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Assessment of the Cohesive Contact method for the analysis of thin-walled bonded structures

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ABSTRACT

Several finite element (FE) techniques for the structural analysis of bonded joints and structures have been proposed in the literature. This paper deals with the assessment of a new surface interaction technique that models the adhesive as a pure contact with cohesive properties. This technique is a new feature of the FE software ABAQUS. The work has two objectives. Firstly, to assess the applicability, efficiency and accuracy of this Cohesive Contact (CC) method in the analysis of three dimensional, thin-walled bonded structures. Secondly, to compare the CC method with a similar technique, called Tied Mesh (TM) method, previously proposed by the authors. By considering as benchmark standard and ad hoc bonded joints and structures, the CC method is checked against a full FE model in the elastic field and with the outcome of experimental tests in the post-elastic field. Also, the TM method is implemented for all these geometries, in order to obtain a comparison. The results show that the CC method gives a fair prediction both in the elastic and post-elastic field, with lower accuracy than the TM method.

1. Introduction

Several FE techniques, both in two and three-dimensions have been proposed in the literature for the structural analysis of bonded joints. Rao et al. [1] developed a special six-node isoparametric element for the adhesive layer. Yadagiri et al. [2] modified that element to include longitudinal and normal stresses and linear viscoelastic response. Carpenter [3] introduced a finite element (FE) formulation for the adhesive of a lap joint. The element is based on the assumptions of the theory of Goland and Reissner [4]. Carpenter and Barsoum [5] improved that work by implementing a four node and a two node FE for modelling the adhesive in a bonded configuration. Carpenter [6] presented a special 2D adhesive element to model the viscoelastic behaviour of the adhesive. Reddy and Roy [7] proposed a special 2D FE based on the updated Lagrangian formulation of elastic solids, for geometric and material nonlinear analysis. Lin and Lin [8] presented a 2D FE formulation for single lap adhesive joints which can analyse the distribution of the shear and normal stresses in a variety of configurations with any possible adhesive layer conditions and non-identical adherends. Edlund and Klarbring [9] developed a special element for geometric nonlinear analysis. Andruet et al. [10] developed an ad hoc model for three-dimensional (3D) analysis of adhesive joints based on shell and solid elements. Goncalves et al. [11] proposed a new 3D FE model to study the behaviour of adhesive joints. Tong and Sun [12] developed a novel FE formulation for adhesive elements specifically for conducting quick stress analysis of bonded repairs to curved structures. Camanho and Davila [13] implemented and assessed a new decohesion element with mixed-mode capability that can be used at the interface between solid FE to model delamination. In a subsequent work, Turon et al. [14] presented a methodology to determine the parameters used in the simulation of delamination in composite materials and assessed that the mesh refinement is not a critical parameter in the simulation of fracture process through this decohesion elements. The main drawback of these methods is the difficulty to implement user defined elements in commercial FE software usually available in the industrial world.

In some recent works, the authors of the present paper investigated the accuracy and the applicability of efficient FE methods for the analysis of thin-walled bonded structures. The peculiarity of these methods is that they rely on standard modelling tools and regular FEs. The method describes the adherends by semi-structural elements (plates or shells), and the adhesive by means of a single layer of solid elements. In [15], two simplified computational methods are compared, in the elastic field, with the prediction provided by an analytical model retrieved from the literature and with the results of a full, computationally intensive, FE analysis. The prediction of the

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elastic stress distribution at the mid-plane of the adhesive layer was assessed for many 2D and 3D geometries. The most promising method, named Tied Mesh (TM) method, was then assessed in the post-elastic field in three steps. First, in [16] a systematic computational campaign on standard T-peel joints was performed. Second, in [17] a comparison between TM method and the outcome of experimental tests on the same T-peel joints is executed. Third, the TM method was assessed against the experimental force–displacement curves obtained on a complex, square, thin-walled beam [18].

In keeping with the same approach of the TM method, an alternative method can be obtained by describing the adhesive layer through a surface-based cohesive behaviour, as implemented in several commercial FE software (i.e. ABAQUS [20] and Lusas [21]). This is a surface interaction property that models the adhesive as a pure contact with cohesive properties and may be used to join both solid elements and structural or semi-structural elements. In the present work, the proposed method, called Cohesive Contact (CC) method, describes the adherends through semi-structural elements (plates or shells). The present work has two aims. Firstly, to assess the applicability, the efficiency and the accuracy of the CC method in the analysis of three-dimensional, thin-walled bonded structures. Secondly, to compare the CC method with the TM method, previously proposed by the authors in [15–18]. The CC method is examined both in the elastic and post-elastic field, through a systematic numerical campaign. In the elastic field, two different single-lap joint configurations are examined and the CC method is checked against a full FE model, taken as reference. In the post-elastic field, two T-peel joint configurations and four square butt-strap joined thin-walled beams are investigated. In this case, the CC method is checked against the experimental curves of a previous campaign [17,18], considered as reference. The TM method is also implemented both in the elastic and post-elastic field, in order to have an additional comparison.

