International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

Aluminum Plate Fracture Analysis using CZM

Vikas K. Tope[1], Dr. K. K. Dhande[2]

[1]P. G. Student, Dr. D. Y. Patil Institute of Technology, Pimpri, Savitribai Phule Pune University, Pune

[2]Professor, Dr. D. Y. Patil Institute of Technology, Pimpri, Savitribai Phule Pune University, Pune

Abstract: ***The main objective of this paper is to model fracture in aluminum specimen using cohesive elements. To find out the parameters for modeling fracture, a tensile test is carried out and further the parameters are calibrated using F.E simulations. The calibrated parameters are then used in F.E simulation to correlate with the experimental mixed mode fracture test.***

Keywords: cohesive elements, cohesive zone, cohesive zone modelling, fracture, ductile fracture, mixed mode fracture

1. Introduction

The presence of a crack can significantly reduce the life of a component or structure. It becomes absolutely imperative to understand the process of fracture to understand the behaviour of metals. Cracks can form due to fatigue, or they can exist as a consequence of manufacturing processes such as deep machining marks or voids in welds and metallurgical discontinuities such as foreign particle inclusions. Fracture mechanics has been used heavily in the aerospace, nuclear and ship industries with a recent extension to the ground vehicle industry.

Under severe impact events in automobile crash events, parts undergo fracture and fail. Traditional techniques like Linear Elastic Fracture Mechanics (LEFM), Elastic Plastic Fracture Mechanics (EPFM) suffer from the disadvantage that only structures with an initial crack can be modelled. In addition, these techniques are single parameter dependent which is stress intensity factor, K. The stress intensity parameter K is a function of boundary conditions and the crack shape. This single-parameter treatment is accurate under very limited conditions of yielding and a state of two-dimensional plane strain only. Thus, the test conditions may or may not match the actual conditions. [2]

In the framework of fracture mechanics, cracked bodies are basically treated in a two dimensional manner, notwithstanding the fact, that frequently three-dimensional finite element analyses of test pieces and structural components are performed. The problem is that a fracture mechanics material property, either in terms of a single-valued parameter, commonly known as fracture toughness, or a relationship between the crack extension resistance and the amount of crack extension, is determined under circumstances describing the near-tip stress and strain fields under limiting conditions. These conditions are usually plane strain, more recently plane stress conditions have also been considered to account for the requirements of light-weight structures which are usually characterized by thin walled design. However, the conditions a structural component is under arefrequently unknown and can substantially deviate from the test conditions for the determination of the fracture properties to be used for the assessment of the component. This problem is known as the transferability problem in classical fracture mechanics. [3]

The cohesive models do not depend on a specific failure mechanism and can therefore be used for arbitrary damage. However, the evolution law may indeed be applicable to a specific class of materials only. Within the group a further distinction can be made by the way of implementation: Models which have a damage law embedded in the continuum formulation are called continuum damage models, whereas the cohesive models do not describe material deformation but only separation. Only cohesive models are considered for the modelling of damage and failure of materials and structure.

The cohesive model employs a material model which is represented by a traction separation law describing the loss of load bearing capacity of the material as a function of a separation, irrespective of the physical details of damage occurring in an actual material. Hence, it can be applied to both ductile and brittle damage and failure processes.A length parameter is already included in the model, the critical separation δ_0.A draw back of the cohesive model is that the crack path has to be pre-defined. Of numerical damage models, the phenomenological cohesive model is the most user friendly one. Among other items, numerical robustness, the mesh insensitivity and the need of only two parameters make the cohesive model a suitable candidate for practical application. [3]

2. Literature Survey

Lot of work has been done in the field of cohesive zone modelling for modelling fracture in ductile materials.

Cornec, Shwalbe, Scheider[2][3] have laid down a handbook for modelling ductile fracture using cohesive elements based mainly on the experience at GKSS. Methods are described for the determination of the cohesive parameters, using a hybrid experimental/numerical approach.

Barenblatt[5] first proposed the idea of cohesive zone modelling in the year 1962.

Scheider et al.[6] investigated the problem of crack-path deviation by means of simulation of crack propagation in a round tensile bar.Cup-cone fracture phenomenon was captured in F.E model.

