Crack Propagation Analysis Using Extended Finite Element Method (XFEM) In Epoxy

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ABSTRACT

The objective of present work is to predict the path of crack in epoxy sheet under mixed mode loading condition. DLSP specimen is selected to generate mixed mode loading and XFEM approach is used to study the crack propagation. Microstructure in the form of RVE for unidirectional and randomly oriented composite material are generated using python scripting with the help of nearest neighbor algorithm. Sensitivity analysis is performed to select the size of RVE. XFEM analysis is carried out to study the microscopic behavior of crack on microstructure of composite material. Deboning behavior is also checked. Then homogenized properties are extracted from microstructure and verified with Halpin-Tsai estimation. These homogenized properties are than used to study the macroscopic crack propagation. Results are compared with experimental results of various literatures. An XFEM result seems to be in good agreement with experimental work. It is showed that crack in unidirectional epoxy sheet always runs parallel to fiber direction. And crack path for perfectly randomly oriented composite is in good agreement with GMTS criteria. Experiment is performed on randomly oriented material made with hand layup and XFEM analysis of the same anisotropic randomly oriented material is carried out. The XFEM and experimental results are in good agreement.

Key word: crack propagation, XFEM, Tensile mode, fiber epoxy

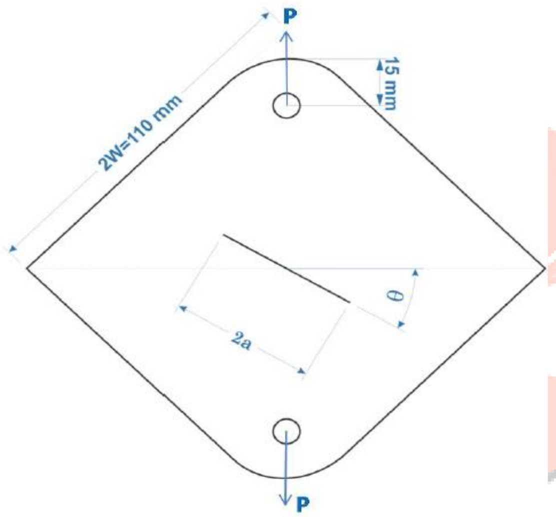
Introduction

The **extended finite element method (XFEM)**, also known as **generalized finite element method (GFEM)** or **partition of unity method (PUM)** is a numerical technique that extends the classical finite element method (FEM) approach by extending the solution space for solutions to differential equations with discontinuous functions. The extended finite element method was developed to ease difficulties in solving problems with localized features that are not efficiently resolved by mesh refinement. One of the initial applications was the modeling of fractures in a material. In this original implementation, discontinuous basis functions are added to standard polynomial basis functions for nodes that belonged to elements that are intersected by a crack to provide a basis that included crack opening displacements. A key advantage of XFEM is that in such problems the finite element mesh does not need to be updated to track the crack path. Subsequent research has illustrated the more general use of the method for problems involving singularities, material interfaces, regular meshing of micro structural features such as voids, and other problems where a localized feature can be described by an appropriate set of basic functions. It was shown that for some problems, such an embedding of the problem's feature into the approximation space can significantly improve convergence rates and accuracy. Moreover, treating problems with discontinuities with extended Finite Element Methods suppresses the need to mesh and Ramesh the discontinuity surfaces, thus alleviating the computational costs and projection errors associated with conventional finite element methods, at the cost of restricting the discontinuities to mesh edges. The present study is the application of this concept for solving three real life problems.

XFEM simulation was carried out for unidirectional fibre composite using homogenized properties and the results are compared with the experimental work done. They showed that the crack will predominantly propagate along the fibre direction, regardless of the specimen geometry, loading conditions or presence of voids. And the results are seems to be in good agreement as shown below. Properties used for simulation of unidirectional fiber composite are E1 = 38000 MPa, E2 = 11000 MPa, E3 = 11000 MPa, v_{12}= v_{13} = 0.261, v_{23} = 0.405, G12 = G13 = 4100 MPa G23 =3910 MPa. It is also checked that changing the material property only changes the load at which material will fail. But the failure pattern (i.e. crack path) will remain same.

The rectangular geometry of the specimen with dimensions 110mm×110mm×1mm. It can be seen that the crack path in XFEM simulation is matching with the crack path observed in experiment. Now, DLSP specimen geometry with dimensions 110mm×110mm×1mm is prepared to check whether changing the geometry changes the crack path or not. As DLSP specimen has the characteristics that changing the crack orientation changes the loading condition, it is also checked that loading condition affects the crack path in unidirectional composite or not.

