The Outlook of the Cohesive Zone Approach[1]

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Abstract

The micromechanical models of damage have found increasing interest. The general advantage, compared with classical fracture mechanics, is that, in principle, the parameters of the respective models depend only on the material and not on the geometry. These concepts guarantee transferability from specimen to structures over a wide range of sizes and geometries. The prediction of crack propagation through interface elements based on the fracture mechanics approach and cohesive zone model is presented. The cohesive model for crack propagation analysis is incorporated into finite element program by interface elements, which simulate the material separation.

1 Introduction

Damage may lead to the initiation and growth of macrocracks in a structure and to the final fracture in the end. The crack tip, the term used very often in the fracture mechanics, is a mathematical idealization. In reality, a region of material degradation exists in some process zone. In this zone the microbehaviour becomes important for constitutive modelling. Three different approaches exist to model damage, material separation, and the fracture phenomena:

- (i) No damage evolution is modelled and conventional material model, e.g. elastic plastic constitutive equations are applied. The process zone is assumed as infinitesimally small, specific fracture criteria, e.g. based on K, J, C* for crack extension are required.
- (ii) Separation of surfaces is admitted if some critical value is reached locally, whereas the material outside behaves conventionally; fracture criterion is a cohesive law.
- (iii) Softening behaviour is introduced into constitutive model; accumulation of damage is described by additional internal variables.

The identification and determination of the micromechanical parameters require a hybrid methodology of combined testing and numerical simulation. Micromechanical modelling encounters a new problem, the material is not uniform on the microscale and the material element has its own microstructure. The concept of a representative volume element (RVE) has been introduced by Hill and others. Many constitutive models for damage evolution exist, e.g.: (i) formation of microcracks and their extension with little global plastic deformation (cleavage fracture), (ii) nucleation, growth and coalescence of microvoids (ductile rupture).

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The crack propagation within a structure can be simulated using several different methods /1, 2, 3, 4/ : (i) node release technique controlled by any fracture mechanics parameter, (ii) constitutive equation including damage (Gurson), (iii) continuum damage concepts based on the theory of Kachanov, Lemaitre, or (iv) on the cohesive zone approach realised by the cohesive elements.

In present time the big effort is concentrated to the application of cohesive models in 3D modelling and to experimental determination of input parameters for models used in FEM. There is strong need to standardize the simulation techniques and the experimental determination of the base data.

2 Cohesive models

The idea for the cohesive model is based on the consideration that infinite stresses at the crack tip are not realistic. Model to overcome this drawback has been introduced by Barenblatt and Dugdale. Both authors divided the crack into two parts: one part of the crack surfaces is crack free; the other part is loaded by cohesive stresses. Most of the newer models developed and proposed are a bit different from Barenblatt's model in that they define the traction acting on the ligament as a function of the opening and not on the crack tip distance as Barenblatt did.

The material separation and, thus, damage of the structure is described by interface elements in FE method. Using this technique, the behaviour of the material is split into two parts: the damage free continuum with arbitrary material law, and the cohesive interfaces between the continuum elements, which specify only the damage of the material. One of the key problems in the application of the cohesive model is the choice of the material law within the cohesive zone. For the determination of the cohesive parameters in the case of normal fracture a hybrid technique has been developed and tested. Cohesive model is a phenomenological model which does not claim to represent the real physical fracture process and the choice of the more general traction-separation law (see the following Figure 1) is in forward of interest of many researchers.

