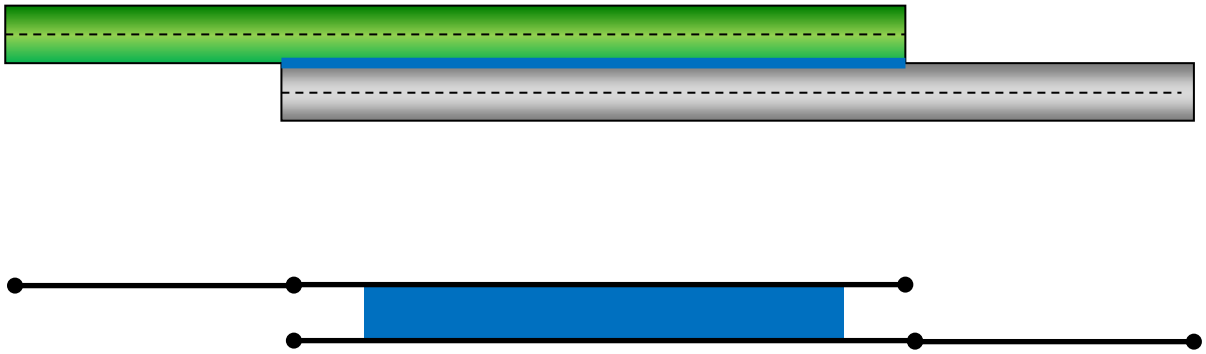


Macro-Element technique	Simplified stress analysis of bonded and/or bolted joints

ELEMENTARY STIFFNESS MATRIX

Contrary to the classical FE, **the shape of interpolation functions is not assumed** a priori. The shape of interpolation functions has the shape of functions solving the ODEs.

One significant consequence is **that only one ME is needed to model an entire bonded overlap** (linear elastic analysis). The displacements, internal forces and adhesive stresses are obtained **at each abscissa of the overlap**.