With above results it is validated that changing the geometry does not affect the crack path in unidirectional composite. DLSP specimen generates mode-I loading for crack angle of 0^0 and crack angle of 45^0. So, it is also validated that loading condition also has no effect on crack path for unidirectional fiber epoxy.



Diagonally loaded square plate (DLSP) specimen geometry is selected for study the effect of tensile mode. DLSP geometry was selected because of simple conjuration, inexpensive preparation procedure, convenience of testing setup and also the ability of introducing complete mode. Also no auxiliary fixture require so less expensive and eliminate the possible error due to the error in manufacturing of auxiliary fixture. Crack angle corresponding to pure mode I are between about 0^0 and 45^0 so less sensitive to crack angle and therefore less incense on KI and KII due to minor inaccuracy in crack line. The geometry and dimensions of the fracture specimens used in the experimental tests where 2a and 2w denotes the length of the crack and denotes the crack inclination angle with diagonal opposite to the loading diagonal. Holes are used to fasten the specimen to the UTM machine fixture. Center crack with different length 35 mm, 45mm, 55mm and 1mm width of different orientation will be created using laser cut. And total 2batch of same specimen will be prepared for guarantee of accurate result.

Experiment work

Crack	Pick load	Initial crack angle(degree)	Crack Propagation angle(degree)
35	5711	0	40
45	4504	0	41
55	3795	0	42

Crack	Pick load	Initial crack angle(degree)	Crack Propagation angle(degree)
35	6703	45	90
45	5895	45	88
55	4951	45	85

ANGLE 0^0

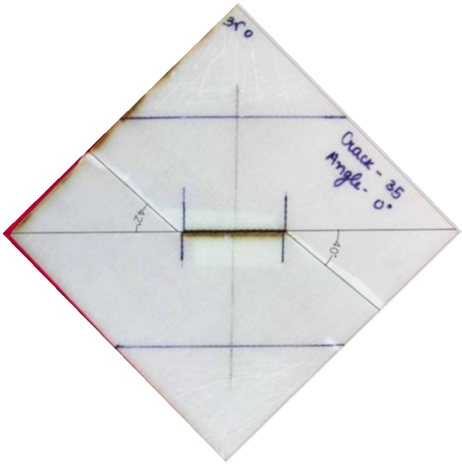


Fig 6.1 Initial crack angle 0^0 with a/w = 0.3

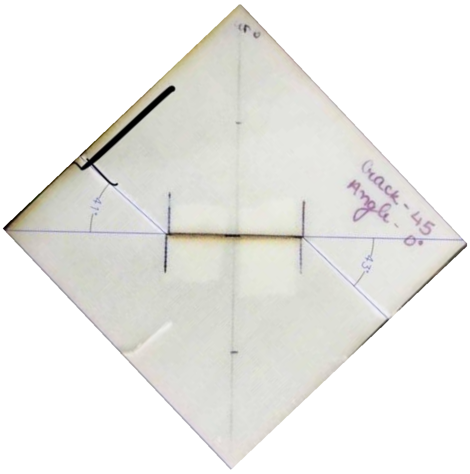


Fig 6.2 Initial crack angle 0^0 with a/w = 0.4

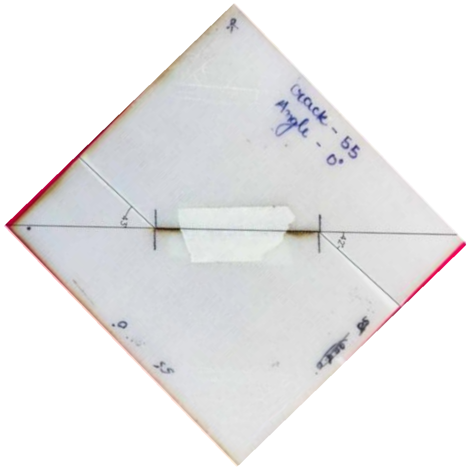
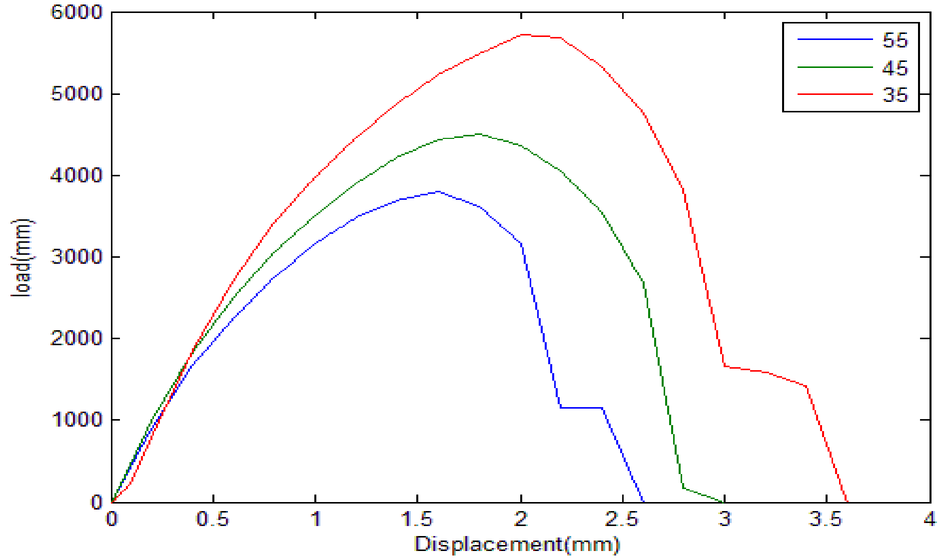


