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DETERMINATION OF COHESIVE PARAMETERS FOR MODE I OF EPOXY ADHESIVE

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Abstract

The paper deals with the determination of cohesive parameters of adhesive Scotch-Weld DP490 3M. Mode I of cohesive damage were examined. Experimental testing was performed on the test specimens to determine the mechanical properties of the adhesive. The results of the experimental testing were compared with the numerical simulation and analytical solution of the same test. The cohesive parameters of the adhesive were obtained from the numerical simulation. Cohesive parameters of adhesive can be used to design real adhesive bond.

Keywords: cohesive parameters; cohesive damage; epoxy adhesive; adhesive bond; Scotch-Weld DP490 3M, Mode I, DCB

1. Introduction

Composite materials [1] are becoming more and more used materials not only in aerospace and automotive industries but also in other industrial sectors where a high strength and stiffness at low weight is required [2], [3], [19]. In aerospace and automotive industries the fiber reinforcement composite materials are most frequently used. For joining of those composite materials with metals the adhesive bond is most frequently the best option. The advantages of adhesive bonds are that they have not Heat-affected zone (such as welding, [8], [9], [10], [20]) and they do not need to drill holes (stress concentrators) as bolted joints and riveted joints [6], [7]. Gluing is also suitable for printed composite parts [11], [12], [13].

Within our research we are designing the methodology of predicting the strength of bonded composite material with metals when designing their structure. With the use of experimental testing and numerical simulations. In practice this methodology should be simply applicable to the majority of real components.

The overall quality of the adhesive bond is influenced by many factors. To the most significant ones belong: the material of adhesive components, the surface treatment of adhesive areas, the quality of degreasing of adhesive areas (These factors were examined [14]). Another, but no less important, factors are the type of adhesive, the thickness of adhesive layer, the technology of adhesion, etc.

The paper [14] and diploma thesis [16] were focused on adhesion properties, specifically on influence material of adhesive components and the surface treatment of adhesive areas. This paper is focused on cohesive properties of adhesive. Cohesive properties of adhesive are linked with specific type of adhesive. Cohesive properties of adhesive are not dependent on the material of adhesive components, the surface treatment of adhesive areas and the quality of degreasing of adhesive areas. However, high strength adhesives can often cause adhesion failure. Therefore it is very important to design a suitable combination of „material-adhesive-surface treatment“. The goal of this article is to determine the cohesive properties of epoxy adhesive Scotch-Weld DP490 3M. In this case it is the determination of cohesive parameters for mode I specifically.

2. Cohesive properties

There are three independent fracture modes, the crack opening mode (Mode I) is regarded as more important than the in-plane shear mode (Mode II) and out-plane shear mode (Mode III) because the Mode I fracture toughness is usually smaller than those of Mode II and Mode III and so the fracture is easily initiated and propagated under the Mode I loading condition. There is also a combination of these modes called 'Mixed-mode'. The individual modes of crack opening are shown in Figure 1. [4] Particular cohesive models are given in [4], [5], [17], [18].

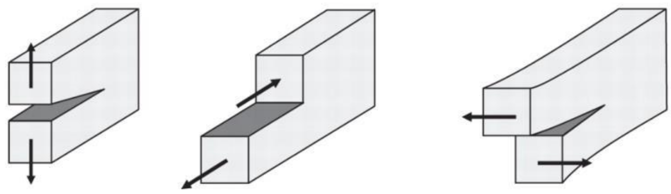

Fig. 1. The crack opening modes (a) Mode I; (b) Mode II; (c) Mode III

3. Specimens

The dimensions of the specimens were defined by standards ASTM D5528 (for DCB test/mode I). This standard does not define the exact dimensions of the specimen, but ranges of each parameters. The shape of the specimens are given in Figure 2.