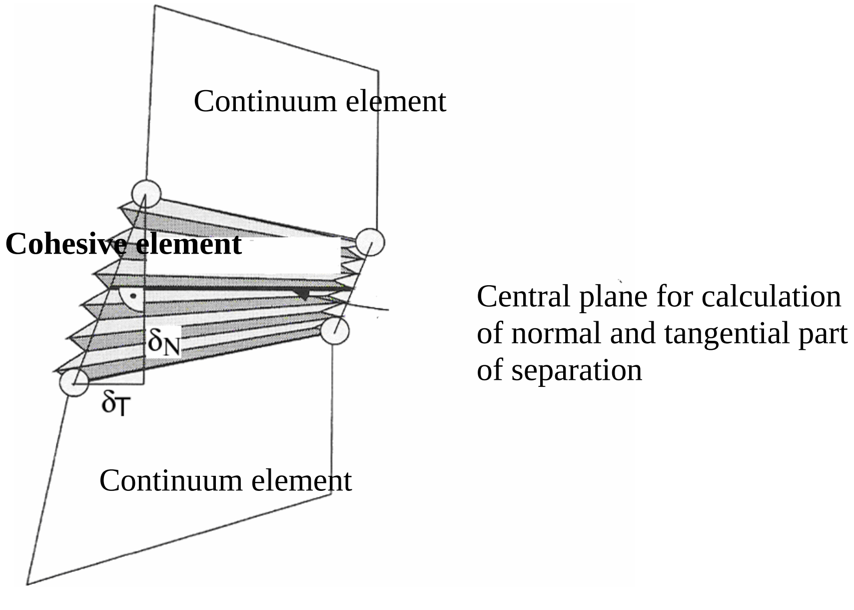

Figure 1. Separation of continuum element connected by a cohesive element

3 Traction-separation laws

Since the cohesive model is a phenomenological model, there is no evidence, which form to take for the cohesive law, T(δ). Thus cohesive law has to be assumed independently of specific material as a model of the separation process. Most authors take their own formulation for the dependence of the traction on the separation. The cohesive laws described below in the Figure 2 are described only schematically, but more information can be found in literature /2/.

