

# FRACTURE STUDIES OF AN ADHESIVE JOINT INVOLVING COMPOSITION ALTERATION

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## ABSTRACT

Adhesive joints are widely used in industries because they have several advantages when compared to welded and riveted joints. One of the important factors is that they distribute the load and stresses uniformly over the entire bonded area providing good vibration resistance. Adhesive joints can readily bond dissimilar materials. The prediction of crack propagation validating the adhesive joint durability and toughness is a significant point which is addressed through various experimental methodologies based on the type of loading conditions. The analysis is hindered by the unpredictable adherend and adhesive behavior due to the loading conditions, the nature of crack propagation, and the geometry. The impact of hardener resin ratio alteration is a parameter which needs to be explored in validating the joint toughness. The Double Cantilever Beam tests which are used for analyzing the fracture toughness for mode-I loading in adhesive joints focus on adhesive thickness variation extensively. The alteration of composition and its role in influencing the crack propagation is explored in a limited perspective. An attempt is made in this work to analyse the adhesive composition variation and its impact on the joint toughness with the help of a DCB test involving three specimens incorporating variations in the hardener resin composition. The analytical and the experimental results provided significant insights on the adhesive joint toughness validation.

**Keywords:** Cohesive Zone Model, Double Cantilever Beam, Traction Separation Law, Finite Element Analysis, Crack Tip Opening Displacement, Strain Energy Release Rate.

## INTRODUCTION

Adhesive joints are known for their load and stress distribution characteristics over the entire bonding zone. They are preferred over other mechanical joints due to their fatigue resistance, crack retardation, galvanic isolation, vibration damping, and enhanced sealing capacity. The validation of adhesive joints is to determine the nature of crack propagation and resistance necessitating the development of suitable methods.

**Role of DCB tests and validation:** The DCB test is used to analyze the fracture behavior of adhesive joints. This test is focused on the measurement of the energy release rate ( $G_c$ ) for the mode-I loading. C.Fan et al used the DCB test for the measurement of fracture toughness of FRP for the mode-I loading. The experimental results were compared with the energy release rate ( $G_c$ ) analytical solution. Andersson.T et al used the DCB test for measurement of the cohesive properties of an Adhesive joint. Y.Freed et al used a DCB specimen for prediction of the crack formation under exclusive mode-I loading of laminated composite adhesive joints. The fracture behavior of Adhesive joints was explored by using a DCB and a Tapered DCB specimen combined by S.Marzi et al.

Cohesive Zone models (CZMs) are found to predict effectively, the mode-I fracture of adhesively bonded joints. They follow an approach which facilitates good flexibility during the adhesive deformation. The CZM was introduced by Barenblatt which is based on the Griffith's theory of fracture. The CZM was used to describe the crack propagation in brittle materials. Then, Dugdale proposed a CZM which considered a Cohesive zone at the crack tip which was suitable for plastic materials. S.Li et al in his work suggests that the strength of adhesive joints have been evaluated by two CZM based approaches namely strength based criteria and energy based criteria. The model can be related to the Traction-separation law where the area under the traction-displacement curve gives the measure of the fracture energy in an adhesive joint.

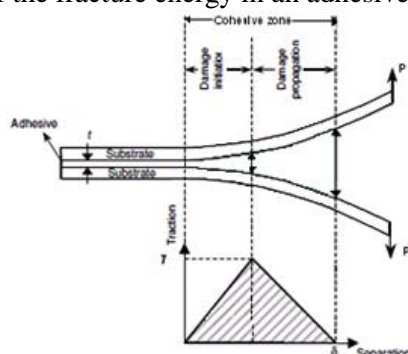


Fig.1.Traction Separation law



Fig.2.Fabricated DCB specimen

**Relations used:** The Mode I fracture toughness or energy release rate is the objective of the DCB test. This is obtained as a result of plotting the applied load vs opening displacement during the test. Sequentially, a critical strain energy release rate against the crack length is also plotted which gives the delamination resistance curve or R curve as specified by ASTM D5528-01. The  $G_C$  calculation from the DCB test is done by considering the Corrected beam theory and Experimental compliance.