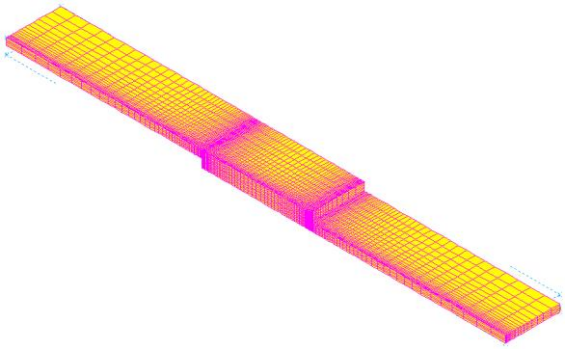


- 6 nodes
- 6 dof in 1D-bar
- 18 dof in 1D-beam

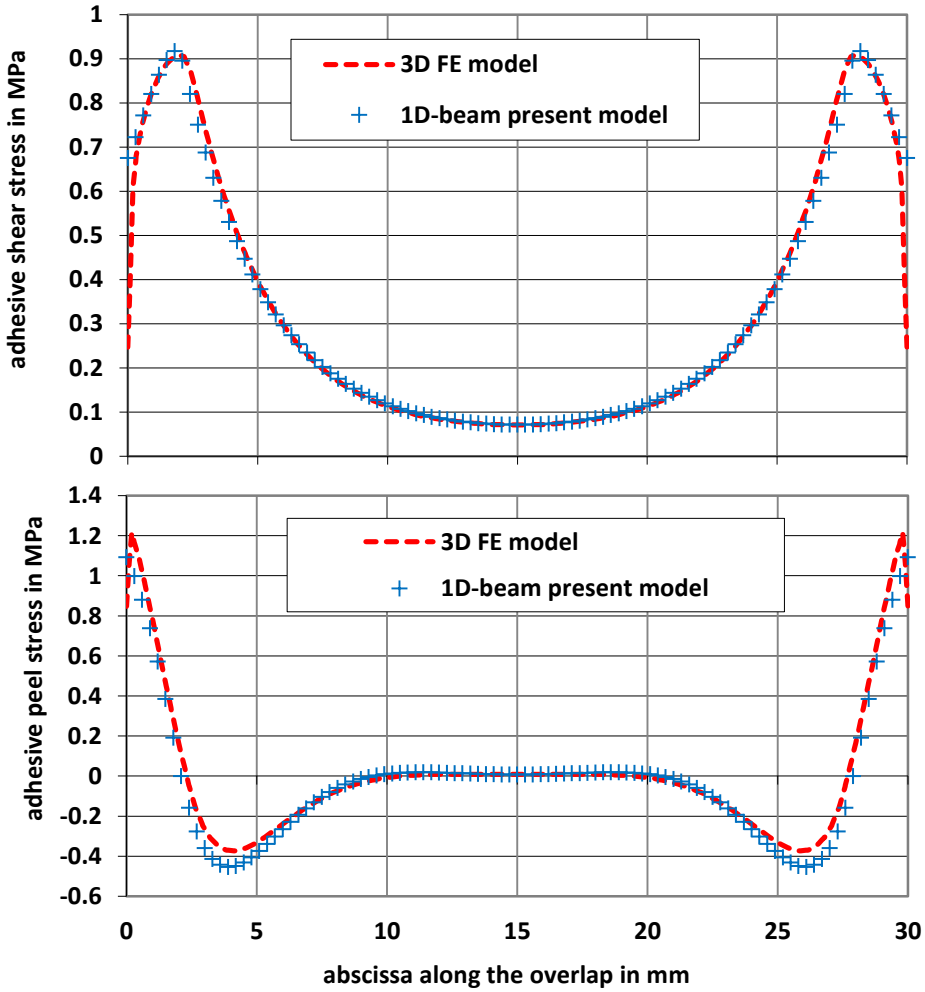
Macro-Element technique

Accuracy, large application field, time reduction

The adhesive stresses are read on the **converged** 3D FE model on the neutral line of the adhesive layer.



Benefit in CPU time: x50

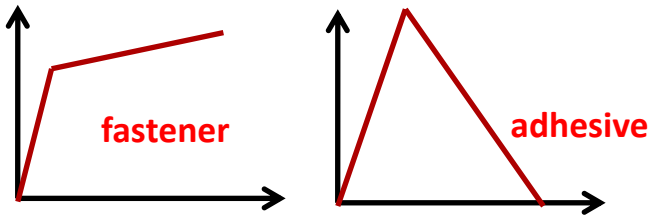


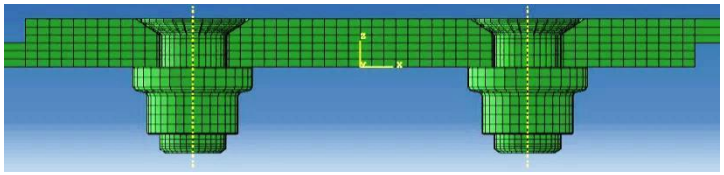
Paroissien, E, Gaubert, F, Da Veiga, A, Lachaud, F, 2013. Elasto-Plastic Analysis of Bonded Joints w Macro-Elements. J. Adhes. Sci. Technol., 27(13), 1464-1498.

Macro-Element technique | **Simplified stress analysis of bonded and/or bolted joints**