Anvari et al. [7] validated the application of rate-dependent cohesive elements in the simulation of ductile fracture in aluminum round bars under dynamic loading conditions. The effects of element size, rate-dependent plasticity of the material and stress triaxiality are also discussed.

Banerjee[8]**et al.** has carried out study to incorporate the stress triaxiality into cohesive zone models applicable to thin walled structures. The number of model parameters involved, the ease of parameter determination and the predictive capabilities of the models over a wide rangeof thin-walled geometries were investigated.

Elices[9]et al. has revieved the cohesive process zone model which can deal with the non-linear zone ahead of the crack tip due to plasticity or micro-cracking. The cohesive model is shown to provide good predictions for concrete and for different notched samples of a glassy polymer.

Chen[10] et al. has determined the cohesive zone parameters namely separation energy and cohesive strength for the 3D finite element modelling of the micro – ductile crack growth in thick, smooth sided CT specimens made of low strength steel.

3. Theory

A. Fracture in Ductile Metals.

Ductile Fracture includes three stages: void nucleation, growth and coalescence. It often occurs shortly after the onset of local necking, and relates to the formation of micro-voids which grow and eventually coalesce as the material is strained. Some of the energy from stress concentrations at the crack tips is dissipated by plastic deformation before the crack actually propagates. The crack moves slowly and is accompanied by a large amount of plastic deformation. The crack typically will not grow unless the applied load is increased. Ductile fracture surfaces have larger necking regions and an overall rougher appearance than brittle fracture surfaces.

B. Cohesive Zone Modeling

CZMs are able to describe materials that exhibit strain-softening type behaviour. The basic assumption underlying them is the formation of a fictitious crack, as an extension of the real crack, referred to also as the process zone, where the material is still able to transfer stresses, although it is damaged. The crack is assumed to propagate when the stress at the crack tip reaches the cohesive strength. When the crack opens, the stress is not assumed to fall to zero at once but to decrease gently with increasing crack width until a critical displacement is reached and the interaction vanishes.

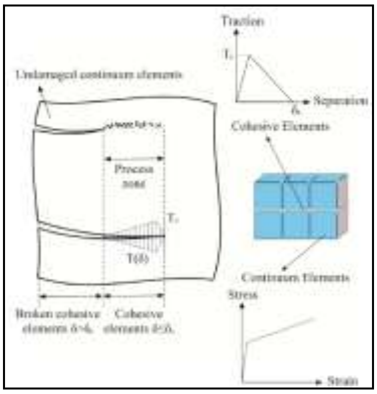

Figure 1: Process zone in cohesive crack model [4]

Within the framework of cohesive modelling and finite elements, contrary to computational crack propagation analyses using fracture criteria, no continuum elements are damaged in the cohesive model. The zone in which damage occurs is reduced to a layer with zero thickness. The cohesive elements, in this layer, model the material separation; the surrounding continuum elements are damage-free. Cohesive interface elements are sandwiched between the continuum elements, which open when damage occurs and lose their stiffness at failure so that the continuum elements are disconnected. For this reason the crack can propagate only along the element boundaries. If the crack propagation direction is not known in advance, the mesh generation has to make different crack paths possible by embedding cohesive elements.

The basic idea of the CZM, shown in Figure 1, is to split the material's behavior in deformation, which is modeled by continuum elements, and damage or separation, which is modeled by embedded interface elements within continuum elements. Ductile fracture process, consisting of initiation, growth, and coalescence of voids, is represented by a Traction–Separation Law (TSL), simulating the deformation and finally the separation of the material in the immediate vicinity of the crack tip. In the cohesive elements, the opening stress is controlled by a traction separation law. The separation, δ, can occur in normal or tangential direction, which happen respectively in mode I and mode II/III fracture. The stresses, T, can also act in normal or in tangential direction. Interface elements representing the damage are implemented between the continuum elements representing the elastic–plastic properties of the material.

