MODELLING BOND FAILURE WITH CZM: ANALYSIS OF A DCB TEST

ASSEMBLY AND BONDING

TFMASA Course

Under

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1. INTRODUCTION

Carbon epoxy laminates are commonly used composite materials in engineering and aerospace applications in which there is a wide range of exploration of mechanically coupled with cohesive zone modelling. Double Cantilever Beam (DCB) testing is the standard test strategy for deciding mode I fracture durability for composites or adhesively reinforced joints. The Cohesive Zone Model (CZM) is a phenomenological model in fracture mechanics in which fracture formation is regarded as a gradual phenomenon in which separation of the surfaces involved in the crack takes place across an extended crack tip, or cohesive zone, and is resisted by cohesive tractions. The current CZM of the plate is Mode I fracture is analysed with specifying interlaminar and intralaminar properties for the laminate. Furthermore, the sensitivity analysis based on variation of damage initiation and damage evolution are performed.

2. OBJECTIVES

The objectives of the research are:

- Behaviour of force vs displacement for surface based CZM for composite plate.
- Sensitivity analysis based on the analysis of damage initiation criterion and damage evolution law.

3. MODELLING

3.1 DESIGN

A composite plate is designed with the dimensions specified in the Fig. 1. It has been designed for 3D deformable shell element with extrusion. The dimensions represent the breadth and length of 30 mm and 150 mm respectively. The extrusion is given of 8 mm which is the thickness. A partition is of 10 mm and 50 mm is created as initial crack length of 50 mm has been used.

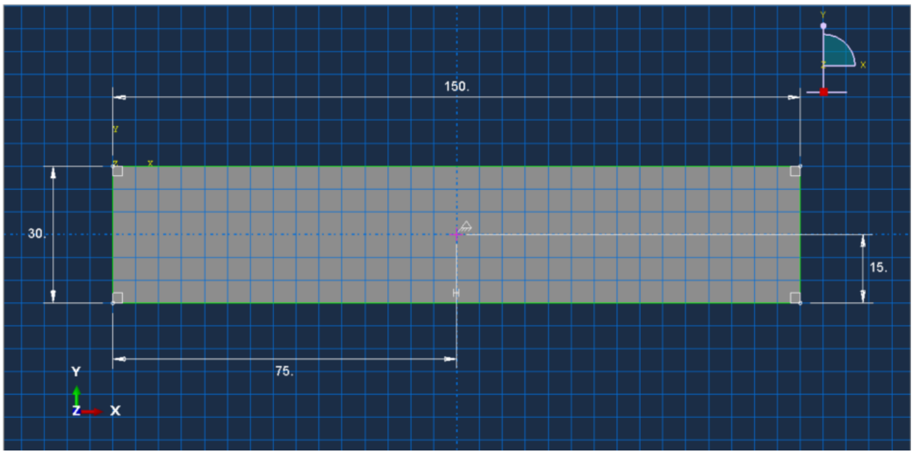

Fig. 1 Composite plate sketch

3.2 MATERIAL

The material used in composite is carbon/epoxy T300/M21 which has the following elastic properties which is pre-defined lamina in nature as mentioned in table 1. It is a composite plate with the laminate stacking as $(0, 45, -45, 90)_{4S}$. And there are 32 plies which means that thickness of each laminate stack is 0.25.

Table 1: Elastic Properties of Lamina for composite

E1	E2	Nu12	G12	G13	G23
170 GPa	9 GPa	0.34	4.8 GPa	4.8 GPa	4.8 GPa

3.3 MESH

The composite plate has been meshed keeping global size as 4, element type as SC8R which is a 8-node quadrilateral in-plane general-purpose continuum shell, reduced integration with hourglass control, finite membrane strains and mesh shape is rectangular.