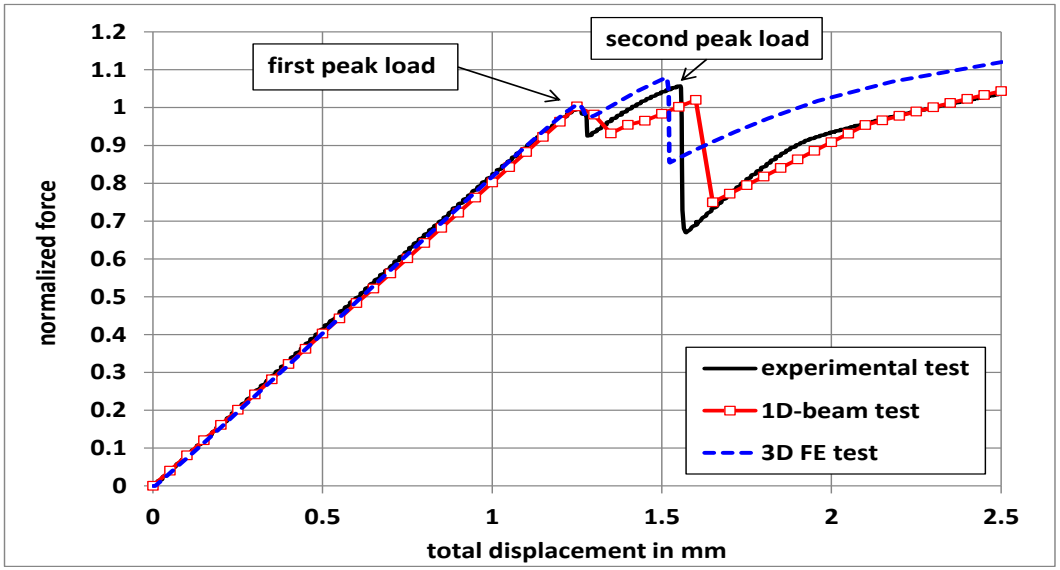
HYBRID (BOLTED/BONDED) JOINTS

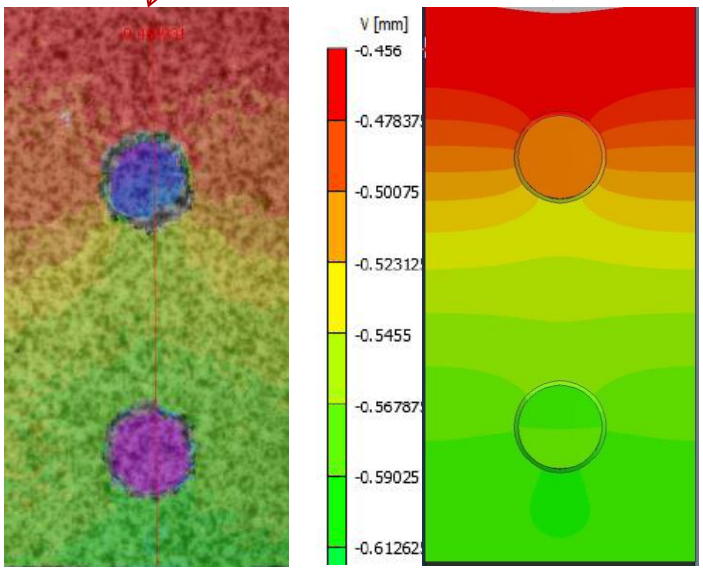
Comparison between experimental test, 3D FE test and 1D-beam ME test of a single lap HBB joint in-plane loaded.





experimental | 3D FE





Paroissien, E., Lachaud, F., Da Veiga, A., Barrière, P., 2017. Simplified Stress Analysis of Hybrid (Bolted/Bonded) Joints. Int. J. Adhes. Adhes., 77, 183-197.

RESEARCH

PhD Thesis	Prediction of failure at adherend/adhesive interface

1st TACCOS PhD Thesis

PhD student	**[1]Thiago Vasconcellos Birro**
Supervision	*[1]Frédéric Lachaud, [2]Maëlenn Aufray, [1]Éric Paroissien*
Project	**PRACCOMET**
Funding	**Région Occitanie, ISAE-SUPAERO (APR2017 UFT MiP)**
Date	December 2017 – December 2020

The measurement of the area subjected of adhesion failure within the 3-point bending test was not used in the frame of the JADH poster. The idea here is to take into account for this information to suggest a experimental and numerical methodology for the prediction of failure at the interface between the adherend and the adhesive as well as for the local load mixity. Various combinations of adherend/adhesive couples will be tested (metal, thermoplastic composite/epoxy, methacrylate)

Thiago will participate in 2 international conferences: (i) oral presentation at ICSAAM 2018 in Tarbes and (ii) poster presentation at EURADH 2018 in Porto.