C. Cohesive Zone Modeling Parameters

The parameters needed to model the cohesive zone law are maximum traction (T_0), maximum separation (δ_0) and cohesive energy (J). The explanations for them are as given below.

a) Maximum traction (T_0): It is the maximum strength of the material also called as ultimate strength of material.
b) Maximum Separation (δ_0): It is the separation where the element fails.
c) Cohesive energy (J): It is the area under the TSL curve and is the energy absorbed by the cohesive element. J-integral at crack initiation can be a good approximate for the cohesive energy.

Typical traction separation law is as shown in figure 2.

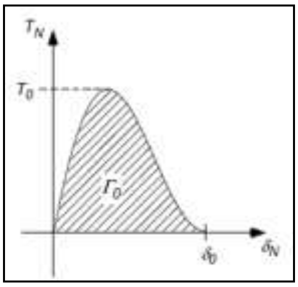

Figure 2: Traction Separation Law

4. Methodology

The different tasks performed in this study are shownschematically in below diagram (Figure 3).

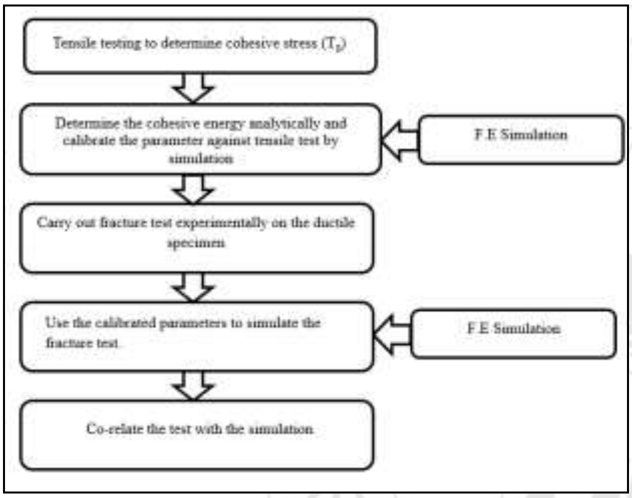

Figure 3: Methodology

5. Tension Test

Tensile testing is done to find out the maximum traction and cohesive energy. Initial value of cohesive energy is estimated by J-integral value at 0.2mm of crack extension.[2]. This value of cohesive energy and maximum traction is calibrated by carrying out F.E simulations.
$J_i = J_{0.2} = 3.75 * S_{ut} * \Delta a$
where,
S_{ut}= ultimate tensile strength.
Δa = crack extension = 0.2mm

A sheet type 12.5mm wide aluminum specimen was used for tensile testing.The specimen is machined according to ASTM E8 standard procedure and is of I.S. 19000 grade. The dimensions of the specimen are as shown in Figure 4.

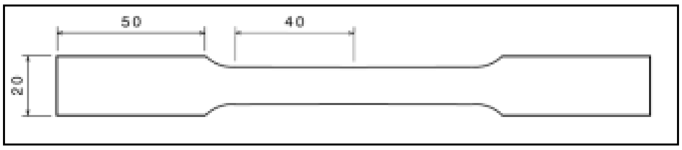

Figure 4: Tensile test specimen (All dimensions in mm)

The test results are as shown in Figure 5 and tested specimen is shown in Figure 6

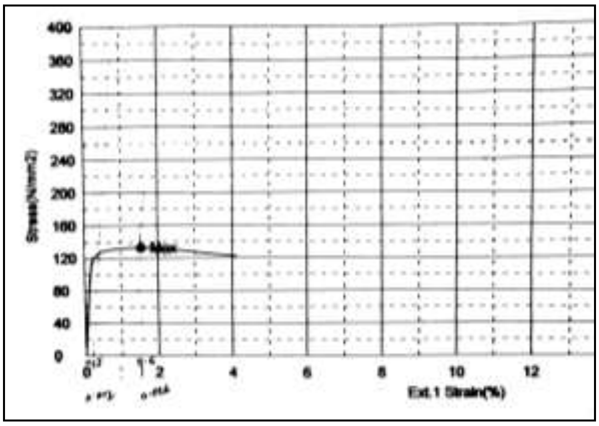

Figure 5: Stress strain curve of tensile specimen

From test results, S_{ut}= 132 MPa and S_y =125 MPa

Maximum traction (T_0) = 132 MPa
J_i = 3.75 * 132 * 0.2 = 99 N-mm
Both the above values are further calibrated.

