Impact Factor (SJIF): 2.125

International Journal of Advance Research in Engineering, Science & Technology

e-ISSN: 2393-9877, p-ISSN: 2394-2444

Volume 3, Issue 1, January-2016

EXPERIMENTAL ANALYSIS OF AN CRACKED ADHESIVE JOINT

Jay Mandaliar[1], Prof. R. B. Barjibhe[2]

[1] Department of Mechanical Engineering, S.S.G.B.C.O.E.T, Bhusawal
[2] Department of Mechanical Engineering, S.S.G.B.C.O.E.T, Bhusawal

Abstract

Adhesive bonding is an alternative toconventional joining systems (e.g., riveting or welding) for a numerous class of components belonging to electronic, automotive, and aerospace industries. However, adhesive joints contain flaws; therefore, the development of such technology requires reliable knowledge of the corresponding fracture properties. This study deals with ideology to obtain a specific Load vs displacement relationship based on the problem for PMMA/polyurethane adhesive joint along with stresses and crack length relation establishment, on Mode-I conditions directly through experiments. This information is valuable for predicting the durability of a structure containing adhesively bonded joints.

Keywords*-adhesive joints, pmma-polyurethane, crack propagation, mode-I failure, load vs displacement.*

I. INTRODUCTION

With the increasing demands from the customers and industry, it is required to stimulate new technology. For instance, in Automobile sector, the present scenario is increasing light weighted technology with maintaining the standards in emission and failure criterions. When it comes to joints, this light weighted combination is required to be joined with high strength low cost materials. These materials are known as adhesives, which, adds little wright to the structure and combination of joining even two dissimilar metals and non-metals is possible which is not possible even with welded joints. The use of adhesive joints in automotive, aerospace, biomedical, and microelectronics industries is widespread; however, inaccurate joint fabrication or inappropriate curing may cause the presence of bubbles, dust particles or un-bonded areas in the bond line. As a result of which it is mandatory to assess the reliability of this adhesive joints in events of fracture in order to avoid an accident. For the study, pre-cracked specimens are used with pre-crack length of 15 mm and 25 mm.

II. LITERATURE SURVEY

Hutchinson and Suo, a practical approach for characterizing the adhesion of polymer coatings to metal substrates is to use sandwich specimens, which can be analyzed using interfacial linear elastic fracture mechanics (LEFM) concepts. ***Wang,*** however, there can be limitations to the use of LEFM in sandwich structures. The first is that the assumed stress fields are not rigorously correct, for example, in the case of large-scale plasticity or in the case of very thin layers where the K-dominant field cannot develop. ***Li et al.,*** the second is that some joints may not have macroscopic defects large enough to be considered cracks for the purpose of fracture mechanics. ***Dugdale and Barenblatt,*** these issues can compromise the utility of LEFM and alternative approaches must be sought. Cohesive zone modeling is one such approach. The key concept of cohesive zone modeling is that the failure process zone can be described by a traction–separation law; more specifically, the cohesive traction, σ(δ), can vary along the failure process zone, but only depends on the local opening, δ. The key is the introduction of a second fracture parameter, e.g., the cohesive strength, in addition to the fracture toughness. This cohesive strength relates the toughness to the critical crack-tip opening required for crack propagation. Recently cohesive zone modeling has been applied to solve interfacial fracture problems. ***Yang and Thouless,*** proposed a modified criterion for mixed-mode interfacial fracture, in which fracture occurs when the mode 1 and mode 2 energy release rates for the cohesive zone reach a critical value. Nevertheless, in both criteria, with independently characterized mode 1 and mode 2 traction–separation laws available, mixed-mode problems with a range of fracture mode-mixes can be fully solved. ***Swadener and Liechti*** examined cohesive zone modeling for a wide spectrum of interface problems, such as glass/epoxy interfacial fracture and adhesion.

Cotterell and Mai; Pandya and Williams, one is through direct tension or shear experiments, however, in these experiments, the damage evolution across the width of the specimen must be uniform, which is usually difficult to achieve. ***Li et al.,*** in the second approach, the cohesive law is derived from simultaneous measurements of the J-integral and the end-opening (both normal and shear) of the cohesive zone. This has been successfully employed in the extraction of traction–separation laws for cementitious components. ***Sorensen***, successfully employed the same for adhesive bonds while, ***Sorensen and Jacobsen,*** employed the approach for fiber-reinforced composites.