Shortcut	Name	Norm dimensions [mm]	Selected dimensions [mm]
L	Length of specimen	min. 125	130
a_0	Initial delamination length	approx. 50	50
b	Specimen width	20 - 25	20
T	Specimen thickness	3 - 5	4

Table 1. Dimensions of specimen according to ASTM D5528

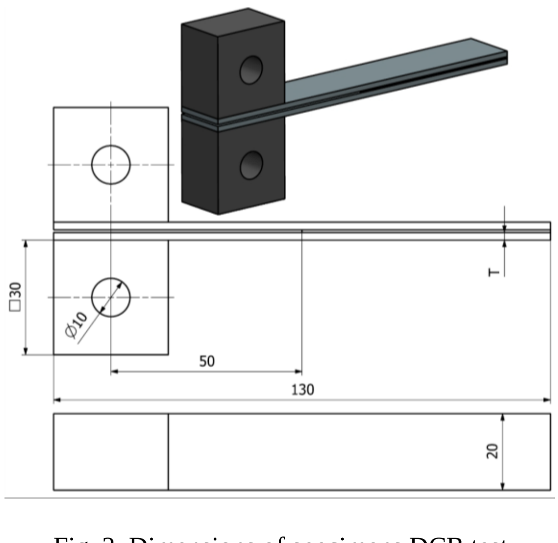

Fig. 2. Dimensions of specimens DCB test

The specimens were made using a water jet cutting machine [15]. The individual parameters of the material are given in Table 2.

Shortcut	Name	Value
E_{11}	Young's Modulus, axial direction	31 [GPa]
E_{22}	Young's Modulus, transverse direction	29 [GPa]
E_{33}	Young's Modulus, normal (out-of-plane) direction	15 [GPa]
G_{12}	Shear Modulus, , axial direction	4.4 [GPa]
G_{13}	Shear Modulus, transverse direction	4.4 [GPa]
G_{23}	Shear Modulus, normal (out-of-plane) direction	3.9 [GPa]
ν	Poisson's Ratio in plane	0.13[-]

Table 2. Material properties of the samples

4. Experimental testing

Experimental testing of samples was performed on the Zwick/Roell Z050 machine. It is a static material testing machine with a maximum pulling force of 50 kN, equipped with extensometers and several types of jaws. Samples were clamped into the jaws of the machine using a special jig. Samples were loaded by pulling. The testing happened quasi-statically. The speed of jaws´s shift was set to 5mm/min according to ASTM D5528. In this measurement, the loading force [N] and the deformation [mm] of the samples were subtracted using extensometers. The figure 3 shows the progress of the DCB test in several selected phases. Measured values from experimental testing can be seen in Fig. 4.