Fig 6.3 Initial crack angle 0^0 with a/w = 0.5



ANGLE 45^0

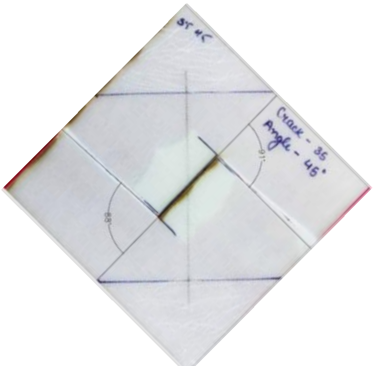


Fig 6.10 Initial crack angle 45^0 with a/w = 0.3

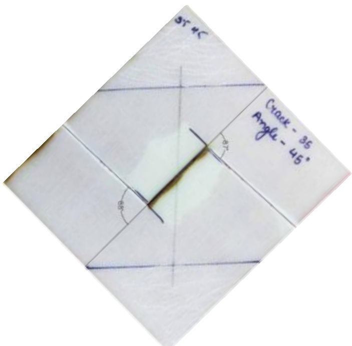


Fig 6.11 Initial crack angle 45^0 with a/w = 0.4

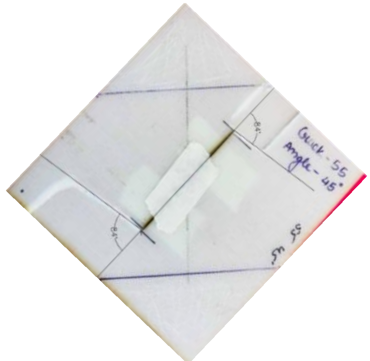
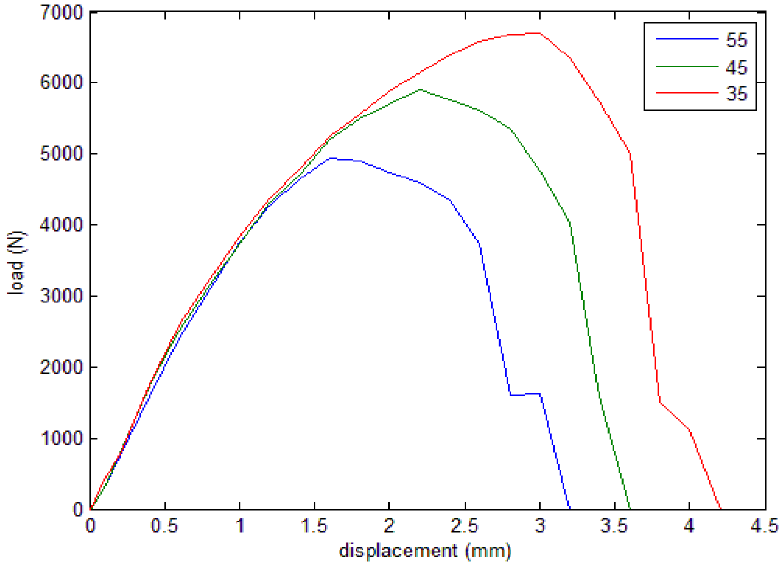


Fig 6.12 Initial crack angle 45^0 with a/w = 0.5



Conclusion

Crack always follows the path that has lower resistance. In composite material Fiber is the strongest one, matrix is weaker and interface is the weakest portion. So, maximum chance of crack to propagate is either through interface or within the matrix portion itself. In unidirectional composite both the paths are parallel to fiber direction. So, crack propagates parallel to fiber direction and it is also shown with experimental work.

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