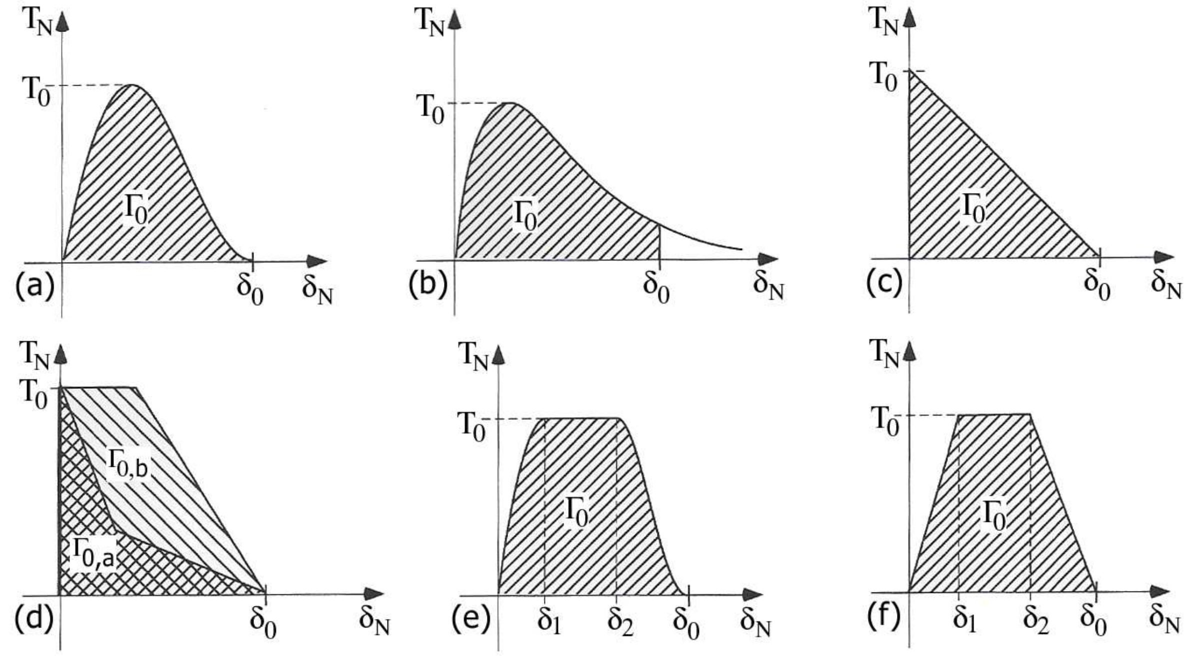

Figure 2: Various cohesive laws used by several authors /2/

The exponential model (b) is used by many authors as to ductile rupture so to cleavage fracture. An exponential relationship between the effective traction (δ) provides a decohesion model. The T-δ response follows an irreversible path with unloading always direct to origin. This model represents all the features of the separation process by: (1) the shape of the cohesive traction/separation curve (T-δ), (2) the local material strength by the peak traction (σ_c), and, the local ductility defined by the work of separation (Γ_c) given by the area under (T-δ) curve.

4 Cohesive model parameters determination

For the determination of the cohesive stress, T_o in the case of normal fracture a hybrid technique has been developed. Using conventional elastic-plastic analysis, the distribution of the axial stress across the notch section of the specimen geometry is determined for the instant of the crack initiation in the centre of specimen. At that event, the axial stress exhibits a maximum in the centre of specimen, which is supposed to be equal to T_o.

The cohesive energy, Γ_o can be determined in a fracture mechanics test by assuming that Γ_o equals the J-integral at initiation of stable crack extension, J_i. The procedure can be taken from the standard test methods /2/. The stretch zone width at initiation is determined on the least three specimens exhibiting ductile tearing beyond the 0.2 mm offset line. The intersection point of the average SZW_i and J-Δa curve defines J_i.

On the following Figure 3 can be seen the distribution of the axial stress in the tensile notch specimen. The result values were determined as the average values from set of ten tested specimens.

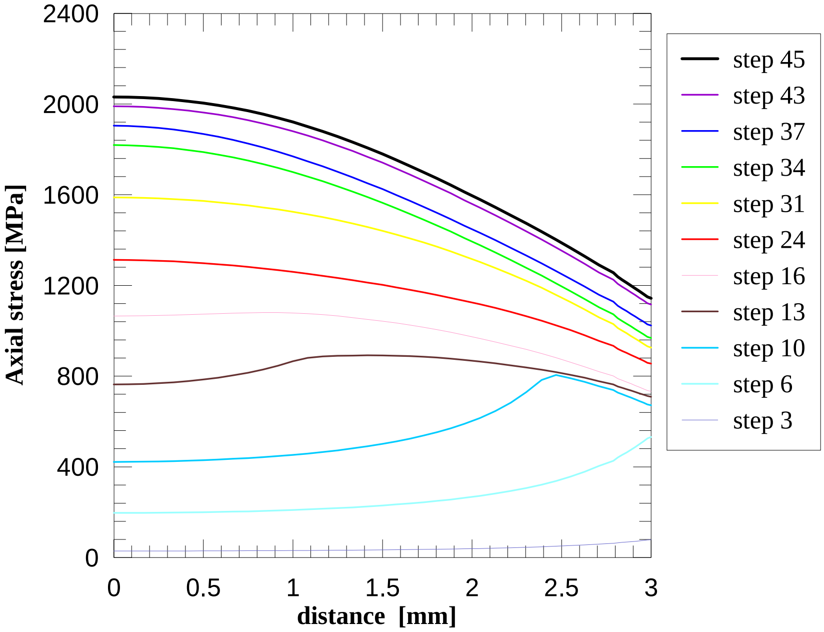

Figure 3: Axial stress distribution in the notch tensile specimen

The averaged value determined from all sets is T_o= 2000 MPa.

The standard CT specimens were used for J-integral determination according the ASTM 1820-99a procedure.