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[2]CIRIMAT, Université de Toulouse, CNRS, INPT, UPS, France

RESEARCH

PhD Thesis	Experimental and numerical modelling of cohesive behavior of adhesive layer as function of adhesive thickness

PhD student	**[1]Agathe Jaillon**
Supervision	*[1]Frédéric Lachaud, [3]Julien Jumel, [1]Éric Paroissien*
Project	**FUI 21: S3PAC**
Funding	**BPI France, Région Occitanie, Région Nouvelle Aquitaine**
Date	April 2017 – March 2020

This PhD Thesis follows the PhD Thesis by Guillaume Lélias (CIFRE SOGETI HT / ISAE-SUPAERO, University of Toulouse, 2013-2016). The objective is to experimentally and numerically model the mechanical behavior of adhesive layers as function of their thickness, including time dependency and non removable strain. The constitutive behavior is regarded as a cohesive zone model in the frame of damage mechanics. The adhesive under study is the methacrylate adhesive SAF30-MIB manufactured by BOSTIK / AEC Polymers (ARKEMA Group).
Agathe delivered an oral presentation at WCARP 2017 in San Diego, after only 10 months as a PhD student.

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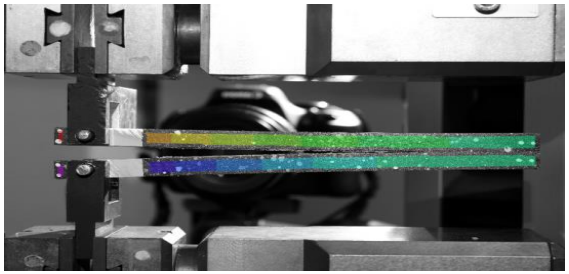
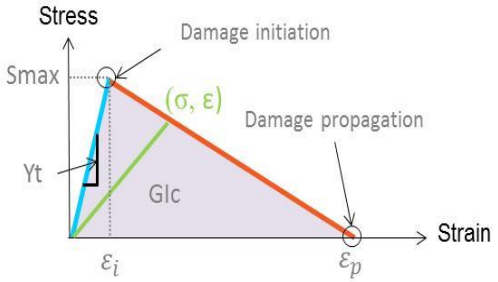
[3]Université de. Bordeaux, Arts et Metiers ParisTech, CNRS, I2M, UMR 5295, France

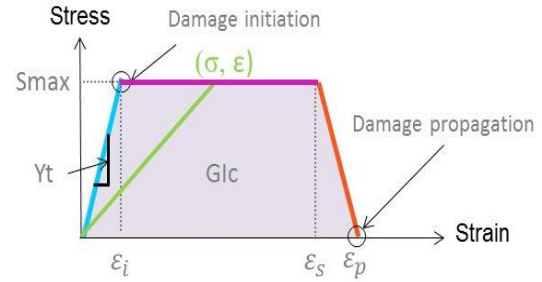
Lélias, G., 2016. Mechanical behavior of adhesively bonded joints: Modeling, simulation and experimental characterization. PhD Thesis, University of Toulouse 3, Toulouse, France.

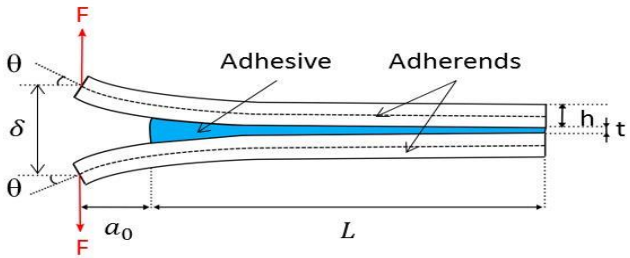
PhD Thesis

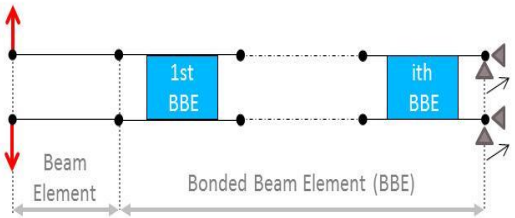
Experimental and numerical modelling of cohesive behavior of adhesive layer as function of adhesive thickness