2. Method

The accuracy and the applicability of the CC method was assessed by comparison with the results of a full FE model (assumed as reference) and of the TM method both in the elastic and post-elastic field. In addition, the results provided by the experimental tests is considered in the post-elastic field. All the computational models were three-dimensional in order to be as general as possible and to evaluate the processing time on a more realistic geometry. In addition, all the models were implemented using the FE software ABAQUS 6.10-2 [20].

CC method: The CC method reproduces the adherends using linear shell elements, with reduced integration (S4R5) and applies a cohesive surface interaction property (*Cohesive Behaviour) to describe the adhesive. Since this work was focused on the assessment of an efficient method for the analysis of thin walled bonded structures, the adherends were modelled with shell elements. The modelling of the adherends through solid hexahedral elements was not considered as a feasible solution, because of the large increase in the number of degrees of freedom of the model, in case of real scale structures. Moreover, in case of brick adherends, the use of cohesive contact has been previously assessed in [19] giving good results. The adherends were described including, between them, the real thickness of the adhesive layer. Hence, the offset between the adherends equals the adherends plus the adhesive thickness. In order to determine the optimum side length of shell elements describing the adherends, a preliminary convergence campaign was performed on the single-lap joint geometry described in Fig. 1. The single-lap joint configuration described in Table 1 with the label Joint 1 was assumed. Four values of the element side length were examined:

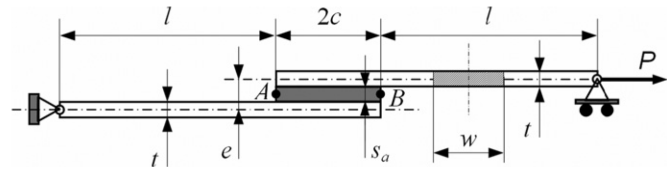

Fig. 1. Benchmark geometry for the single-lap joint.

Table 1
Comparison between peak shear and peel stress values, provided by the CC method at four different side element lengths, with the ones provided by the full FE model.

Point	Shear stress (MPa)		Peel stress (MPa)	
	A	***B***	***A***	***B***
CC method				
***e*/4**	10.2	20.1	0.0	39.2
***e*/2**	11.9	18.4	6.3	34.4
e	**13.8**	**16.1**	**4.2**	**23.9**
2*e*	12.9	13.2	1.3	10.0
Full FE				
	19.8	**19.8**	**28.2**	**28.2**

$e/4$, $e/2$, e, $2e$ (Fig. 1). As presented in the Results section, the element side length providing the best trade-off between accuracy and computational efficiency was the one corresponding to the distance between the mid-planes of the adherends, e. This result is in accordance with the approach adopted in the TM method [15–18], where the same element side length e was used both for the adherends and for the adhesive. Since the adhesive is described as a cohesive-contact property, the method is easier to define than modelling the adhesive layer through solid elements. The cohesive-contact interaction describes the adhesive constitutive behaviour in terms of normal and tangential stiffness in the elastic field, while a cohesive zone model can be used to describe its post-elastic behaviour. In particular, the normal and tangential stiffnesses are simply obtained as the ratio of Young's modulus and shear modulus to the thickness of the adhesive layer.

Full FE model: The full FE model exactly reproduces the geometry of the joint and incorporates its material properties. The adherends are described by linear hexahedral elements (C3D8) of cubic shape, with a side length of 0.1 mm in the overlap region. The adhesive is described by linear cohesive hexahedral elements (COH3D8), with a thickness of 0.025 mm and a side length of 0.1 mm. The element dimensions adopted in the analysis were chosen after a mesh convergence procedure focused on the peak stresses arising at the mid-plane of the adhesive layer.

TM method: The TM method describes the joint through an approach quite similar to the one of the CC method. The only difference is that the adhesive is described through a layer of elements, which are quadratic hexahedral (C3D20R) in the elastic analyses and linear cohesive hexahedral (COH3D8) in the post-elastic analyses. This choice was performed because quadratic hexahedral elements provide a more accurate description of the elastic stress field, while cohesive hexahedral elements allow more efficient and accurate modelling of the post-elastic behaviour. An internal kinematic constraint (Tied Mesh) was introduced to fill the gap between the adhesive and the adherends. Further details about this method can be found in [18].

2.1. Computational campaign

The computational campaign, aimed at assessing the applicability and the accuracy of the CC method, was organised in two