ISSN: 2278-0181
PECTEAM - 2K18 Conference Proceedings

Analytical Composition Response Probing of an Adhesive Fastener

[1]Dr. M. D. Mohan Gift,
[1]Associate Professor,
Department of Mechanical Engineering,
Panimalar Engineering College,
Chennai-602103

[2] Prof. C. Karthikeyan,
[2] Associate Professor,
Department of Mechanical Engineering,
Panimalar Engineering College, Chennai-602103

Abstract- **Adhesive fasteners are used in a wide range of engineering applications because they have an immense edge when related to other traditional fasteners. An important point of consideration is their ability to distribute the weight consistently over the connected region resulting in excellent damping qualities. Adhesive fasteners can be used for the bonding of dissimilar substrates. The calculation of crack travel parameters is used as a tool for quantifying the adhesive joint's finer qualities. This is done with the help of different experiments based on the prevalent loading scenarios existing in the engineering applications. The frequent investigations are often slowed down by the irrationality of the substrate and adhesive performance which may be attributed to the character of crack travel, and the specimen geometry. The effect of resin and hardener proportion ratio alteration is an important point which needs to be addressed for the adhesive joint validation and existence. The Double Cantilever Beam (DCB) test used exclusively for the mode-1 loading criteria is selected as an overall tool for all the tests conducted which successfully incorporated the resin and hardener proportion changes. The alteration of the resin and hardener proportion and its influence on the crack travel is explored in a limited direction and perspective. An effort was made in this research work towards analyzing the adhesive mixture variation and its impact on the joint sustenance with the help of tensile tests involving RH components including variations in the hardener resin mixture. The diagnostic and the investigational outcomes provided considerable insights on the adhesive joint toughness justifications.**

Keywords: Resin - Hardener, Critical Strain Energy Release Rate, Double Cantilever Beam.

I. INTRODUCTION

Adhesive fasteners are considered for their impeccable weight and unpredictable load withstanding qualities on the bonding area prevalent over the complete connecting region. They are chosen over other mechanical fasteners due to their weakness resistance, crack inhibition, galvanic segregation, pulsation elimination, and better closing qualities. The endorsement of adhesive fasteners is done with the help of a thorough understanding of the crack travel characteristics and factors inhibiting it. This evokes an urgent need to evolve the growth of appropriate and systematic investigations in this direction.

II. SIGNIFICANT PARAMETRIC LITERATURE

The Double Cantilever Beam (DCB) test is deployed to scrutinize the failure response of adhesive fasteners under the first modality of load applications. This method is more focused on the measurement and procurement of the energy release rate (G_c) under the modality-1 load facilitation. Fan [1] made an effective investigation using the DCB method for the procurement of the fracture robustness of fibre reinforced composite substrates formed fastener under the modality-1 load facilitation. The analytical responses were successfully projected along with the critical strain energy release rate (G_{ic}) values. Anderson [2] under the auspices of the DCB test investigated the cohesive characteristics of a composite substrate adhesive fastener. Freed [3] used a DCB tests for prediction of the delamination configuration under restricted mode-1 load facilitation of a variety of refined alloyed adhesive fasteners. The fracture probes for several fasteners were done using DCB methods on a tapered and notched specimen by Marzi[4].

Cohesive Zone models (CZMs) are used for the forecast of the fracture of adhesive fasteners under all modes of loading and also promote remarkable accuracy in the solutions. The CZM was discovered by Barenblatt[5] founded on the Griffith's theory of fracture. The CZM was initially focused on the study of the crack travel modalities in the materials which were highly brittle. Consequently, the CZM based methodologies were effectively extended by Dugdale [6] which formulated a region of cohesiveness near and at the crack tip suitable for plasticity in fasteners. Li [7] in a remarkable research suggested the evaluation of cohesive strength of adhesive fasteners using two CZM based methodologies which were both strength and energy criteria based. The CZM is always associated with the Traction-Separation Law (TSL). Here, the region under the traction-displacement curve indicates the quantity of the fracture energy in an adhesive fastener [8].