III. ADHESIVE JOINTS.

3.1 Application.

The material combination that has been selected is PMMA/Adhesive. Poly methyl methacrylate has wide number of industrial application, such as,

1. Automotive Industry
2. Marine Applications
3. Aviation Industry
4. Electronic Components
5. Interiors and Furniture
6. Architecture and Construction.

Adhesive material (Loctite MS 930) is selected as an adhesive in order to obtain the required bonding between PMMA Blocks.

IV. EXPERIMENTAL WORK

The double cantilever beam (DCB) configuration was used to determine the mode 1 traction–separation laws. [1] The specimen geometry is shown in Fig. 4.2. A pre-existing crack in the middle of the adhesive layer was cut using a sharp razor blade of 15mm length. It turned out that the fracture process zone in these experiments was large [25].

$$J = 12\frac{(pa)^2}{Eh^3} + P(w'_1 + w'_2) \qquad (5.1)$$

where P is the applied load per unit width, a is the crack length, h is the adherend thickness, and E is the elastic modulus of the steel adherends, and w0 1 and w02 are, respectively, the rotations of the upper and lower adherends at the crack tip.

The J-integral approach can be applied if the materials possess elastic stress–strain behaviour. The adherend is an elastomer, which was considered to be a nonlinear elastic material. Evaluating J-integral along a path just outside of the failure process zone yields

$$J = \int_0^{\delta'_n} \sigma\,(\delta_n)\,d\delta_n \qquad (5.2)$$

where δ_n and δ'_n are the normal opening and the normal end-opening of the cohesive zone, respectively, and r is the normal traction. J reaches a steady-state value, J_{SS}, when δ'_n attains δ_{nc}, the critical normal end-opening. The entire failure process zone is described by the cohesive law.

Due to its path independence, the J-integral in Eq. (5.2) is equal to that obtained by Eq. (5.1). The normal end-opening δ'_n can be recorded in digital images, thus differentiation of Eq. (5.2) with respect to δ'_n gives,

$$\sigma(\delta'_n) = \frac{\partial J}{\partial \delta'_n} \qquad (5.3)$$

Thus, the mode 1 traction–separation law can be obtained by simultaneously measuring the J-integral and the normal end opening δ'_n.

For a Double Cantilever Beam geometry it is possible to find out the J Integral directly from experimental data under mode-I testing using the below mentioned relations.

$$J = \frac{12\,P^2 a^3}{E\,B^2 h^3} \qquad (5.4)$$

where, P is the load obtained directly during the experimental procedure, a is the crack length respective to the load, E is the Elastic modulus of the adhesive, B is the width of the adherents and h is the height of the adherent.

4.1 Specimen Preparation: [1]

The specimens were manufactured in two different ways.

- Method (1): The two plates with applied adhesive are cured. After the curing process, specimens are cut from the plates.

The specimens for measuring the unconfined tensile behaviour of the PU bond were obtained from thin films. In this case, the PU fluid was applied on top of a PMMA block to form a thin film with thickness of 5 ± 0.1 mm.

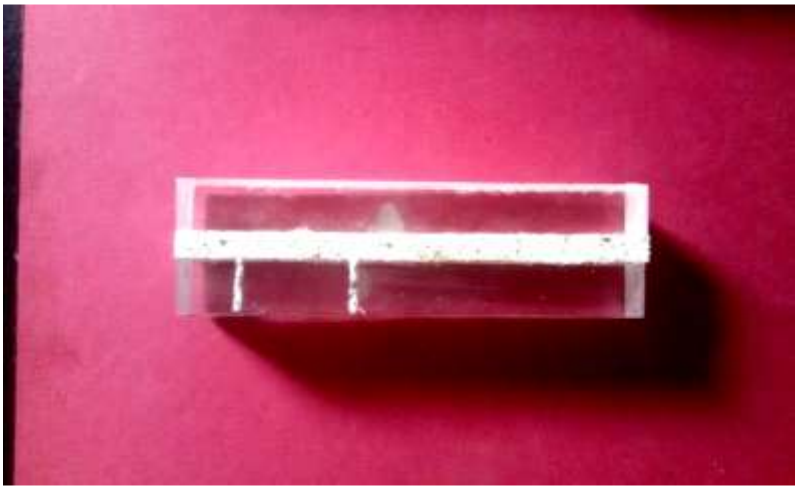


Figure 4.2: Actual DCB test configuration and specimen

Table 4.1 Dimension of Specimen Geometry

Sr. No.	Material	Length (mm)	Width (mm)	Height (mm)
1	PMMA	90	20	10
2	ADHESIVE	90	20	05

4.2 Testing of Specimen:

The most straightforward method to test adhesives was to use a test specimen made entirely of the adhesive material. When extracting constitutive relations from experiments on a thin film adhesive it is of utmost importance to know the stress distribution in the test specimen. As mentioned earlier, the stress distribution relies highly on the geometry of the specimen. The specimen as shown in fig 4.1 were prepared and tested on the universal testing machine. The required date was collected, such as maximum stress, maximum strain, the graph of load vs. displacement and the cohesive law has been derived from it.