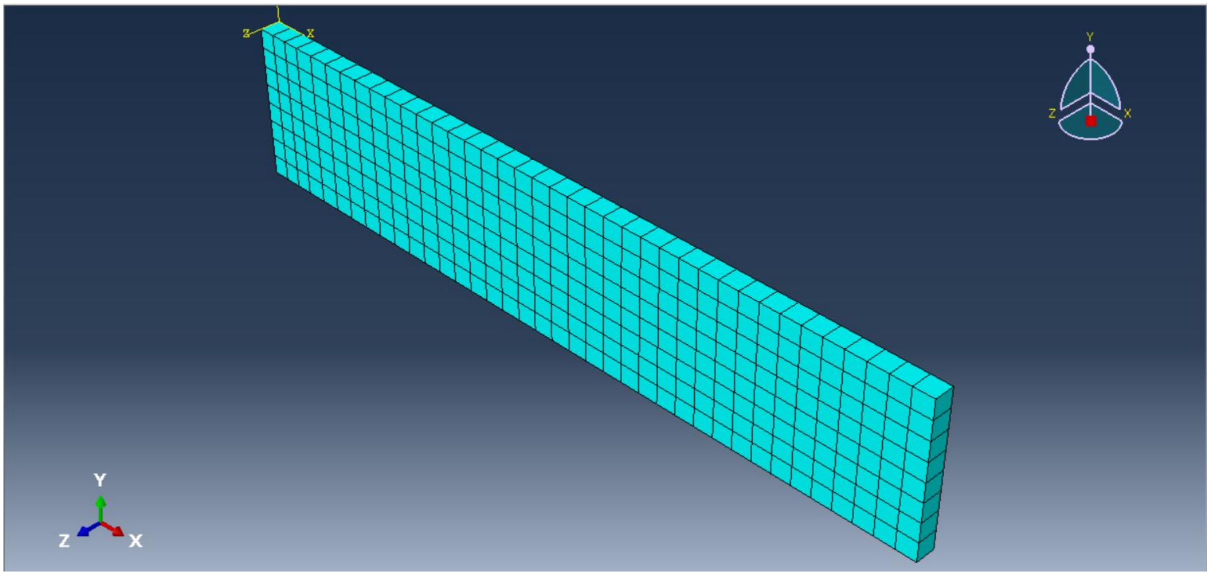

Fig. 2: Composite plate mesh

3.4 ASSEMBLY

The model has to be assembled by keeping both parts together at one plane and aligning them together. Fig. 3 represents the assembly of the model.

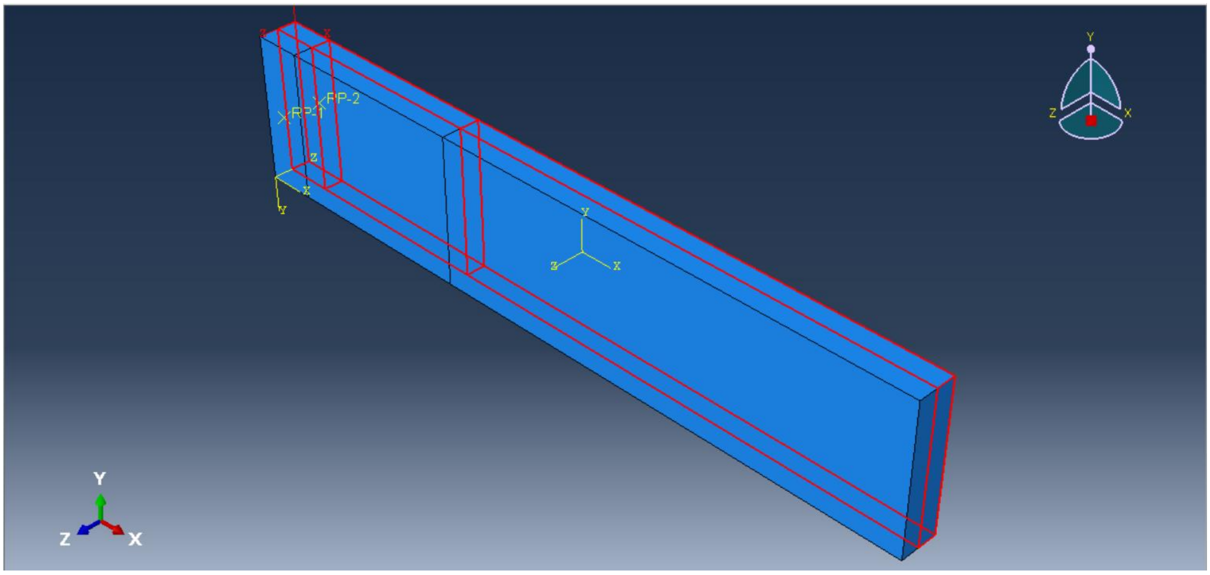

Fig. 3: Composite plate Assembly

Reference points are created along with datum of xyz axis on the surface centre between the crack length of 0mm to 50mm. The reference points are crated on both the faces of the model hence creating 2 points where forces can be applied and also assigned as a set.