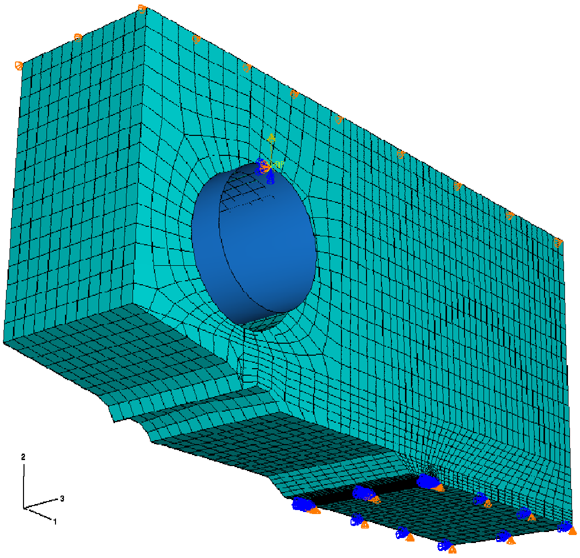

Figure 4: FE mesh for CT specimen

The experimentally determined value of J_i was found to be J_i =115 +- 5 MPa.mm and this value was calibrated using numerical procedure in WARP3D. The shape of the traction-separation can be seen in Figure 5.

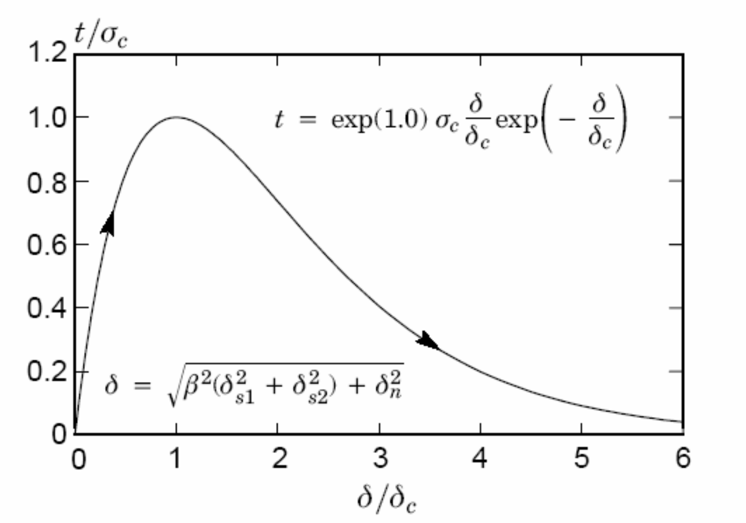

Figure 5: Traction-separation law for ductile rupture

The calibration process was applied on three combination values T_o and J_i marked cohe_1, cohe_2, cohe_3, see Tab. 1 and Figure 6.

	T_0 [MPa]	J_i [Mpa.mm]	$\delta_0/2$ [mm]
Cohe_1	2000	110	0,0101
Cohe_2	2000	120	0,011
Cohe_3	2000	130	0,012

