

Research project offer



Location : ISAE SUPAERO, Toulouse, France

Department : DMSM

Research group : “Joining” transversal axis [MS2M and MSC]

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OFFER DESCRIPTION

Title : Simplified stress analysis of multilayered structures under 1D-beam kinematics

Proposed duration and period : 6 months, S1 2021

Context

Aircraft structures are designed by the assembly of beams with concentrated caps and of thin plates. The objective is to set the material where it is needed to maximize the strength-to-mass ratio. The aircraft structural components are mainly assembled thanks joining technologies related to bolting. If bolting joining technologies are well controlled, its main drawback is the local reduction of the strength-to-mass ratio. Indeed, to reduce the local stress level to be transferred, the joining areas are mainly characterized by an increase of the thickness of materials to be assembled. On the contrary, it is acknowledged that the adhesive bonding technology allow for the increase of static and fatigue strength while reducing the mass. As a result, in the frame of the cost reduction, a solution for the design of aircraft structures could be built them by laying up adhesively bonded material sheets, in order to locally set the material where it is needed while avoiding over thicknesses.

The Finite Element (FE) method is able to address the stress analysis of multilayered structures. Nevertheless, since analyses based on FE models are computationally costly, it would be profitable both to restrict them to refined analyses and to develop for designers simplified approaches, enabling extensive parametric studies. As highlighted in several literature surveys [1-3], a large number of simplified approaches for the stress analysis of bonded joints exist in literature. One of promising techniques is the macro-element technique, the efficiency of which has been demonstrated in the case of two bonded beams (see Figure 1). The macro-element technique method, originally presented in [4,5], is inspired by the FE method and allows for the resolution of the set of governing differential equations. The displacements and forces in the adherends, as well as the adhesive stresses, are then computed. The method consists in meshing the structure. A fully bonded overlap is meshed using a unique 4-node macro-element, which is specially formulated. This macro-element is called bonded-bar (BBa) or bonded-beam (BBe). According to the classical FE rules, the stiffness matrix of the entire structure – termed K – is assembled and the selected boundary conditions are applied. The minimization of the total potential energy leads to find the vector of nodal displacements U such that $F=KU$, where F is the vector of nodal forces. This approach based on macro-elements takes advantage of the flexibility of FE method. Indeed, by employing a macro-element as an elementary brick, it offers the possibility to simulate complex structures involving single-lap bonded joints at low computational costs [6]. The current method makes use of simplifying hypotheses of classical models, such as Volkersen, Goland and Reissner or Hart-Smith [7-11], describing the joint as two beams of one or two parameter elastic foundation.

Previously, two internal Research Projects (2017-2018) were led on this topic leading to the publication of scientific papers [12-13] as well as to an oral presentation at the 5th International Conference on Structural Adhesive Bonding in July 2019 in Porto (PT). The topic of the present offer is the following of both previous internal Research Projects.

Objectives and work

The objective of the present Research Project is to formulate the stiffness and mass matrices of a multi-layered macro-element:

- with homogeneous material and geometrical properties

- with graded material and geometrical properties

The formulation is based on a dedicated strategy and makes use of Taylor expansion power series [12,14].

The works shall include:

- bibliographic review on the stress analysis of bonded joining of materials and structures
- bibliographic review on the stress analysis of multi-layered structures
- development of stiffness and mass matrices for homogeneous ME
- development of stiffness and mass matrices for graded ME

It is indicated that the following topics are reasonably not included and could constitute further Research Projects:

- use of these stress analyses to provide design guidelines
- use of these MEs for inverse identification
- use of these MEs for design optimization

References

[1] JW van Ingen, and A Vlot. *Stress analysis of adhesively bonded single lap joints. (Report LR-740). Delft University of Technology (April 1993).*

[2] MY Tsai, and J Morton. *An evaluation of analytical and numerical solutions to the single-lap joint. Int J Solids Structures. 31, pp. 2537-2563 (1994).*

[3] LFM da Silva, PJC das Neves, RD Adams, and JK Spelt. *Analytical models of adhesively bonded joints-Part I: Literature survey. Int J Adhesion Adhesives. 29, pp. 319-330 (2009).*

[4] E Paroissien E, M Sartor, and J Huet. *Hybrid (bolted/bonded) joints applied to aeronautic parts: Analytical one-dimensional models of a single-lap joint. In: Advanced in Integrated Design and Manufacturing in Mechanical Engineering II. S Tichkiewitch, M Tollenaere, and P Ray (Eds.), Springer, pp. 95-110 (2007).*

[5] E Paroissien, M Sartor, J Huet, and F Lachaud. *Analytical two-dimensional model of a hybrid (bolted/bonded) single-lap joint. J Aircraft. 44, pp. 573-582 (2007).*