3.5 INTERACTIONS & CONSTRAINTS

The step where the test gives good results is the phase of interaction. The model has been given interaction between the plates from 50 mm to end of the plate which allows it to fix them together. The interaction has properties of cohesive behaviour and damage behaviour. The cohesive behaviour has properties for K_{nn}, K_{ss} and K_{tt} as 1×10^6.

The material damage behaviour in initiation has normal only stress as 42 MPa and Shear-1 & Shear-2 only stress as 67 MPa. In evolution for energy type and linear softening with mixed mode behaviour for Benzeggagh-Kenane with BK exponent as 2.1 is applied. The fracture energy provided in normal fracture energy is given as 0.9 J and 1st and 2nd shear fracture energy as 2.4 J. The stabilization has a viscosity co-efficient of 0.0001 specified. In case 1 we need to keep initiation as mentioned but in case 2 we change the shear 1 and shear 2 only stress as 30, 60 and 90 MPa respectively for linear and exponential softening with mixed mode behaviour as off.

The model has been given 2 constraints with the reference points to the surface of the plate as a coupling which has been restrained in U1, U2, U3, UR1, UR2 and UR3 directions which is kinematic in nature.

3.6 BOUNDARY CONDITIONS & LOADS

The composite plate has been given 2 boundary conditions on the both the reference points respectively with movement restriction in all directions except UR2 as a displacement has been applied of 5 mm on both sides as loads.

3.7 FIELD OUTPUT REQUESTS

The results obtained need to be filtered out to provide results close to the operations made and field of interest for the study of the composite plate. Hence in field output request we add stress, deformation, forces, strain and contact which are needed to be known.

4. RESULTS

4.1 SURFACE BASED CZM (3A)

The modelling of composite ply in FE simulation has been done with linear elastic with giving engineering constants. This approach is used to simulate interface failure modelling of cohesive layer between two sections of the model. The initial model where the traction shear force is considered as 67 MPa as shear component and 42 MPa as normal, the von mises equivalent stress is obtained as 810 MPa as in Fig. 4 with displacement of 5mm on each side of the plate. The maximum displacement shown in the contour Fig. 5 is 5.537mm of the reference point defined on the outer side of the plate. The graph for intial study shows saw-tooth like behaviour for force displacement curve as shown in Fig. 6.