Figure 4.3: Universal Testing Machine used for Testing

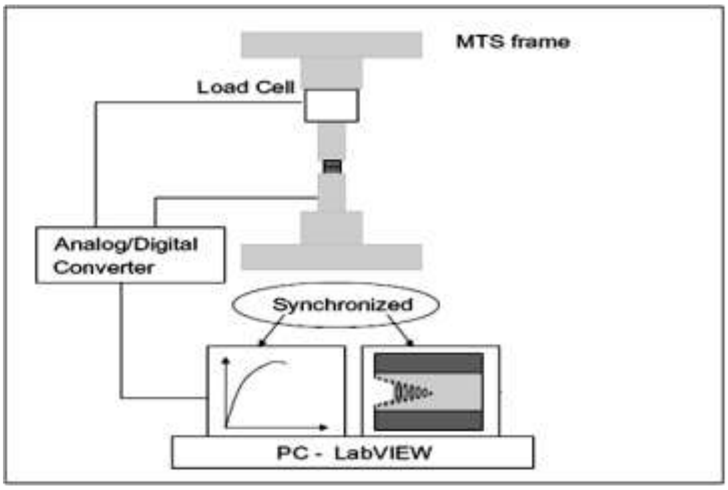


Figure 4.4: Schematic of experimental set-up [1]

All the experiments were conducted at room temperature using a load cell based materials testing system under constant crosshead speed. The material testing system used in the experimental work is a Universal Testing Machine with 10 KN Capacity and an accuracy of ± 1%. The differences noticeable under tensile loading and reliance on crosshead displacements would clearly lead to low measurements of moduli. In all total six experiments were conducted for the same samples with different openings as 2 samples of 05 mm opening, at the constant loading rate of 0.3 mm/s. [1]

V. RESULTS AND DISCUSSION

5.1 EXPERIMENTAL DATA SHEET OF SPECIMEN NO: 1,

Part	: PMMA+ PU
Batch No.	: DC Beam
Spec No.	: No.2
Load Cell	: 9800N.
Temperature	: 25 ºC
Speed	: 0.3 mm / sec
Pre Tension Load	: 0 N.
Gauge Length	: 100mm.
Peak Load	: **234.22 N.**
Peak Elong	: 8.7 %
Break Load	: 29.40 N.
Break Elong	: 15.1 %
Tens Strength	: 2.342 MPa
CS Area	: 100.00 Sq.mm.
Width	: 5 mm
Thickness	: 20 mm
Break Strength	: 0.294 MPa

With respect to the above experimental input data the next table shows the result values obtained from the experimental testing.

Graph: 5.1 Load vs displacement of Specimen 1.

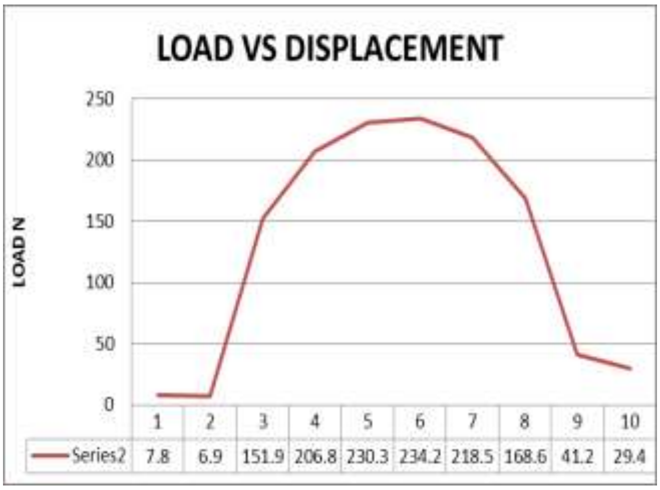


Figure 5.2: Load vs. Displacement of specimen 1.

5.2 EXPERIMENTAL DATA SHEET OF SPECIMEN NO: 2

With respect to the above experimental input data the next table shows the result values obtained from the experimental testing.

Table 5.2: Experimental Data of the Specimen 2.