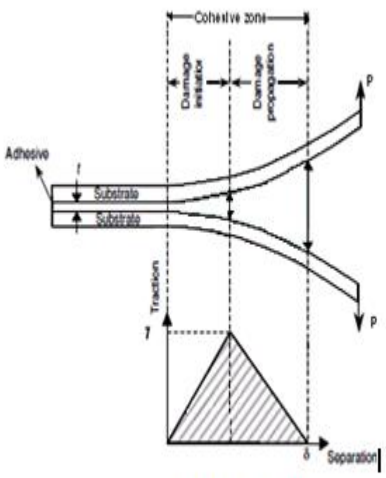


Fig 1: triangular TSL

III. THEORIES OF FAILURE

The extent of fracture toughness calculation is successfully attributed to the attainment of the critical strain energy release rate (G_{ic}). This is the ultimate purpose for which the DCB test is utilized successfully. The purpose is realized as a result of several plots drawn between the functional load vs crack tip opening displacement which are directly attained from the digital readouts in the tensile testing equipments. As an extension of the plots, a critical strain energy release rate (G_{ic}) against the crack travel extent is also graphed which yields the delamination inbition curve or the R curve which is specifically outlined in the ASTM D5528-01 [8].The G_{ic} calculation from the DCB experiments are done by considering the Corrected Beam Theory(CBT) and the Compliance Calibration Theory(CBT).

The following equations are considered for obtaining the value for G_c

$$G_{ic} = \frac{1}{2X} C^2 \frac{dP}{da} \text{----------} (1)$$

$$G_{ic} = \frac{12\, C^2\, x^2}{E_s\, B^2 y^3} \text{------------} (2)$$

IV. INVESTIGATIONAL PARTICULARS

The outlined investigation probes the compiled outcomes of DCB experiments done on an adhesive fasteners having mild steel substrates (EN 24B) and Araldite 2015 epoxy resin. The selection of mild steel substrate material is because of the existence of a wider plastic region when compared with other alloys particularly aluminum which is compared in the investigations of Azari [10]. The impact of elaboration of adhesive plastic indulgence inside the regular plastic region was larger in steel. This is also compared to aluminium alloy based substrates in the works of Pardoen [11]. So, the mild substrate justifications were done under the standards outlined in ASTM D5528-01[9].

TABLE 1 ARALDITE 2015

Sl.No	Property	Value
1	Modulus of Elasticity(E)	2.07×10^5 MPa
2	Proportionality (μ)	0.29
3	Material density(ρ)	7849 kg/m^3

TABLE 2 EPOXY PROPERTIES

Sl.No	Property	Value	Standard
1	Tensile force	55 Mpa	ISO 526
2	Bonding modulus	3000 Mpa	ISO 179
3	Shear stress	70 Mpa	ASTM D 2339

EN 24 B PROPERRTIES

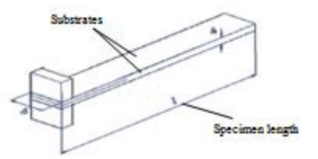


Figure 2. ASTM D 5528(01) configuration

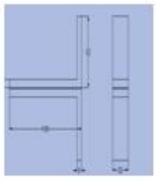


Figure 3. DCB dimensional geometry.

Figure 4. Formulated DCB composition with EN 24 B

IV RESIN HARDENER PROPORTION DETAILS AND IMPLEMENTATION

The particulars of the resin and hardener are outlined in the following table.

TABLE 3
RESIN HARDENER (RH) IMPLEMENTATION DETAILS

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

The mating surfaces of the EN 24B substrates are sanded uniformly with quality grade sand papers and applied with acetone for contagion elimination. This is implemented to allow consistent load transfer and debonding reduction. The EN24B RH components assimilating the RH variations as outlined in the table 3 were retained under dead load for duration of 8 to 10 hours. After this, they were clamped in workshop equipment vice for 24 hours and then eliminated for moisture traces completely before initiating the analytical procedures. The adhesive thickness was systematically ensured using teflon inserts of 1mm each in all the three RH configurations. The pre-delamination length was retained as 25 mm. A spring load based and actuated fixture as illustrated in the figure is used to retain the RH varied RH components in a unique tailor made tensile testing equipment. The tensile testing equipment is preferred for its utmost capacity of 5 tons which integrates a digital encoder and a gear rotational speed option for systematic mode-1 loading. The RH components were subjected to a constant load displacement rate of 1mm/min.

Figure 5. RH RH components loaded under mode-1.

The load displacement curves directly and separately procured from the unique tensile testing equipment listed previously for the three RH components are given below.

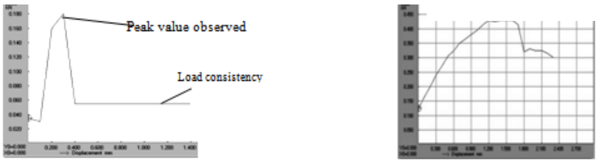


Figure 6. P-δ curves for RH-A, and RH-B direct from read out

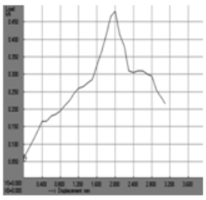


Figure 7. P-δ curves for RH-C direct from read out.