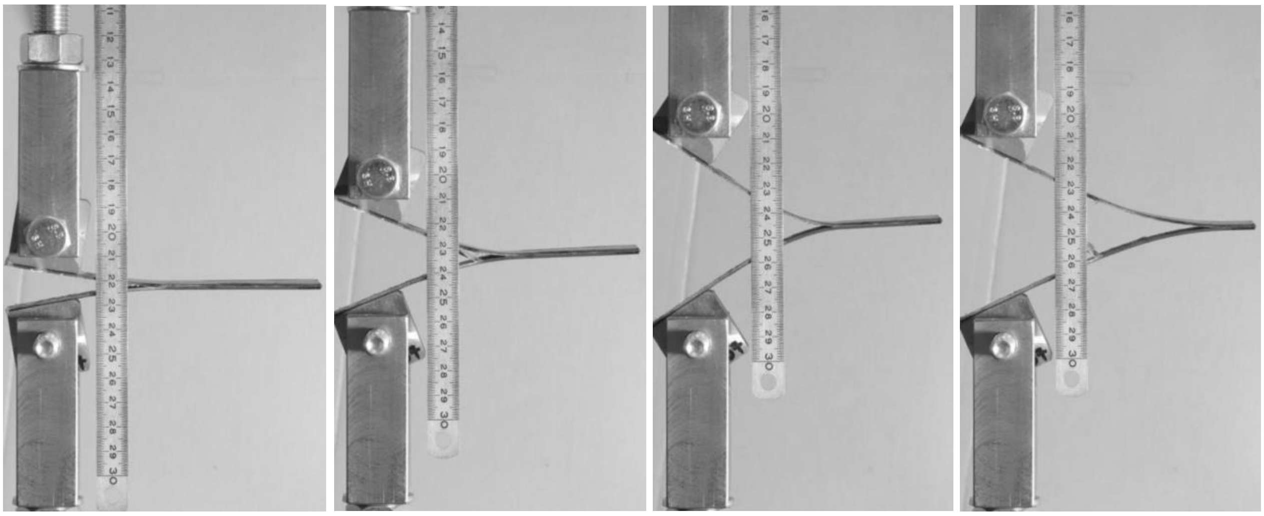

Fig. 3. Progress of the DCB test in several selected phases

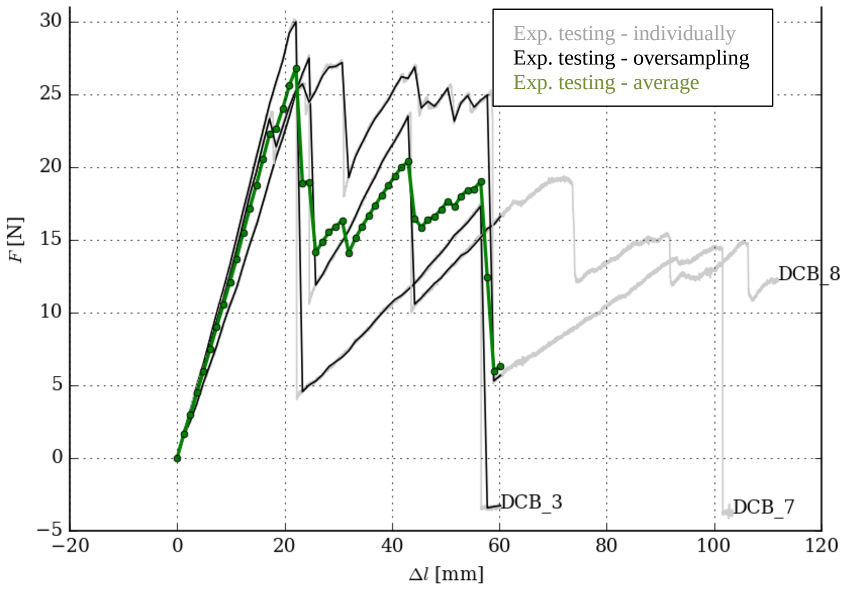

Fig. 4. Measured values from experimental testing

5. Numerical simulation

Cohesive model is created in software Abaqus 6.14. This is a nonlinear solution. Laminate beams are made of 3D elements (type BRICK). Dimensions and material properties are the same as for real test specimens (Figure. 2, Table 2). A cohesive contact is set between two beams. The clamping prisms are replaced by a boundary condition. Computational model of DCB test is given in Figure 4. Examples of results of numerical simulation DCB test are shown in Figure 5 and 6. Results of numerical simulation and experimental testing DCB tests are given in Figure 7.