**Experimental details:** The present work analyses the results of a DCB test done on an adhesive joint having mild steel adherends and Araldite adhesive. The selection of mild steel over Aluminium as Adherend material is due to the presence of a larger plastic zone in steel compared to Aluminium as outlined by Azari et al. The increase of adhesive plastic dissipation inside the full plastic zone was more in steel compared to aluminium as suggested by Pardoen et al. Hence the adherends were selected as mild steel in the DCB specimen geometry which is based on ASTM D5528-01.

**Table.1. Adherend properties**

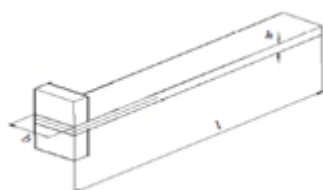
Property	Value
Young's modulus(E)	$2.1 \times 10^5$ MPa
Poisson's ratio ( $\mu$ )	0.3
Density( $\rho$ )	7850 kg/m <sup>3</sup>

The specimens are joined using the epoxy resin Araldite LY 556 and the anhydride hardener HY 906. The adhesive is selected for its ability to perform under elevated temperatures and good fatigue resistance. Several literatures including R. Kottner et al, T.Nishioka et al validate the selection of the Araldite epoxy resin.

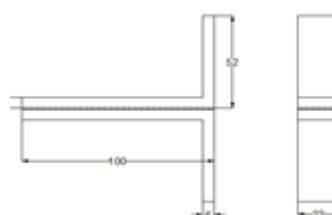
Properties of Araldite LY 556 and Hardener HY 95

**Table.2. Araldite properties**

Property	Value	Standard
Tensile strength	55 Mpa	ISO 527
Flexural modulus	3000 Mpa	ISO 178
Shear strength	70 Mpa	ASTM D 2344



**Fig.2. ASTM geometry**



**Fig.3. DCB geometry**

**Variation of adhesive composition:** The details of the variation of the proportions of the resin and hardener are given in the following table.

**Table.3. Hardener resin variation**

Adhesive	% of Hardener –Resin	Hardener	Resin
A	50%-50%	5ml	50ml
B	60%-40%	2.5ml	37.5ml
C	70%-30%	2.5ml	58.3ml

The bonding surfaces of the steel adherends are scrubbed with sand paper and wiped with acetone for contamination removal. This is done to facilitate consistent load transfer and to avoid debonding.

The DCB specimens incorporating the composition alterations as specified in table 3 were initially kept under dead weight for 8 to 10 hours. Subsequently, they were clamped in a machine vice for an entire day and dried completely before subjecting for analysis. The adhesive thickness was maintained using a Teflon insert at 1mm in all the three specimens. The pre-crack length was kept as 25 mm. A spring actuated fixture as shown in the diagram is used to clamp the DCB specimen in a tensile testing machine. The tensile testing machine is selected for its maximum capacity of 5 tons incorporating a digital encoder, and gear rotational speed facility for gradual loading. The DCB specimens were loaded at a constant displacement rate of 1mm/min.

## RESULTS AND DISCUSSION

The load displacement curves separately obtained from the tensile testing machine for the three DCB specimens are given below.