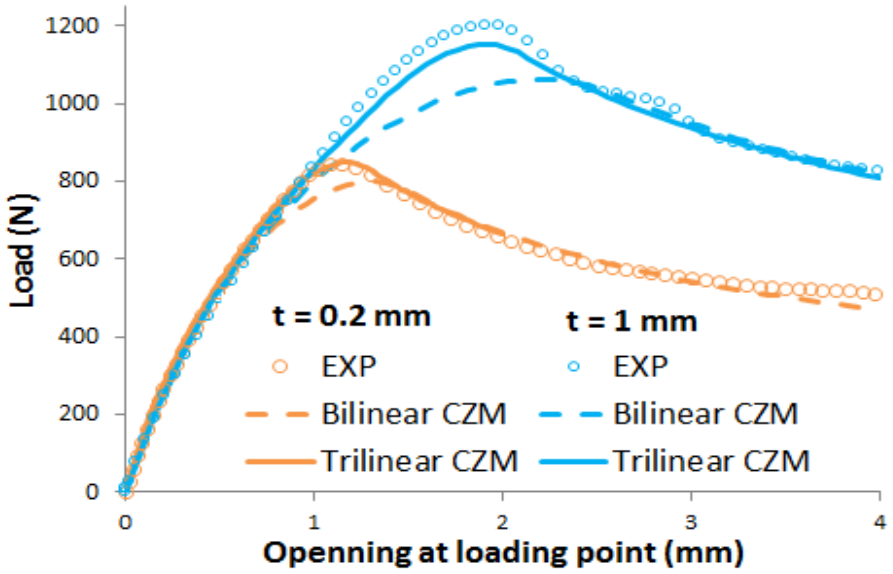












A. Jaillon, J. Jumel, F. Lachaud, E. Paroissien and J. Renart. Thickness influence on a structural methacrylate adhesive behavior. Proceedings of 6th World Congress on Adhesion and Related Phenomena (WCARP 2018), 25 February – 2 March 2018, San Diego (CA)

RESEARCH

PhD Thesis	Formulation of elementary stiffness and mass matrices of macro-elements simulated bonded overlaps in a plate kinematics

TACCOS support

PhD student	**[1]Benjamin Ordonneau**
Supervision	*[1]Michel Salaün, [1]Éric Paroissien*
Project	**SCODyn**
Funding	**CETIM, DGA**
Date	October 2018 – September 2021

The macro-element (ME) technique has been developed at ICA since 2004. The objective of this PhD Theses is to develop methodologies for the formulation of new MEs, in terms of stiffness and mass matrices, able to simulate a bonded overlap of two plates undergoing multi-axial loading. It is then expected to extend the application field of the ME technique from characterization specimen or structures undergoing uni-axial loading to 3D thin structures.

[1]Institut Clément Ader (ICA), Université de Toulouse, ISAE-SUPAERO, INSA, IMT MINES ALBI, UTIII, CNRS, France

RESEARCH

PhD Thesis	Particle-based numerical simulation to predict strength and controlled fragmentation for space structures

TACCOS support

PhD student	**[1]Lorraine Silva**
Supervision	*[1]Christine Espinosa, [4]Lucas FM da Silva*
Project	**SIMPACOS**
Funding	**ED MEGeP**
Date	October 2018 – September 2021

Aiming at maximizing safety of service removal operations for future missions (Earth observation, climate study, agriculture/environment), puts light on the need to enhance the risk estimation linked to the integrity persistence (or non-vulnerability) during the atmospheric re-entry phase with various scenario. Assigning a dual function of integrity and loss of integrity to a multi-material bonded structure when desired is the challenge of this study. The scientific issue consists in defining the key material and geometrical properties of bonded structures from the design phase to achieve the dual functions of controlled integrity and controlled fragmentation.

[1]Institut Clément Ader (ICA), Université de Toulouse, ISAE-SUPAERO, INSA, IMT MINES ALBI, UTIII, CNRS, France
[4]Department of Mechanical Engineering, Faculty of Engineering, University of Porto, Portugal