Figure 6: Fractured aluminum specimen

6. F.E Simulation of Tension Test

Cohesive elements were embedded into continuum C3D8I elements in the centre of F.E model as shown below in figure 7. Cohesive elements selected were of type COH3D8 which are 8 node three dimensional cohesive element.

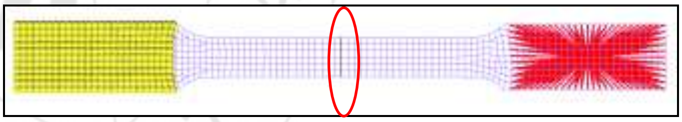

Figure 7: FE Model of tensile test specimen

Engineering stress-strain data was converted to true stress-plastic strain data for simulation in ABAQUS. Nodes highlighted are constrained in all dof's and load is applied through a rigid element on the opposite side.A damage initiation criteria based on maximum stress reached was used in the cohesive model. The stress level was set to the maximum stress to be reached in the model. Once, the stress is reached damage starts occurring in the cohesive elements. The stiffness of cohesive elements was set to the young's modulus of aluminum which is taken as 60000 MPa in x,y and z directions. The results of calibration exercise conducted are shown in figure 8.

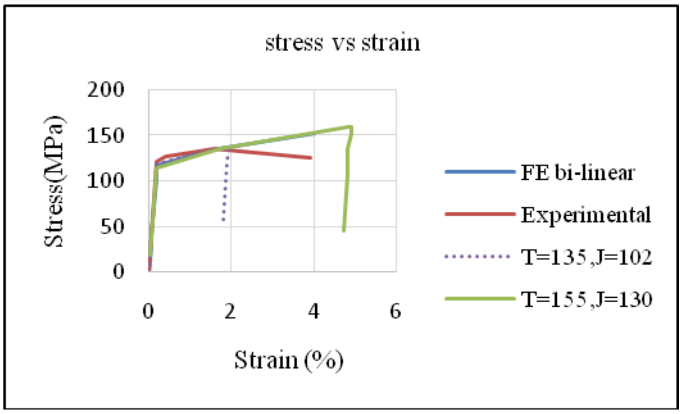

Figure 8: Stress strain graph for different values of T&J

A bilinear material model is taken for modelling continuum elements as fully plastic model does not yield required values of strain for given value of load in F.E simulations. As a result, a slightly higher value of T is chosen so as to give required value of displacement during fracture test. From the calibration exercise, values of T=155 and J = 130 are finalized. Figure 9 shows the F.E plot of tension test just after fracture.

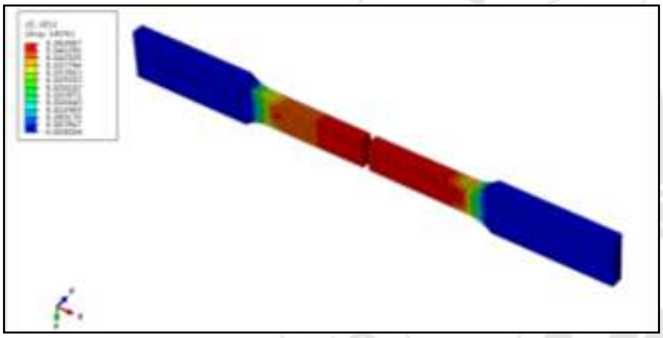

Figure 9: F.E plot of tension test just after fracture.

7. Mixed Mode Fracture Test

A mixed mode fracture test is conducted on universal testing machine. Fixture and test specimen are as shown in below diagram.

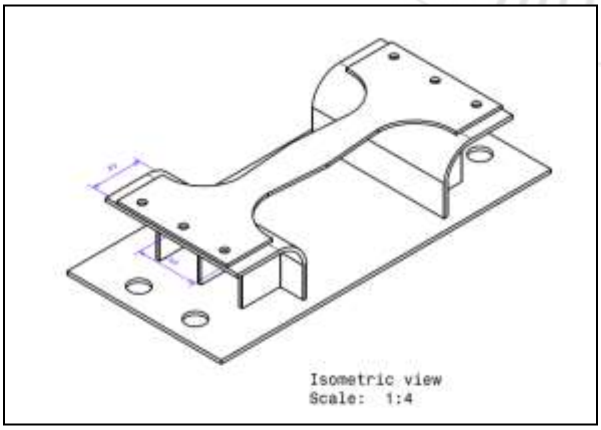

Figure 10: Mixed mode fracture test set-up

Fracture test specimen chosen is of same grade as the test specimen. It is 200mm wide, 500mm in length and 5mm thick. It is 66mm wide at the centre and 50mm wide at the fillets.

