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In memoriam prof. dr. Ioan A. Silberg

ADHESIVE INFLUENCE MODELING ON DOUBLE-LAP JOINTS ASSEMBLIES

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ABSTRACT. The paper presents a numerical analysis of metal-composites plane assemblies joined with adhesive. After the CAD model, constraints and applied load definition, we made a stress field analysis.

The aim of this work is to validate an analytical model, based on an energy method, developed by the author. Thus the analytical model makes it possible to determine the rigidity of the assembly and to obtain a simple formulation very rapidly which gives the total behavior of the assembly.

Keywords: *Stress Analysis, Adhesives, Numerical modeling*

INTRODUCTION

The adhesive bonded joints assembling method distributes the stresses over the whole joining surface and removes the stress concentrations to the boundary of holes generated by bolting or riveting assemblies. The mechanical performance of an adhesive bonded joint is related to the distribution of the stresses in the adhesive layer. Consequently it is essential to know this distribution, which, because of its complexity, makes prediction of fractures difficult.

From the first works of Volkersen [1] when only a distribution of the shear stress in the adhesive joint was taken into account to the more recent studies by finite elements, many formulations have made it possible to define the stress field in such assemblies better and better.

Following Goland and Reissner [2], Volkersen [3] introduced into his new analysis the normal stress "stress of shearing" (peeling stress) which is variable in the thickness of the adhesive layer. This assumption enabled him to build a stress field observing the boundary conditions of the assembly. However, due to the complexity and difficulty of its implementation, this analytical formulation is not easily applicable.

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Gilibert and Rigolot [4, 5] propose, based on the method of the asymptotic developments connected in the vicinity of the ends, an analytical formulation of the stress field over the entire covering length. If this formulation constitutes a clear improvement of the modeling of the field of the constraints on the level of the ends and represents experimental reality better, it is however not valid near the free edges.

Adams and Peppiatt [6], in their finite element analysis, circumvented this difficulty by studying a joint modified by the addition of a regularizing part. However even this study is not satisfactory on the level of the ends.

Tsai and Oplinger [7] develop the existing traditional solutions by the inclusion of shearing strains, neglected until there. The solutions obtained ensure a better forecast of the distribution and intensity of the shear stress.

Mortensen and Thomsen [8, 9] developed the approach for the analysis and the design of the adhesive bonded joints. They held into account the influence of the interface effects between the adherents and they modeled the adhesive layer by assimilating it to a spring.

Nemes [10, 11] use a technique based on the minimization of the potential energy. The first stage consists in building a statically acceptable stress field, i.e. verifying the boundary conditions and the equilibrium equations. Then, the potential energy generated by such a stress field is calculated. In the third stage, the potential energy is minimized in order to determine the stress distributions. As we have just seen, the analytical formulations and the finite element analysis provide a stress field satisfying for the median part of the joints. On the other hand, these two approaches provide results that do not satisfy the boundary conditions imposed at the ends of covering. The majority of the degradation phenomena are observed in the vicinity of joints end (non-linear behavior, damage, cracking, even fracture). The analytical study that follows gives a first solution of the stress field respecting the whole of these conditions.

RESULTS AND DISCUSSION

NUMERICAL MODELING BY FINITE ELEMENTS

1. Meshing and boundary conditions

The objective of this study is to compare our analytical models of the adhesive-bonded joints with models made of finite elements.

For the numerical analysis by finite elements of the adhesive-bonded joints, we used the computer code SAMCEF from SAMTECH®.

The diagram of the C.A.D., basis of the finite element model, is presented in figure 1. The diagram also describes the boundary conditions and the applied load.