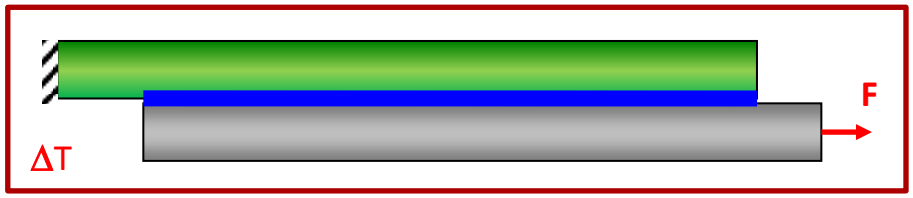
Collaboration with U Porto

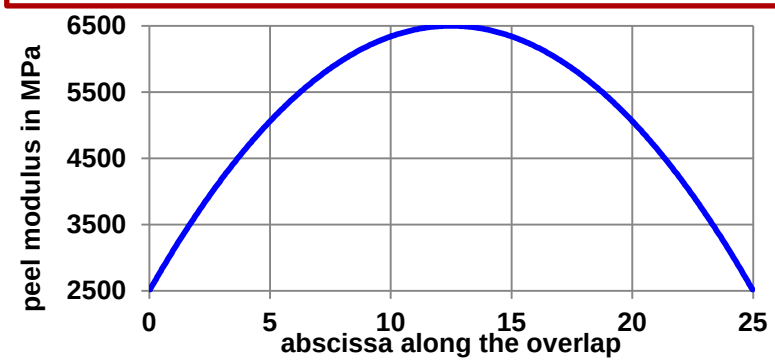
Simplified stress analysis of functionally graded adhesive (FGA) joints

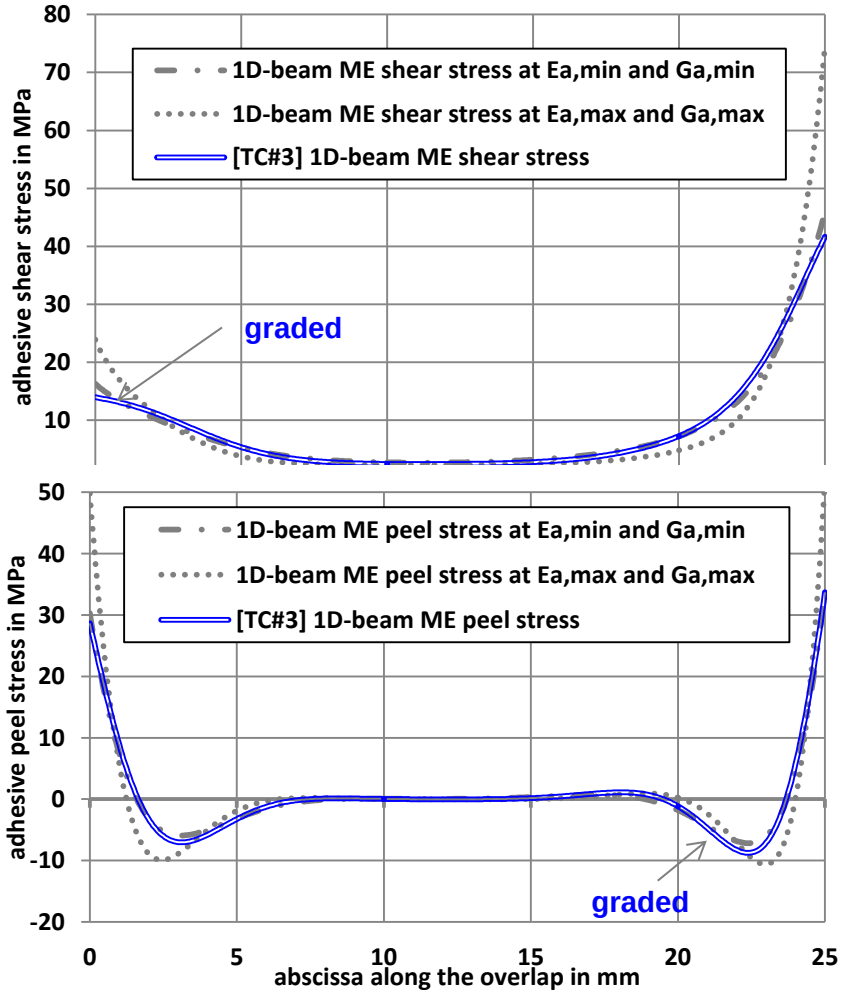
coming from **G. Lélias PhD Thesis defense** and **JADH 2017** (then **TACCOS**)

Simplified models (ME and power series) for unbalanced FGA joints under **mechanical and thermal loading**:

- reduction of peak stresses?
- a solution for graduation optimization







Paroissien, E., da Silva, L.F.M., Lachaud, F., 2018. Simplified stress analysis of functionally graded single-lap joints subjected to combined thermal and mechanical loads. Accepted into Composite Structures

Thank you for your attention!

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