The corresponding results derived from the tests are noted.

TABLE 4 Extent Of Load Displacement Facilitation

RH type	Highest load (KN)	crack travel (mm)	Load array (KN)	Displacement (mm)
A	0.178	0.2	0 - 0.159	0 - 0.15
			0.159 - 0.17	0.15 - 0.29
B	0.42	1.18	0 - 0.37	0 - 1.07
			0.37 – 0.42	1.07 – 1.19
C	0.47	1.9	0 – 0.45	0 – 1.82
			0.45 – 0.47	1.82 – 2.01

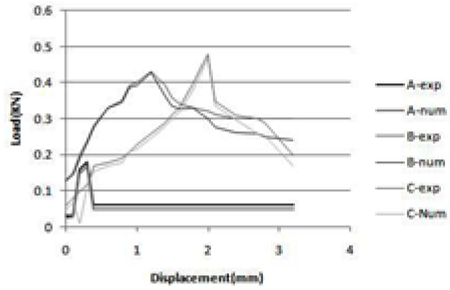


Figure 8. Load displacement link.

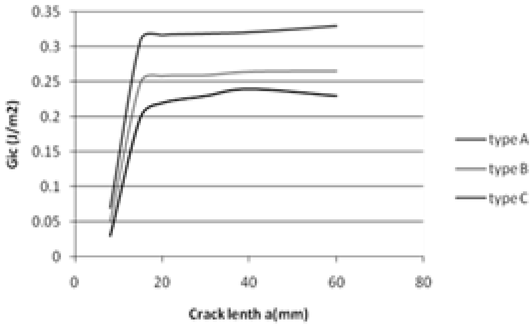


Figure 9. Critical Strain Energy release rate(G_{Ic}) vs delamination(a).

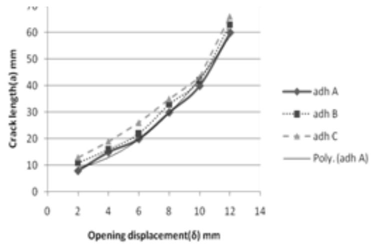
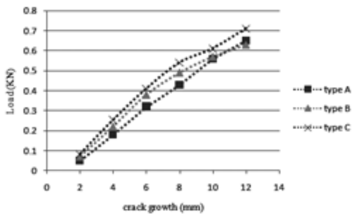


Figure 10. Crack travel facilitation (a) vs crack mouth opening displacement (CMOD – δ)



The findings articulate the impact of the proportionality variation due to the furtherance of the resin composition on the mode-1 loading and the equivalent crack travel in the 3 RH components. In all the three RH components evaluated, the analysis involved an enclosure of a cohesive region at the initiating point of the delamination which is evident from the specification of the triangular TSL[8]. The further increase in delamination is seen to be comparative with the realization of highest traction and followed by a sequential reduction. It was observed that the crack inhibition was non-uniform for the first 13 mm. Further readings revealed gradual stabilization. Finally the end of the delamination sequence revealed the total separation of the steel substrates.

The curves exhibiting the load against delamination and the critical strain energy discharge rate against the crack travel in all the three RH components are plotted which is revealed in figures 8 and 9. The curves plotted for the three RH components show coincidence at some ranges and minor divergences in the remaining ranges. The delamination (R) curves and the delamination travel vs crack mouth opening displacement revealed in the figures 10 and 11 are found to exhibit similar distinctiveness which point to the influence of the RH variation. The curves shown in the figure 8 revealed the coincidence of the original linear zone with the numerical data points. The abrupt decline in load after the load crest is endorsed to a sudden delamination after the initiation phase. The curve prolongs in a linear fashion until the fulfillment of the delamination .This may be attributed to the upliftment of the delamination inducing force over the existing failure criteria of the RH components involved. The G_{ic} vs crack mouth opening displacement curve drawn as revealed in figure 9 exhibits a proportional increase followed by a a leveling off phase. This may be due to the starting elastic response followed by delamination increase for the three RH components.

Figures 10 and 11 are found to show the response of the three RH components with minor lapses when compared with the figures 8 and 9 which exhibited the coincidences of the G_{ic} vs crack mouth opening displacement curves. Also the curves outlined in the figures 10 and 11 are found to have more precise deviations of the response of the three RH components. The crack travel extent recorded for the curve polotting reveal corresponding minor variations and as a result, the degree of coincidence between the plots were procured. The endeavor to study the delamnination was more visible in figures 8 and 9 as they coincided to a significant level with the curves procured from the digital read out of the tensile testing equipment.