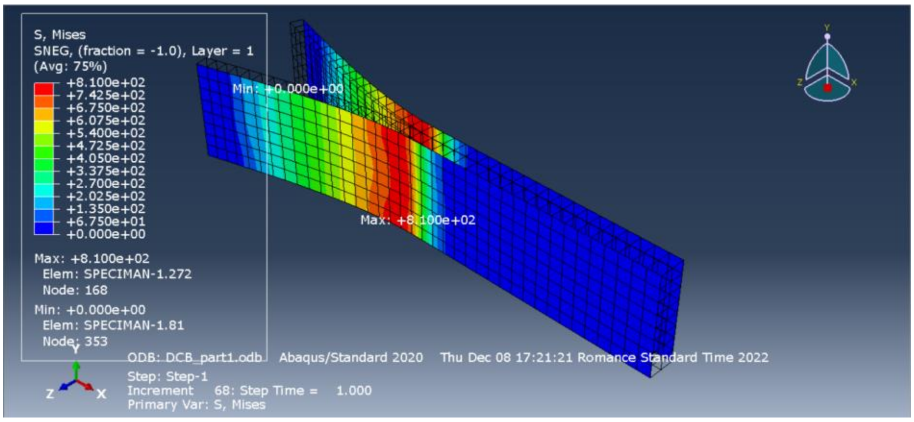

Fig. 4: Von mises stress in the DCB specimen

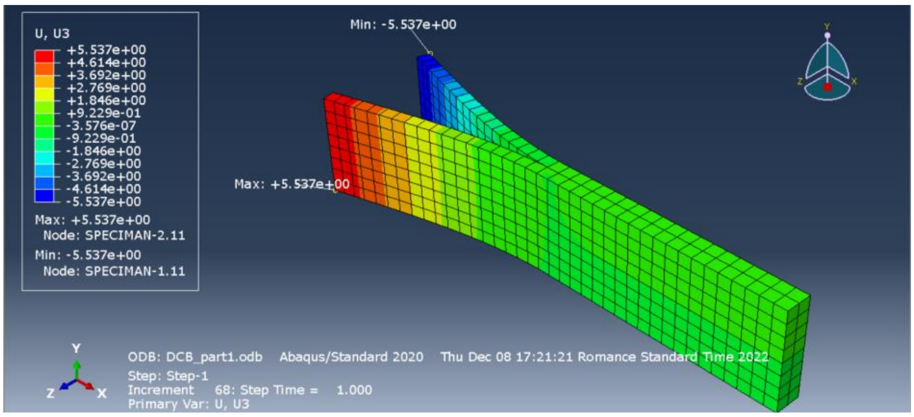

Fig. 5: Maximum displacement in the DCB specimen

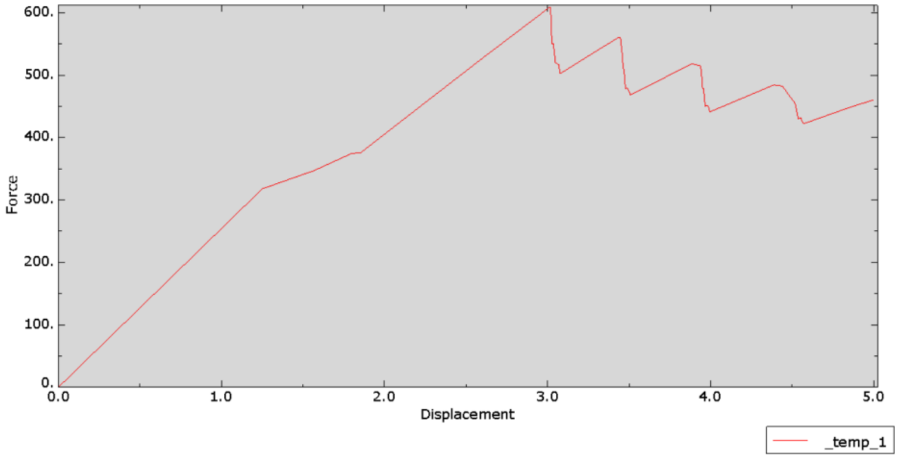

Fig. 6: Force vs displacement in the DCB specimen

4.2 SENSITIVITY ANALYSIS (4D)

The analysis is done based on effect of damage initiation criterion and damage evolution law on global response of the system i.e., force/displacement curve. The modelling done considering Linear softening with application of 3 maximum tractions values in shear directions ranging from 30 MPa to 90 MPa. The Maximum nominal stress criterion is used to model the calculations of damage initiation. Furthermore, using the same set of traction values as 3 cases and changing damage evolution law from linear to exponential softening the comparative analysis is performed.

The mises stress and displacement values obtained are tabulated in table 2.

Table 2: Stress and Displacement results for linear and exponential softening

Linear Softening		
Case	Von Mises stress (MPa)	Max. Displacement (mm)
Maximum traction: 30 MPa	810.4	5.537
Maximum traction: 60 MPa	769.6	5.514
Maximum traction: 90 MPa	816.8	5.530
Exponential Softening		
Case	Von Mises stress (MPa)	Max. Displacement (mm)
Maximum traction: 30 MPa	1511	5.752
Maximum traction: 60 MPa	1511	5.752

Maximum traction: 90 MPa	1511	5.752

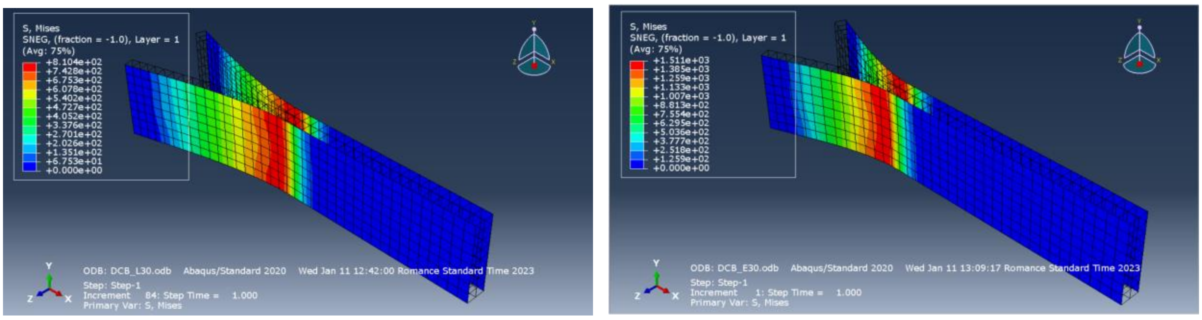

Fig. 7: Von mises stress for 30 MPa traction (a) Linear softening (b) Exponential softening