Part	: PMMA+ PU
Batch No.	: DC Beam
Spec No.	: No.5
Load Cell	: 9800N.
Temperature	: 25 ºC
Speed	: 0.3 mm / sec
Pre Tension Load	: 0 N.
Gauge Length	: 100mm.
Peak Load	**: 229.32 N.**
Peak Elong	: 8.4 %
Break Load	: 0.00 N.
Break Elong	: 0.0 %
Tens Strength	: 2.293 MPa
CS Area	: 100.00 Sq.mm.
Width	: 5.000 mm.
Thickness	: 20.000 mm.
Break Strength	: 0.000 MPa

Graph 5.2: Load vs Displacement of Specimen 2.

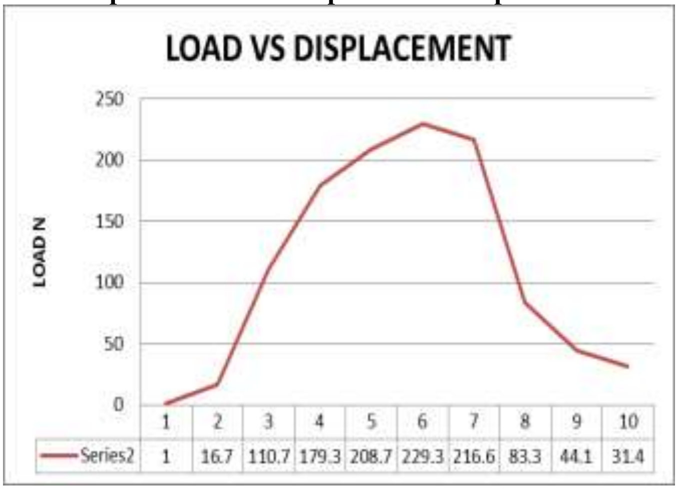
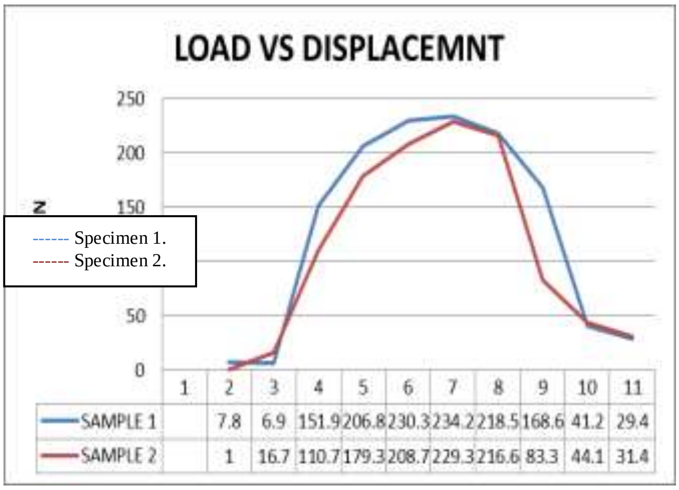


Figure 5.4: Load vs. Displacement of Specimen 2

VI. CONCLUSION AND FUTURE WORK

Graph 6.1: Comparison of Load vs. Displacement



The graph 8.3 shows the comparison of traction-separation results of 5mm opening specimen under tensile load. The maximum load capacity for specimen no.1 was 234.22 N and the same for the specimen no. 2 was 229.32N.
The maximum traction recorded was 3.32 MPa for specimen no. 1 and the same for the specimen no. 2 was 3.26 MPa. The maximum separation [CTOD] recorded for the specimen no. 1 was 15.9 mm and the same recorded for specimen no. 2 was 13.1 mm. the peculiarity of the graph is the non-Zero opening recorded throughout the testing.

As such the work done is only for 15 mm opening, it can be concluded from the different specimen geometry with variable artificial crack length openings and the same law can be validated. It is clear from the observation of the results that the opening and the maximum load capacity for such a joint as compared with two separate geometries are same.

Apart from the work done emphasis can be laid upon the various parameters in future as mentioned below.

1. Fracture Tensile Tests were carried out at one opening only. However need to be conducted over a wide range of openings.
2. Fracture Tensile Tests were conducted for one strain rate only at room temperature. However it is needed to be conducted for different displacement rates.
3. The fracture toughness studies were done at room temperature. It is suggested to conduct the test at low temperatures and elevated temperatures.