Finite element analysis using Ansys 14 was undertaken to predict the stress spread and delamination resistance of the 3 RH components. Pure distinctiveness under plane strain circumstances were measured for the adhesive response as a result of the mode-1 conditions. The adhesive region was created using the boundary elements as revealed in the figure 13. The 2D proportional inter 202 category element distinctiveness was chosen for the adhesive region. The constituent length was fixed as 1mm. The steel substrates were created using 8 node iso-component blocks. The RH components were found to exhibit the stress spread along the various zones under mode-1 loading which is revealed from the figure 12.

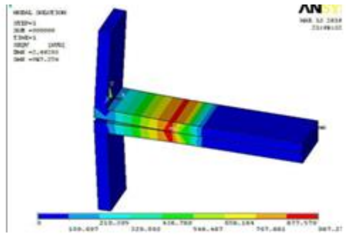


Figure 12. Stress spread patterns in the various zones of RH component-A

Figure 13. Mapped adhesive zone in RH component-A

VII. FINAL REMARKS

A critical probing was undertaken to scrutinize the response of the RH components under the auspices of the mode-1 loading modality which were successfully facilitated by the DCB tests. The results were found to distinctly reveal the response of the adhesive layer under the three variations created in the RH composition of the epoxy. The delamination nature of the crack travel in both the analytical and finite element analysis was monitored and scrutinized. The augmentation and furtherance of the results reveal the coincidence of the epoxy response to a exacting extent.

REFERENCES

[1] Chengye Fan., Ben Jar, P,.Y., Roger Cheng, J,.J., "Cohesive zone with continuum damage properties for simulation of delamination development in fibre composites and failure of adhesive fasteners", Engineering Fracture Mechanics ,vol.75, (2008)., 3866–3880.

[2] Anderrson,T., Biel,A., "On the effective constitutive properties of a thin adhesive layer loaded in peel", International journal of fracture, vol.141(1-2), (2013)., 227-246.

[3] Yuval Freed., Leslie Banks-Sills., "A new cohesive zone model for mixed mode interface fracture in biomaterials" Engineering Fracture Mechanics, vol.75 (15), (2008)., 4583–4593.

[4] Stephan Marzi., Anders Biel., and Ulf Stigh., "On experimental methods to investigate the effect of layer thickness on the fracture behavior of adhesively bonded fasteners", International Journal of Adhesion and Adhesives, vol.31(8), (2011), 840–850.

[5] Barenblatt, G I., "The mathematical theory of equilibrium cracks in brittle fracture", Applied Mechanics, vol.7, (1962)., 55–129.

[6] Dugdale, D S., "Yielding of steel sheets containing slits", Journal of the Mechanics and Physics of Solids, vol.8, (1960).,100–4.

[7] Li, S., Thouless, M.D., Waas, A.M., Schroeder, J.A., Zavattieri, P.D., "Mixed-mode cohesive-zone models for fracture of an adhesively bonded polymer–matrix composite", Engineering Fracture Mechanics, vol.73, (2006)., 64–78 .

[8] Khoramishad,H., Crocombe A.D., Katnam, K.B., Ashcroft I..A., "Predicting fatigue damage in adhesively bonded fasteners using a cohesive zone model", International Journal of Fatigue, vol. 32, (2010)., 1146–1158.

[9] ASTM. D-5528-01., “Standard test method for Mode I interlaminar fracture toughness of unidirectional fiber-reinforced polymer matrix composite”, ASTM Annual book of ASTM standard, vol. 15.03, (2002)., 254-263 .
[10] Azari, S., Ameli, A., Datla, N.V., Papini, M., Spelt, J.K., “Effect of substrate modulus on the fatigue behaviour of adhesively bonded fasteners”, Material Science and Engineering , (2012)., 534:594–602.
[11] Pardoen, T., Ferracin, T., Landis, C.M., Delannay, F., “Constraint effects in adhesive joint fracture”, Journal of the mechanics and physics of Solids, vol.53, (2005)., 1951–83.
[12] Huntsman data sheet of Araldite adhesives for advanced materials, Huntsman International LLC(2001- 2014).
[13] R, Kottner., R, Hynek., T, Kroupa., “Identification of parameters of cohesive elements for modeling of adhesively bonded fasteners of epoxy composites”, Applied and Computational Mechanics, vol.7, (2013).,137–144.
[14] Nishioka, T., Atluri, S.N., “Finite Element Simulation of fast fracture in Steel DCB specimen”, Engineering Fracture Mechanics, Vol. 16(2), (1982)., 157-175.