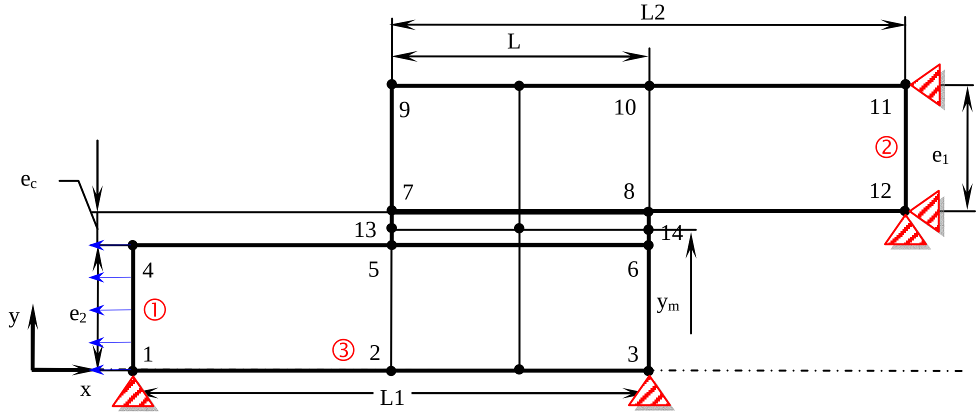
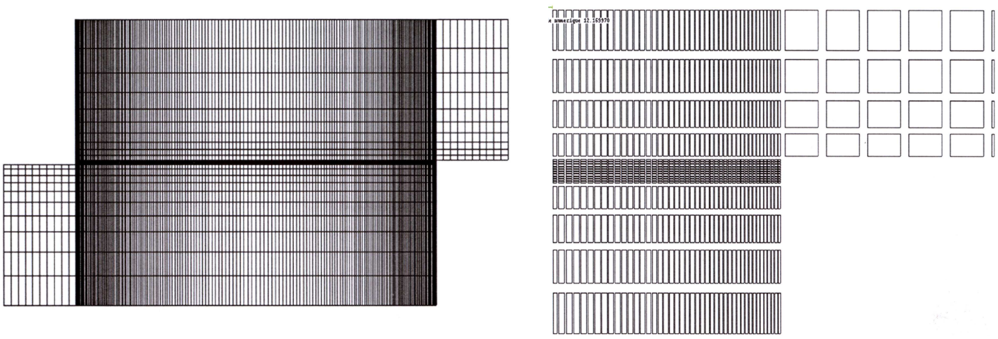


Figure 1. CAD diagram of a double-lap adhesive-bonded joint.

The double-lap assembly is modeled by 2D quadrangles of degree 2 and interface finite elements (x → z, y → r, z → θ). The displacements along x and y on face ② of the upper substrate and those along y on face ① of the lower substrate are blocked. The load is applied as a pressure on face ① (Figure 1).

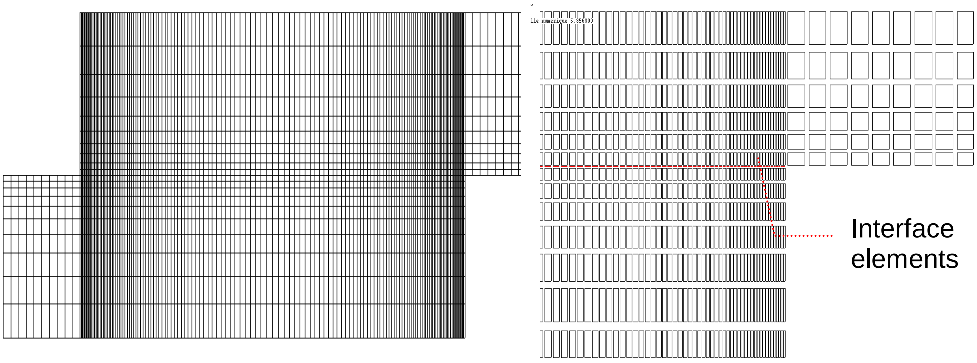
Figure 2 shows an example of the grid used in this study where all the finite elements are quadrangles. We imposed ten finite elements in the to the adhesive layer.



a) b)

Figure 2. Numerical modeling of a double-lap bonded joint with quadrangles elements: a) assembly; b) detail.

Figure 3 shows an example of the grid used in this study where all the finite elements which mesh the adhesive are interface type. We imposed 1 finite element row in the adhesive layer.



a) b)

Figure 3. Numerical modeling of a double-lap bonded joint with interface elements: a) assembly; b) detail.

2. Load transfer

To compare the analytical model with the finite elements model we determine the load transfer in the middle of the bonded substrates, Figure 4.

We can note some differences in the variation of the load given by the ideal model in the case of a metal-composite assembly (Adherent 1 – Aluminium AU 2024 T3, Adhesive – Araldite AV119, Adherent 2 – Glass fiber ± 45°), (Figure 4), while it still has a similar evolution.

The point of equivalence in stress in the two substrates is shifted (according to the length of the join) from approximately 1 % in the finite element analysis. It should be noted that the position of this point varies according to the characteristics of the substrates: it is centered compared to the length of the join for substrates of equivalent total rigidities, and shifts on both sides as a function of the ratio of the rigidities of the bonded substrates.

3. Stress distributions

The stresses in the adhesive are very important to predict the failure moment. For that it is primordial to have their distributions.

Figure 5 shows the stress distributions in the assembly in the form of cartography.

We can observe that the distribution curves had the same shape like the curves obtained by the analytical model [11], and so the model is validated.