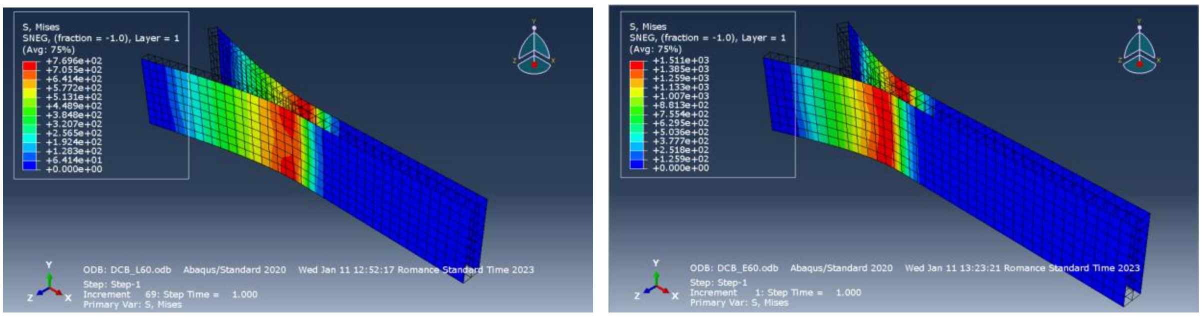

Fig. 8: Von mises stress for 60 MPa traction (a) Linear softening (b) Exponential softening

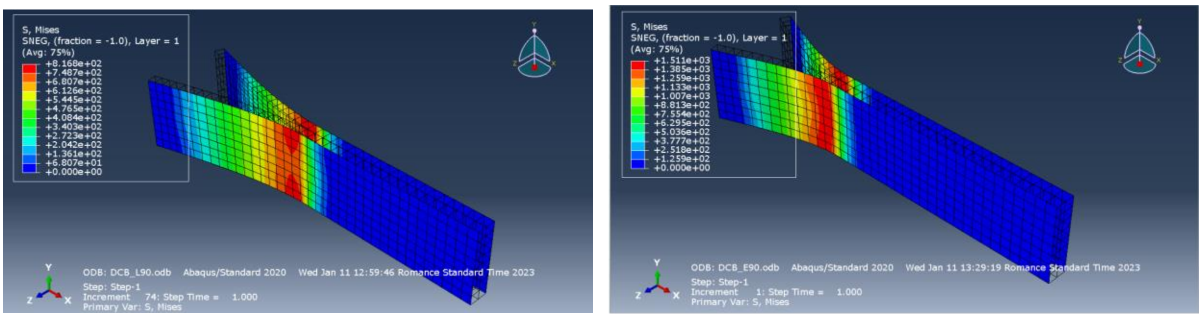

Fig. 9: Von mises stress for 90 MPa traction (a) Linear softening (b) Exponential softening

So as can be seen for linear softening the variation in displacement (Fig. 10 to 12) is almost insignificant when traction is changed for damage initiation but there is significant change in von mises stress with maximum stress value of 816.8 MPa obtained for 90 MPa nominal traction value.

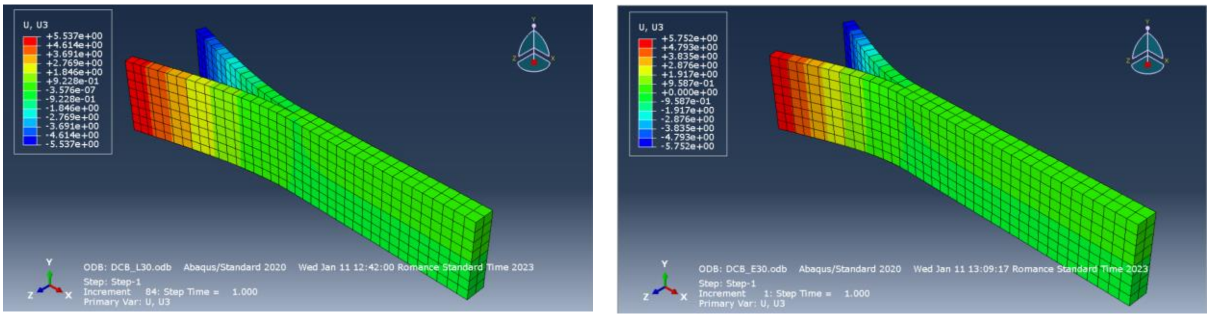

Fig. 10: Maximum displacement for 30 MPa traction (a) Linear softening (b) Exponential softening