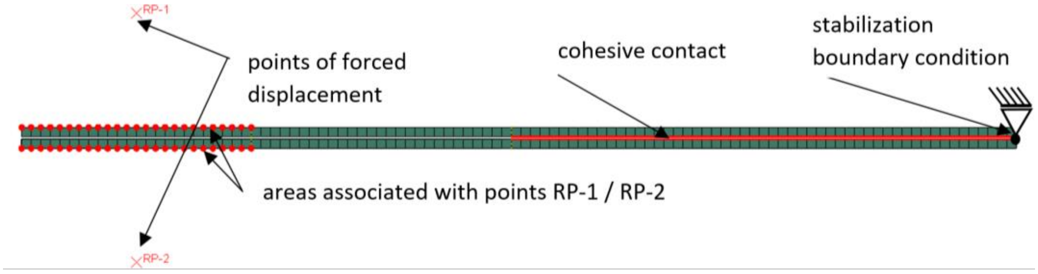

Fig. 5. Computational model

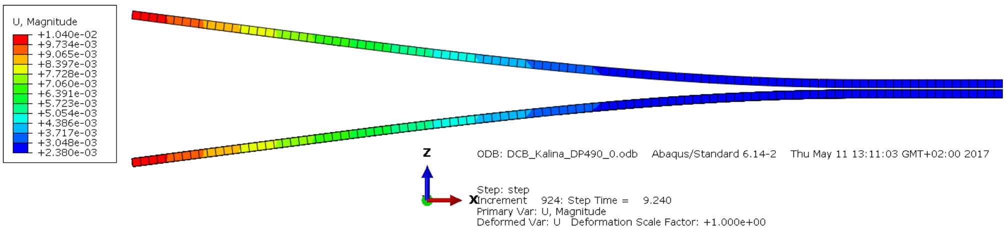

Fig. 6. Example of results of numerical simulation DCB test – result of displacement (m)

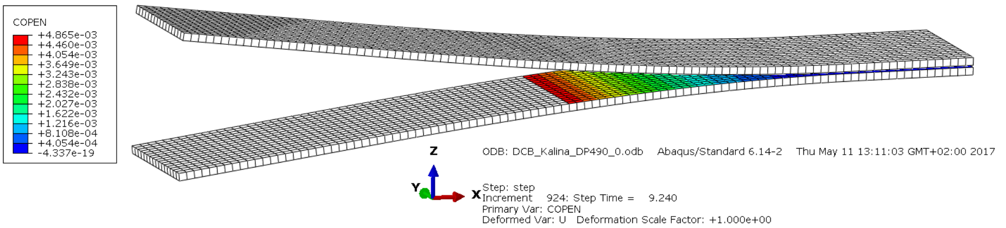

Fig. 7. Example of results of numerical simulation DCB test – result of crack opening (m)

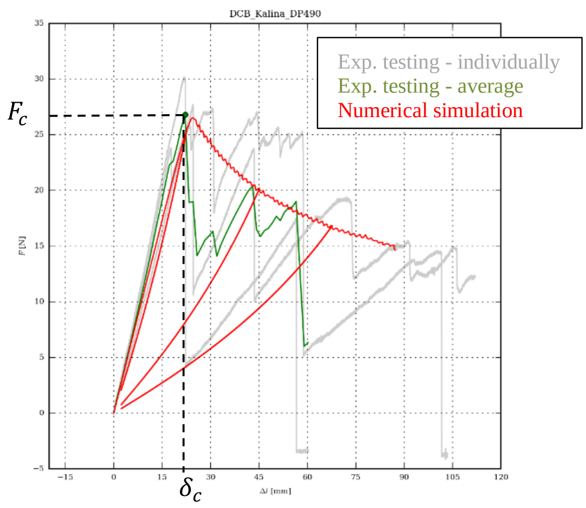

Fig. 8. Results of numerical simulation and experimental testing DCB tests

Important outputs from numerical simulation: $\delta_c = 21.393\ mm$; $F_c = 26.666\ N$; $G_{Ic} = 905.528\ \frac{J}{m^2}$.

6. Analytic solution

The analytic solution of DCB test was calculated based on Bernoulli beam theory and linear elastic fracture mechanics (1,2) [4]:

$$F_{el} = \frac{3}{2}\frac{E_1 I}{a_0^3}\Delta \tag{1}$$

$$F_{del} = \sqrt{\frac{3}{2}\frac{(bG_{IC}E_1 I)^{3/2}}{E_1 I \Delta}} \tag{2}$$

$$G_{IC} = \frac{3F_c\delta_c}{2ba_0} \tag{3}$$

Where F_{el} is the linear part of the reaction force (before damage); F_{del} is the non-linear part of the reaction force (during damage); Δ is the prescribed displacement; I is the moment of inertia of the delaminated part; a_0 is the prescribed delamination length; E_1 is Young´s modulus; G_{Ic} is the critical value of the strain energy release for Mode I conditions [4]; *b* is specimen width; F_c is the critical value of the force and δ_c is critical value of the displacement (opening).