Fig.3. Clamped DCB specimen

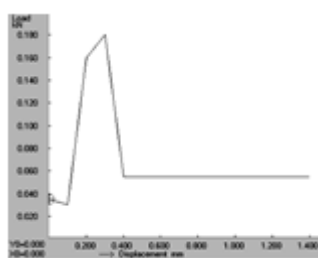


Fig.4. P- $\delta$  curves for specimens A&B obtained directly from UTM

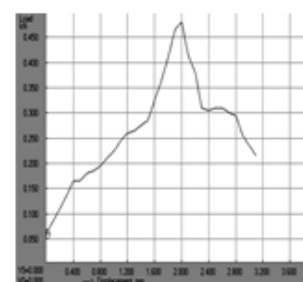
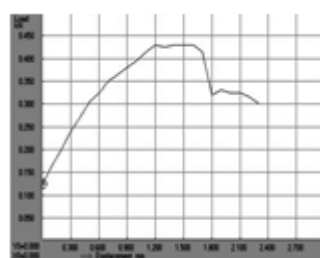


Fig.5. P- $\delta$  curves for specimen C obtained directly from UTM

The observations made during the tests are highlighted

Table.4. Range displacement tabulation

Specimen	Maximum load (KN)	crack length (mm)	Load range (KN)	Displacement (mm)
A	0.18	0.3	0 - 0.162	0 - 0.2
			0.162 - 0.18	0.2 - 0.3
B	0.43	1.2	0 - 0.4	0 - 1.1
			0.4 - 0.43	1.1 - 1.2
C	0.48	2	0 - 0.46	0 - 1.8
			0.46 - 0.48	1.8 - 2

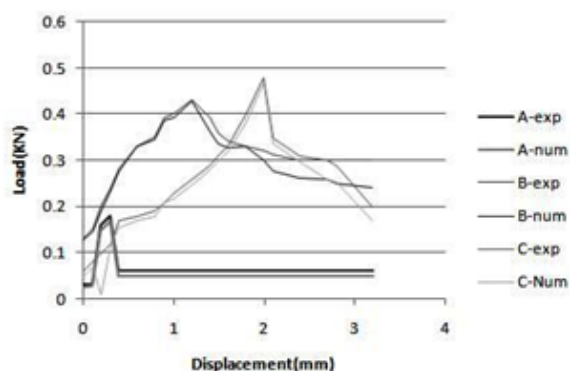


Fig.6. Load displacement correlation

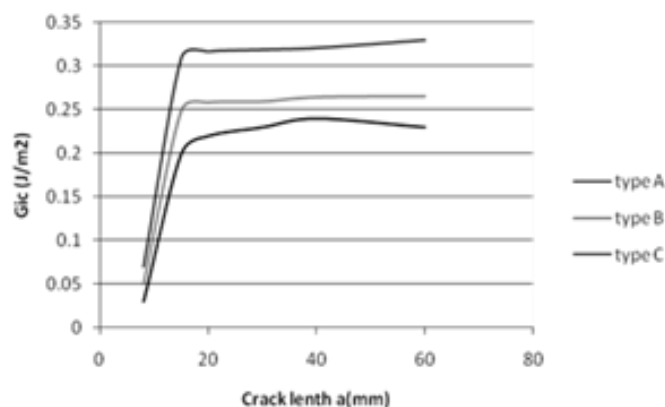
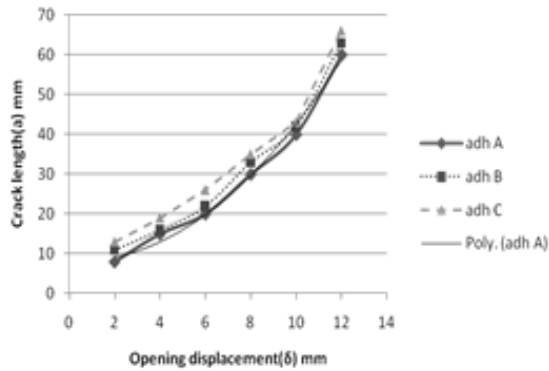
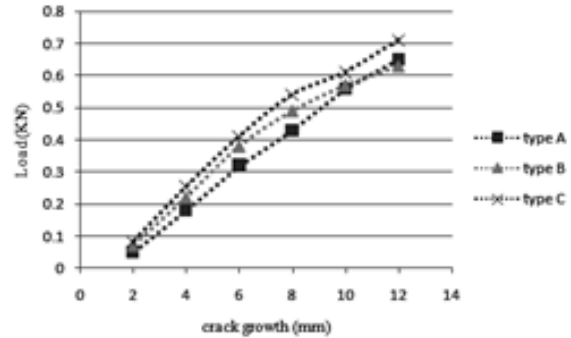