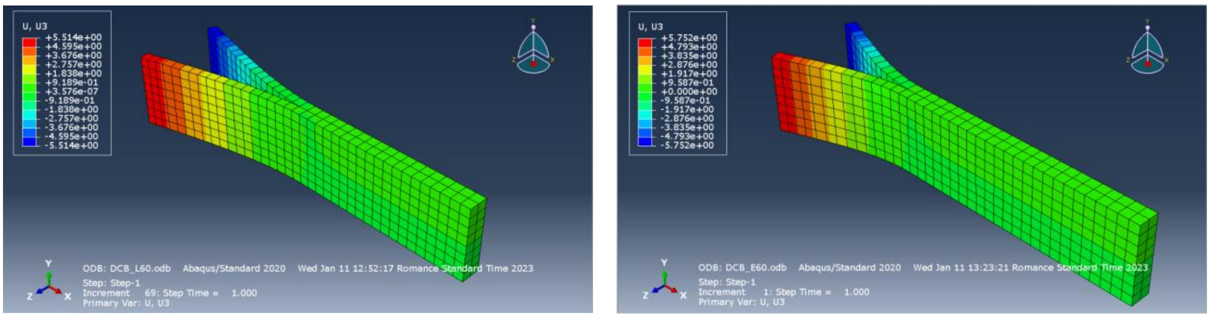

Fig. 11: Maximum displacement for 60 MPa traction (a) Linear softening (b) Exponential softening

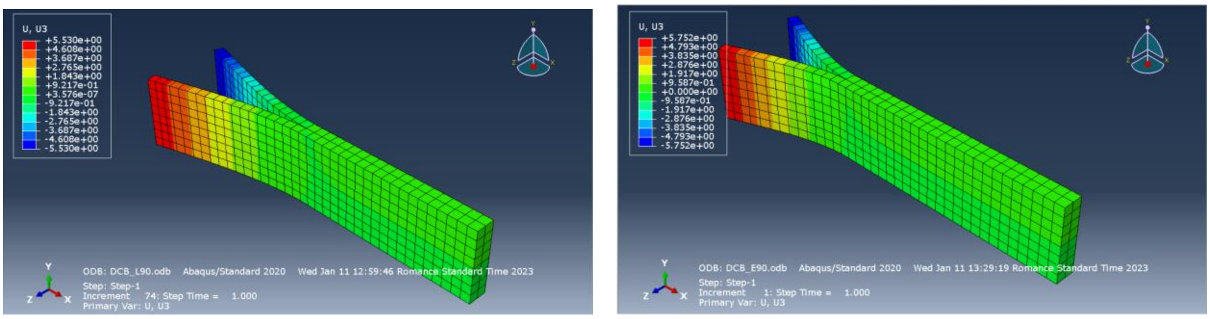

Fig. 12: Maximum displacement for 90 MPa traction (a) Linear softening (b) Exponential softening

In the case of exponential hardening the for all the values of nominal tractions the maximum von mises stress at the crack opening region is comparatively high with value of 1511 MPa as compared with linear hardening cases. The max displacement variation is almost same as the given displacement is same for all the cases.

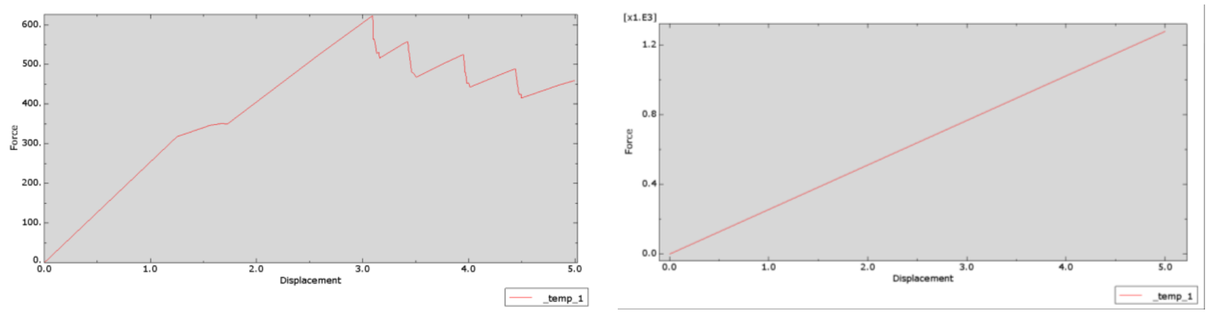

Fig. 13: Force vs displacement for 30 MPa traction (a) Linear softening (b) Exponential softening