Load is applied through a bending pin on to the plate and the load vs vertical deflection of plate is noted. Figure 11 shows the fracture in the specimen happening at a distance of 155mm from the ends

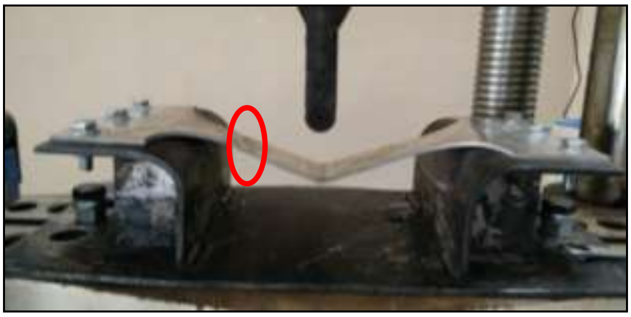

Figure 11: Mixed mode fracture test.

8. F.E Simulation of Fracture Test

Figure 12 shows the F.E setup for fracture test. Highlighted nodes are constrained in translational dof's. Displacement is applied through a rigid indentor in vertical direction. Tie contact is given between the specimen and support. The reaction force and the displacement of the reference node is noted down to correlate with the stress test. Cohesive elements are embedded between the continuum elements as shown in figure 13.

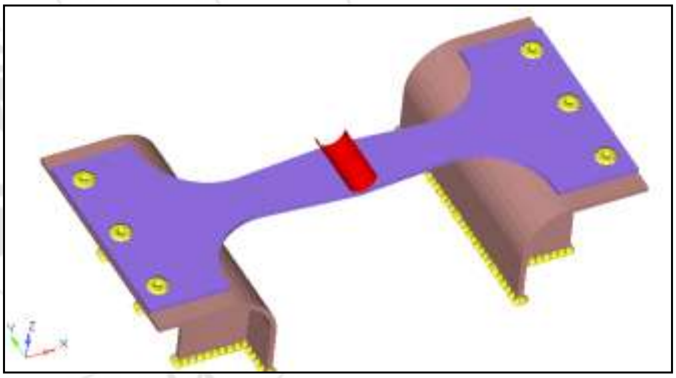

Figure 12: F.E test set up of fracture test.

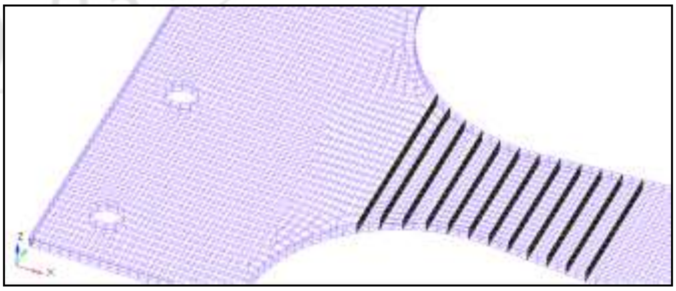

Figure 13: Embedded cohesive elements.

Figure 14 shows fracture in the F.E specimen happening at 145mm from the ends.