FIG.7. STRAIN ENERGY RELEASE RATE( $G_{IC}$ ) VS CRACK LENGTH(A)



**Fig.8. Crack growth vs Opening displacement**



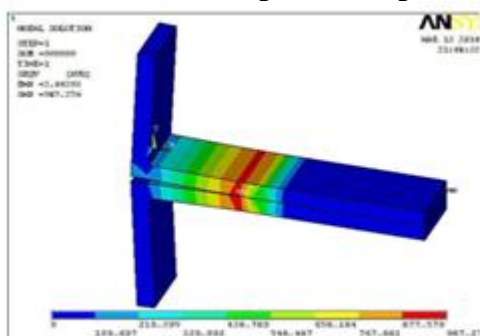
**Fig.9. Load vs crack growth**

The observations reveal the effect of the increase in the resin composition on the load applied and the corresponding crack length in the 3 dcb specimens. In all the three types tested, the analysis involved an inclusion of a cohesive zone at the starting point of the crack by specifying a suitable traction separation law. The increase in separation is seen to be proportional to the attainment of maximum traction limit followed by subsequent decrease. It was found that the crack retardation was erratic for the first 15 mm followed by stabilization. Finally the subsequent crack propagation resulted in total detachment of the steel adherends.

The graphs showing the load displacement characteristics and Strain energy release rate vs the crack length in all the three specimens are drawn as shown in figs 8 and 9. The P- $\delta$  curves obtained for the three specimens show convergence and marginal deviation to some extent. The R curves and the Crack growth vs CTOD as shown in the figures 10 and 11 also reveal the same characteristics which indicate the influence of the adhesive. In all the three experimental curves in the P- $\delta$  plot in fig 8, the initial linear region coincides with the numerical values. The sudden reduction in load after the load peak is attributed to an unstable crack growth during its initiation. The curve continues as linear until the starting of crack propagation which is due to the exceeding of the crack driving force over the fracture toughness of the specimens used. The R curve plotted as shown in fig 9 shows a linear rise followed by a plateau level which indicates initial elastic behavior followed by crack length increment for all the three specimens.

Figs 10 and 11 reveal the characteristics of the three specimens with minor variations when compared with Figs 8 and 9 showing the correlations and the R curves. Also Figs 10 and 11 have more pronounced variations and clear differentiations of the performance of the three adhesive types. The crack growth, and crack lengths monitored for drawing the plots reveal relatively small deviations and hence the degree of similarity between the curves were obtained. The attempt to study the propagation was more clear in figs 8 and 9 as they correlated to a particular level with the plots which were directly obtained from the tensile testing machine.

Finite element analysis using Ansys 14.5 was done to find the stress distribution and fracture toughness of the adhesive joint. Transverse Isotropic characteristics under plane strain conditions were considered for the DCB behavior due to mode-1 loading. The adhesive layer was modeled using the interface elements as shown in the fig 13. The 2D linear inter 202 type element characteristics was selected for the adhesive zone. The element length was taken as 1mm. The steel adherends were modeled using 8 noded isoparametric elements. The specimens revealed the stress distribution during the loading conditions observed as given in fig 12.



**Fig.10. Stress distribution**



**Fig.11. Meshed Adhesive layer**

## CONCLUSION

An experimental attempt was made to study the nature of crack propagation in the conducted DCB test for mode-1 fracture in the adhesive joints. The DCB tests were conducted incorporating adhesive composition variation as an investigating parameter which had a significant influence over crack propagation. The

characteristics of crack propagation, in both the experimental and numerical levels were analyzed. The correlation of the results from ANSYS and the experiments was also found to converge to a particular extent as revealed from the plots.

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