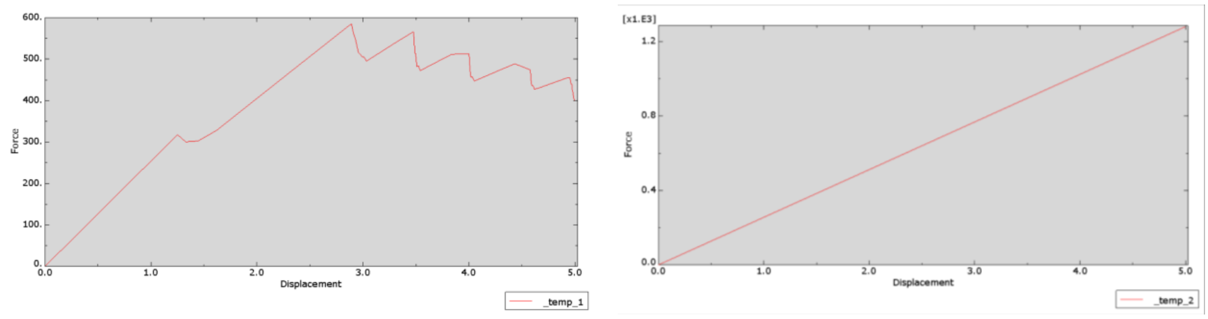

Fig. 14: Force vs displacement for 60 MPa traction (a) Linear softening (b) Exponential softening

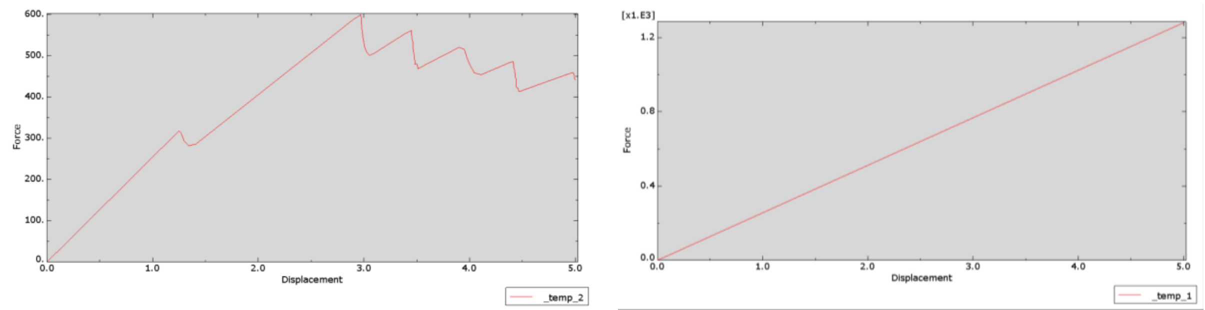

Fig. 15: Force vs displacement for 90 MPa traction (a) Linear softening (b) Exponential softening

The above graph shows saw-tooth like behaviour with force-displacement curve (Fig. 13 to Fig. 15) as the displacement is increased. The maximum value of force reached in linear softening damage evolution is around 600 N and then decreases as we increase the displacement. Whereas for all the cases with varying traction the value of reaction force increases with displacement.

5. CONCLUSION

The present case study of DCB test is performed using numerical modelling in ABAQUS for a crack opening under Mode I loading conditions. To induce the mode I crack propagation, the Double Cantilever Beam (DCB) setup was considered. Due to presence of cohesive layer in between the plates no stable crack propagation was present and a saw-tooth like force-displacement curve was observed. The DCB test is sensitive to von-mises stress when linear softening is considered in damage evolution for increasing value of nominal tractions. In the case of exponential softening, the sensitivity is almost nullified as there is no variation in stress values as we change the nominal tractions. Thus, it can be concluded that the study is sensitive towards damage initiation with linear softening.