Table 1: The tested input data

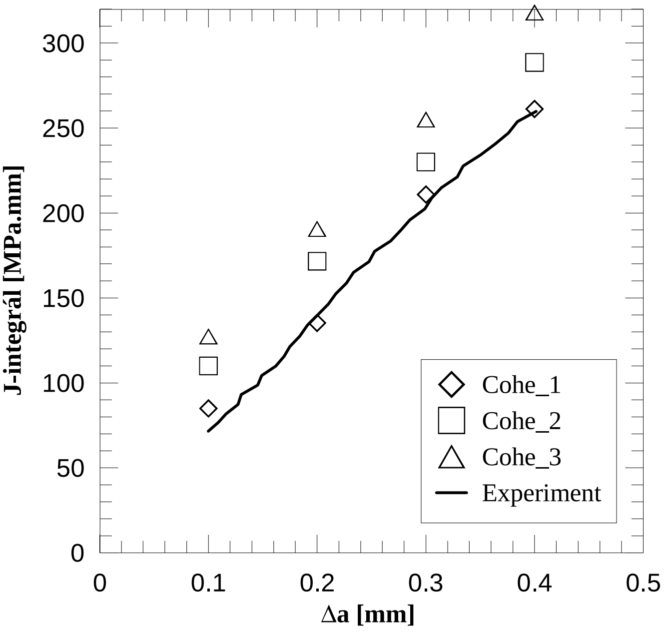

Figure 6: J-R curve in the initial phase of the crack propagation

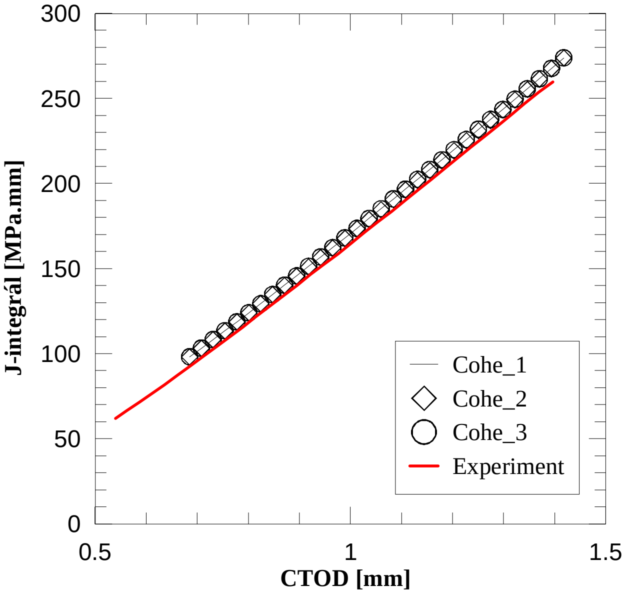

Figure 7: J-CTOD curve in the initial phase of the crack propagation

For simulation at given material curve the cohesive parameters seem to be:

T_o=2000 MPa
J_i=110 MPa.mm

5 J-R curve prediction

The experimental results of the SE(B) specimens were available in the form of the J-Δa diagram. Numerical modelling found strong dependence on the mesh size, especially on the mesh size in the direction in the thickness of the body. There is no information in literature about recommendation, only notice saying this can be a key problem of modelling. Therefore more than 15 FE meshes were tested. The mesh used for modelling is in the Figure 8.

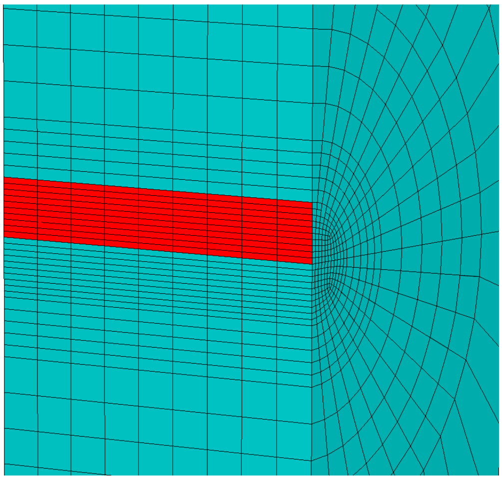

Figure 8: The detail of the crack tip

The characteristic mesh size of the cohesive element was then 0.2 x 1.4 x 0 mm. The dependence of the J integral on the increment of the crack is illustrated in the Figure 10. Some material curves received by the standard material tests for the same material show necessity of the diligent approach and accurate methods for the material curve determination. The best coincidence with the experimental data was in case of the material curve obtained from the tensile specimens and modified by Mirone /6/.

6 Summary

A procedure has been tested for application to the assessment of engineering structures. This procedure consists of a specific traction-separation law of the cohesive model and methods for determining of the material parameters. The traction-separation law is characterized by the constant cohesive stress, T_o which is preceded by a steep slope and by the cohesive energy, Γ_o which also characterizes the material properties in the process zone.