4. The material geometry is needed to be tested for Mode-II (Shear Load) and Mode-III (Mixed Mode) loading.
5. Experimental evaluation can also be done with variable loading angles in order to study the various fracture parametric behavior.
6. Fatigue crack growth studies may also be conducted applying realistic spectrum variable amplitude conditions.
7. Strain field distribution may be obtained using soft computing and CAE software under various conditions.

VII. REFERENCES.

1. Jay Mandalia, Rahul B. Barjibhe "Mode-I Traction-Separation of an Adhesive Joint" International Journal of Advance Research in Engineering, Science & Technology, Volume 2, Issue 12, December- 2015, PP - 1114-1119.
2. Young Zhu, K. M. Liechti and K. Ravi-Chandar, "Direct extraction of rate dependent Traction-Separation for Polyurea/Steel Interface", 'International Journal of Solids and Structures', 2009, Vol. No. 46, PP 31-51.
3. Adams, R.D., Comyn, J.C. and Wake, W.C. "Structural Adhesive Joints in Engineering", Chapman & Hall, London, 1997 UK.
4. Akisanya, A.R., "Brittle fracture of adhesive joints", International Journal of Fracture, 1992, Vol. 58(2), PP 93–114.
5. Barenblatt, G. I., "The Formation of Equilibrium Cracks during Brittle Fracture. General Ideas and Hypothesis, Axisymmetrical Cracks", 1959, PMM Journal of Applied Mathematics and Mechanics 23, 434–444.
6. Camacho, G. T., Ortiz, M., "Computational Modeling of Impact Damage in Brittle Materials", 1996, International Journal of Solids Structures 33, 2899–2938.
7. Espinosa, H. D., Dwivedi, S., and Lu, H. C., "Modeling Impact Induced Delamination of Woven Fiber Reinforced Composites with Contact/Cohesive Laws", 2000, Computational Methods in Applied Mechanics, Vol. 183, 259–290.
8. Espinosa, H. D., Zavattieri, P. D., Dwivedi, S., "A Finite Deformation Continuum/Discrete Model for Description of Fragmentation and Damage in Brittle Materials", 1998, Journal of Mechanics and Physics of Solids 46, 1909–1942.
9. Foulk, J. W., Allen, D. H., Helms, K. L. E., "Formulation of a Three-dimensional Cohesive Zone Model for Application to a Finite Element Algorithm", 2000, Computational Methods in Applied Mechanics. Vol. 183, 51–66.
10. Geubelle, P. H., and Baylor, J., "The Impact-Induced Delamination of Laminated Composites: A 2D Simulation", 1998, Composites, Part B, 29B, 589–602.
11. Goglio, L., Rossetto, M., "Ultrasonic testing of anaerobic bonded joints". 2002, Ultrasonics, Vol. 40(1–8), 205–210.
12. Kinloch, A.J., "Adhesion and adhesives, Science and Technology. Chapman & Hall, London, 1986.
13. Needleman, A., "An Analysis of Tensile Decohesion Along an Interface", 1990. Journal of Mechanics Physics of Solids, Vol. 38, 289–324.
14. Needleman, A., "A Continuum Model for Void Nucleation by Inclusion Debonding". 1987. ASME Journal of Applied Mechanics, Vol. 54, 525–531.
15. Siegmund, T., Brocks, W., "A Numerical Study on the Correlation between the Work of Separation and the Dissipation Rate in Ductile Fracture", 2000, Engineering Fracture Mechanics, 67, 139–154.
16. Tvergaard, V., and Hutchinson, J.W., "The Relation between Crack Growth Resistance and Fracture Process Parameters in Elastic-Plastic Solids". 1992, Journal of Mechanics and Physics of Solids, Vol. 40, 1377-1393.
17. Xu, X. P., and Needleman, A., "Numerical Simulation of Fast Crack Growth in Brittle Solids", Journal of Mechanics and Physics of Solids, 1994, Vol. 42, 1397–1434.
18. M. Alfano, F. Furgiuele, L. Pagnotta, and G. H. Paulino, "Analysis of Fracture in Aluminum Joints Bonded with a Bi-Component Epoxy Adhesive", Journal of Testing and Evaluation, 2010, Vol. 39 No. 2, PP 1-8
19. Parmigiani, J.P., Thouless, M.D., "The effects of cohesive strength and toughness on mixed-mode delamination of beam-like geometries", 2007, Engineering Fracture Mechanics Vol. 74, 2675–2699.
20. Leffler, K., Alfredsson, K.S., Stigh, U., "Shear behaviour of adhesive layers". 2007, International Journal of Solids and Structures, Vol. 44, 530–545.