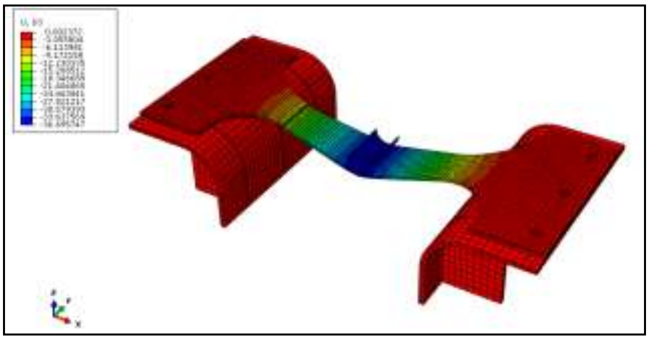

Figure 14: F.E simulation of fracture test

9. Results

Correlation between experimental and simulation is done on the basis of two parameters:
1) Location of crack
2) Load vs deflection curve

Location of crack from the end	Experiment	F.E Simulation
	155 mm	145 mm

Figure 15 shows the correlation plot between F.E and test. The difference between the slopes is attributed to the bi-linear nature of material model employed in F.E model while in reality aluminum more or less approximates to elastic fully plastic in nature.

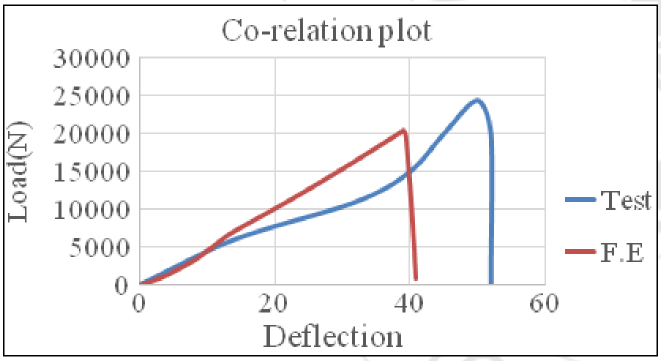

Figure 15: Load deflection curve of test vs F.E results

10. Conclusion

Cohesive zone modelling is a phenomenological method, which implies it can be applied to various materials and separation phenomena.

The presence of a crack is not mandatory for CZM.

The material model of continuum elements play important role in modelling the behavior. Materials exhibiting pronounced work hardening before fracture can be better modelled using cohesive elements.

Crack path need to be defined in F.E model to simulate fracture and separation phenomena.

11. Scope for Future Work

Effect of different traction separation laws can be investigated.

Crack propagation can be studied in irregular mesh pattern.

Study the effect of various parameters such as stress triaxiality and strain rate on cohesive zone modelling.

References

[1] Ralph I. Stephens, Ali Fatemi, Robert R. Stephens, Henry O. Fuchs "Metal fatigue in Engineering", 2nd ed., Wiley Inter-Science, pp.123-124
[2] A.Cornec, Ingo Scheider, Karl-Heinz Schwalbe "On the practical application of the cohesive model", Journal of Engineering Fracture Mechanics, Sept.2003, 70, 14, pp.1963-1987
[3] A.Cornec, Ingo Scheider, Karl-Heinz Schwalbe "The SIAM method for applying cohesive models to the damage behaviour of engineering materials and structures", GKSS, 2009
[4] Tayyebe Seif "Ductile fracture analysis in a steel plate by cohesive zonemodelling"
[5] G.I.Barenblatt "The Mathematical theory of equilibrium cracks in Brittle Fracture", Advances in Applied Mechanics, 1962, 7, pp.55-129
[6] I.Scheider , W. Brocks "Simulation of cup–cone fracture using the cohesive model", Journal of Engineering Fracture Mechanics, 2003, 70, pp.1943- 1961
[7] Majid Anvari, I.Schedier, Christian Thaulow "Simulation of dynamic ductile crack growth using strain-rate and triaxiality-dependent cohesive elements", Journal of Engineering Fracture Mechanics, 2006, 73, pp.2210-2228
[8] Ingo Scheider, M.Rajendran, Anuradha Banerjee "Comparison of different stress-state dependent cohesive zone models applied to thin-walled structures", Journal of Engineering Fracture Mechanics, 2011, 78, pp.534-543
[9] M.Elices, G.Guinea, J. Gomez, J.Planas "The cohesive zone model: advantages, limitations and challenges", Journal of Engineering Fracture Mechanics, 2002, 169, pp.137-163
[10] C.R.Chen, O.Kolednik, I.Scheider, T.Siegmund, A.Tatschl, F.D.Fischer "On the determination of the cohesive zone parameters for the modelling of micro-ductile crack growth in thick specimens", International Journal of Fracture, Apr2003, 120(3), pp.517-536