7. Comparison of the Experimental testing, Numerical simulation and Analytical solution

We are interested in stiffness of the adhesive (k_{NN}), maximum load force (F_C) and critical value of the strain energy release for Mode I conditions (G_{Ic}). The Figure 8 shows that the numerical simulation is closer to the values from the experimental measurement than the values of the analytical solution. The analytical solution is suitable for quick approximate design. Usually we require that the glued joint is operated before the first failure. The first part of the chart describes the stiffness of the adhesive (to the first failure). The second part of the chart describes the damage progress. Therefore, the accuracy in the first part of the chart is more important to us.

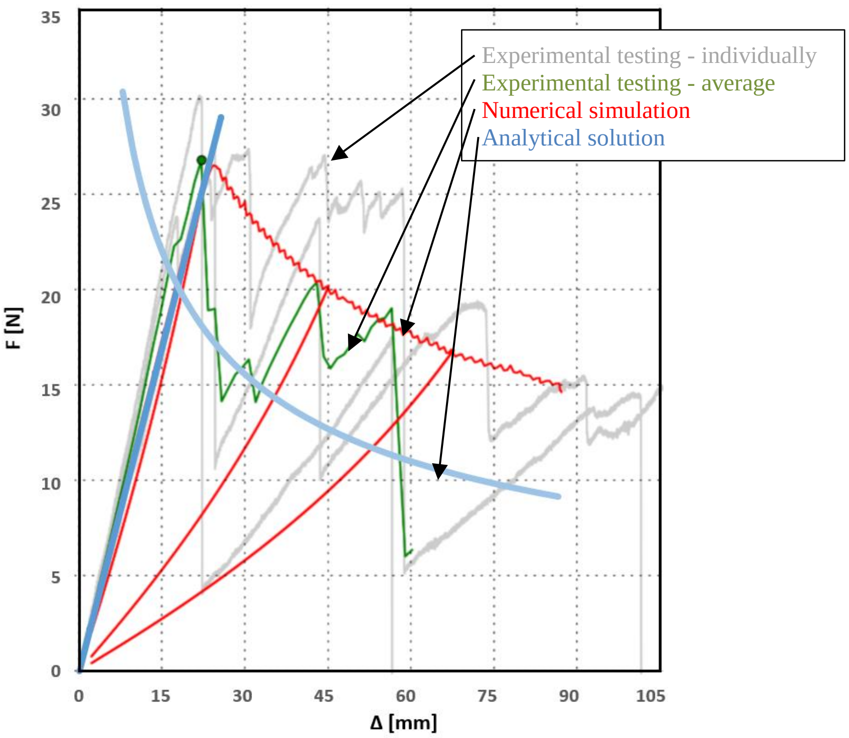

Fig. 9. Comparison of the experimental testing, numerical simulation and analytical solution

8. Conclusion

The goal of this article was to determine the cohesive properties of mode I of epoxy adhesive Scotch-Weld DP490 3M. Experimental testing of samples was performed and compared with numerical simulation and analytic solution of DCB tests.

From a comparison of experimental testing, numerical simulation and analytical solution it follows that the numerical simulation is closer to the values from the experimental measurement than the values of the analytical solution. The analytical solution is suitable for quick approximate design.

Based on numerical simulation cohesive parameters of adhesive Scotch-Weld DP490 for mode I were obtained. Critical value of the strain energy release for Mode I conditions (G_{Ic}) is equal to 905.528 [J/m^2=N/m]. Stiffness of the adhesive (k_{NN}) is equal to 200 [Gpa/m]. Obtained cohesive parameters of adhesive can be used to design real, shape complicated adhesive bond. For the future, it was planned to testing, simulation and comparison of ENF tests to determine cohesive properties for mode II (in-plane shear).

9. Acknowledgments

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