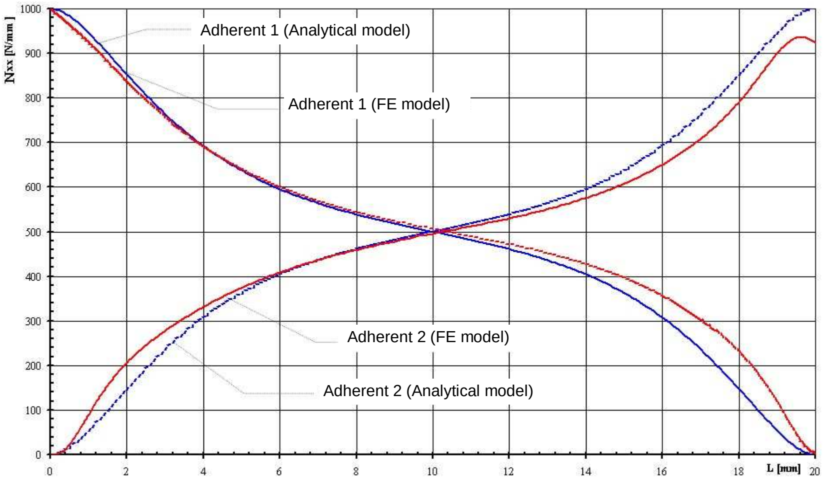


Figure 4. Load transfer in an AU 2024 T3-AV 119-VE ±45° assembly.

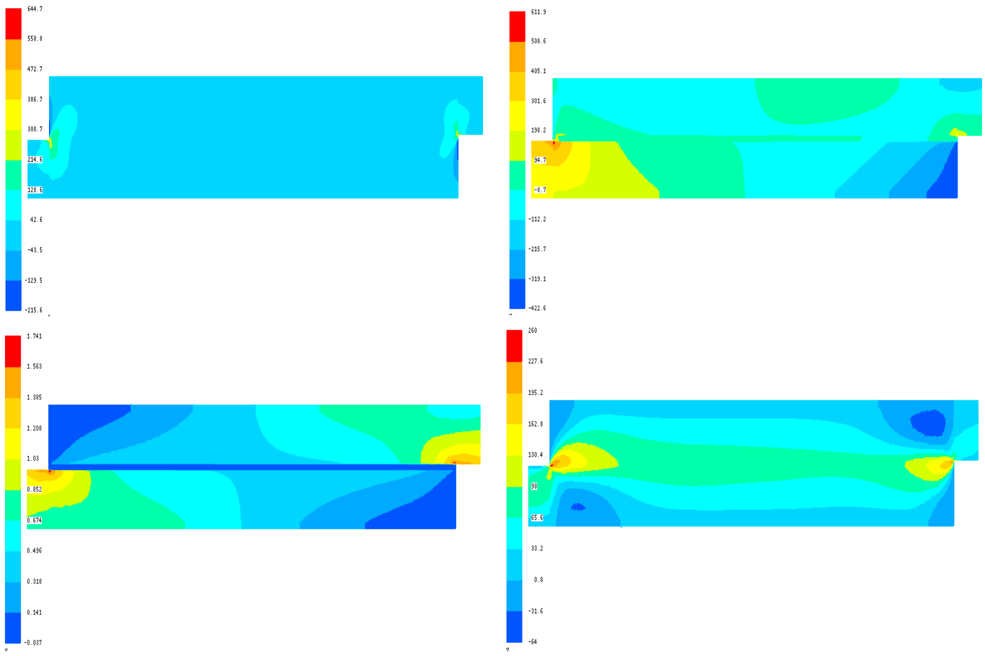


Figure 5. Stress distribution in double-lap bonded joint

CONCLUSION

Adhesive joining is a simple method of assembly. Its interest lies in the fact that it minimizes the machining of the parts to be assembled. The performance of the adhesive bonded joints depends on the performance of the adhesive. The latest generations of adhesives, delivered in the form of film, make it possible to minimize the number of operations to make the join and greatly increase the mechanical resistance. However, the design engineer must have at his disposal methods and/or reliable computer codes for pre-dimensioning with known margins.

The objectives of our studies were to entirely develop analytical models for dimensioning adhesive-bonded joints.

The basis of our analytical model was the analysis of the stresses applied to an elementary volume of the assembly under consideration, observing the boundary conditions, the geometry and materials of the assembly. The application of an energy method made it possible to obtain the stress distribution in any point of the structure [11]. The behavior law enabled us to obtain the deformations then, by integration, the displacements. The problem for stress, deformation and displacements was thus entirely defined.

The validation of the analytical model is presented by comparison with finite elements models. For the assembly, the total force-displacement behavior is well defined. Thus, the analytical model makes it possible to determine the rigidity of the assembly and to obtain a simple formulation very quickly, which gives the total behavior of the assembly.

The comparison was also carried out for the stress distribution in the substrates and the adhesive joint. We showed that the transfer of force by joining was well determined by the model. The distribution of stress in the adhesive remained very close to the solution given by finite elements.

The analytical model underestimated the stresses in the adhesive leading to an over-estimate of the forces at rupture. However, this model is reliable and allows fast analysis of this type of assembly.

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