- The shape of the *J-Δa* curve and therefore the observed crack propagation modelling is strongly controlled by the material curve (equivalent stress – equivalent strain curve). The precise determination of the material curve is a key point of the correct modelling and application of the cohesive elements.
- The strong dependence of the convergence and a numerical stability on the mesh size was found.

The present applications of cohesive models are still far away from practical engineering employment in structural integrity assessments. There is a strong need to standardize the simulation techniques and determination of the model parameters. Enhanced computational equipment is required, e. g. parallel processing for large number of elements and nodes necessary for advanced investigation of micro- and macrostructures. New experimental test methods are required for especially for determining micro structural properties and for the calibration of numerical analysis.

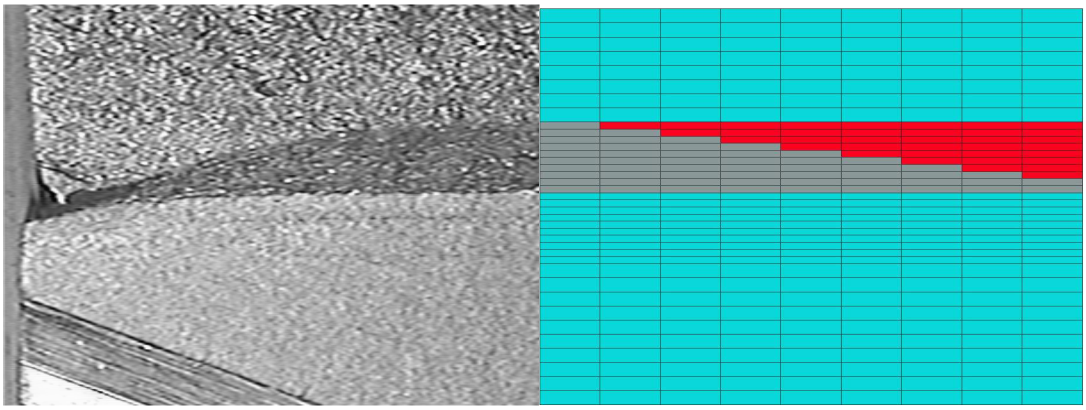

Figure 9: The reconstruction of the crack path

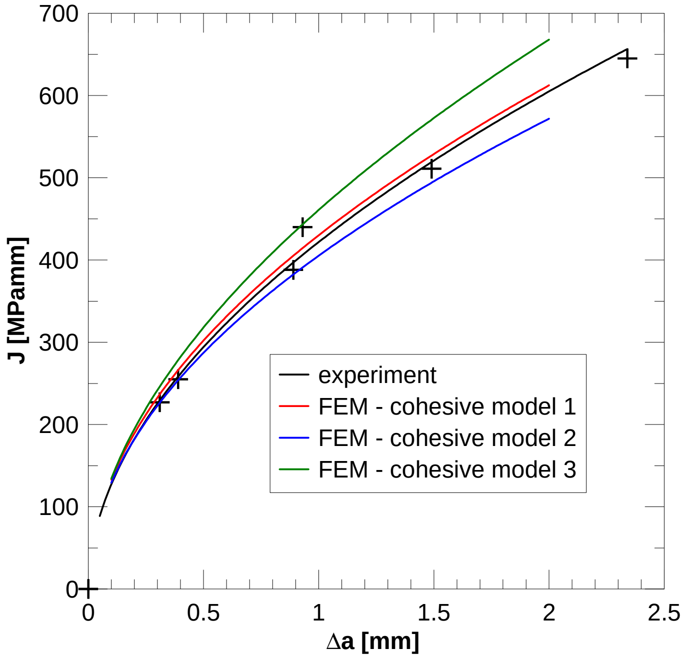

Figure 10: J-R curve prediction

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