[6] SE Stapleton. *The analysis of adhesively bonded advanced composite joints using joint finite elements. PhD thesis. University of Michigan (2012).*

[7] Volkersen O. *Die Niekraftverteilung in Zugbeanspruchten mit Konstanten Laschenquerchritten. Luftfahrtforschung 1938; 15:41*

[8] M Goland, and E Reissner. *The stresses in cemented joints. J App Mech. Trans. ASME. 11, pp. A17-A27 (1944).*

[9] LJ Hart-Smith. *Adhesive-bonded single-lap joints. NASA CR 112236 (January 1973).*

[10] F Mortensen. *Development of tools for engineering analysis and design of high-performance FRP-composite structural elements. PhD Thesis. Aalborg University, Denmark (1998).*

[11] MY Tsai, DW Oplinger, and J Morton. *Improved theoretical solutions for adhesive lap joints. Int J Solids Structures. 35, pp. 1163-1185 (1998).*

[12] V Torrelli, E Paroissien, 2020. *Simplified stress analysis of multilayered bonded structure under 1D-bar kinematics. Composite Structures, 112, 112641.*

[13] K Sekmen, E Paroissien, F Lachaud, 2020. *Simplified stress analysis of multilayered adhesively bonded structures. International Journal of Adhesion and Adhesives, 97, 102497.*

[14] B Ordonneau, E Paroissien, M Salaün, J Malrieu, A Guigue, S Schwartz, 2020. *A methodology for the computation of the macro-element stiffness matrix for the stress analysis of a lap joint with functionally graded adhesive properties. International Journal of Adhesion and Adhesives, 97, 102505.*

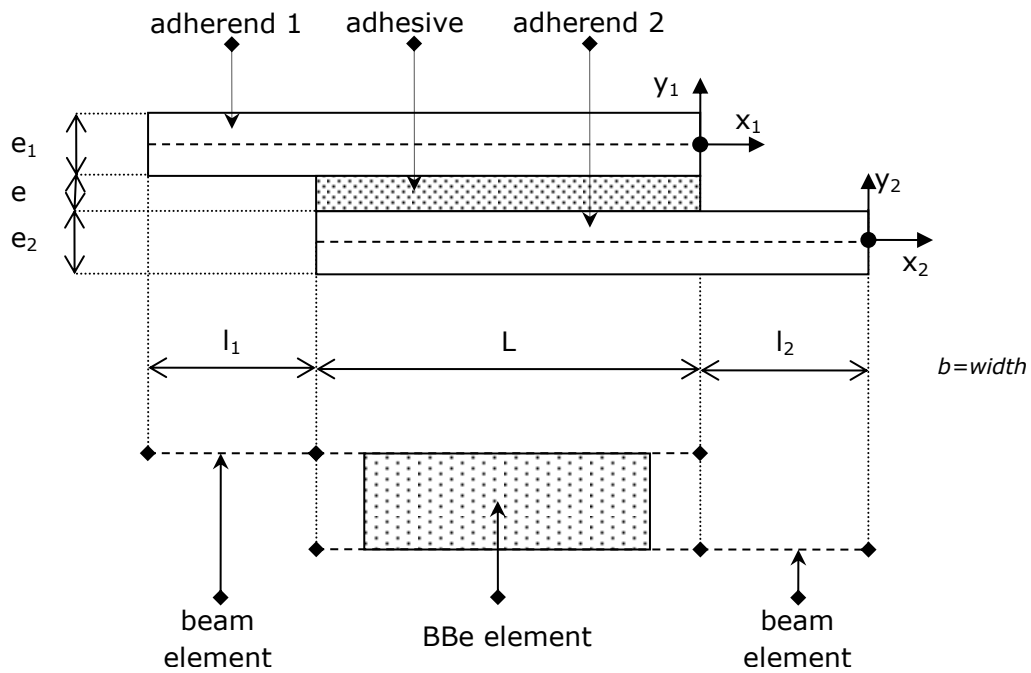


Figure 1 – Modeling with macro-element technique.

Possibility to continue with a PhD (Yes/No) : TBD

REQUIRED APPLICANT PROFILE AND SKILLS

<p>Study level (tick possible choices)</p>	<p><input type="checkbox"/> Undergraduate students (3rd or 4th year) <input checked="" type="checkbox"/> Master students (1st or 2nd year) <input type="checkbox"/> PhD students</p>
<p>Required profile and skills</p>	<p>This offer is suitable to students in last year of MSc, MEng in Solids Mechanics, Structures Mechanics.</p> <p>The expected specific skills are :</p> <ul style="list-style-type: none"> • Fundamentals of strength of materials • Basics on the FE method and CAD
<p>Other useful information</p>	<p>Feel free to take contact</p>