# MIXED-MODE I+III DELAMINATION OF FLAX / EPOXY LAMINATED COMPOSITE

TAHIR BIN MOHAMMAD

A Project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Science (Mechanical Engineering)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

SEPTEMBER 2017

*Dedicated to My Family, Friends*

*&*

*Special dedication to my Wife and Mother*

# ACKNOWLEDGEMENT

I am very thankful to perform my graduate work at University Teknologi Malaysia. Therefore, I would like express my gratitude and thank for many people for their part in my success.

First, I wish my deepest gratitude to my supervisor, Mr Wong King Jye, the substance of genius for his precious guidance and constant motivation throughout the course of work. I gratefully acknowledge his meticulous efforts of adventure in regards to project. Without his guidance and persistent help this dissertation would not have been possible.

Not forgetting my special appreciation to the faculty and staff of mechanical Engineering department for providing laboratory facilities to complete my research work. Moreover, I thank all my close friends whom lead their hand throughout the course of study. Followed by, my special thanks to my wife and parents for being pillar for me and provide moral support throughout this course of study as well.

Last but not least, I would like to thank the Almighty God "*Allah*" for bless me and guide right path to complete my final year project successfully.

# ABSTRACT

This research describes delamination of flax/epoxy composite under mixed-mode I + III. The aim of this research is to study behavior mixed mode I+III delamination of flax / epoxy laminated composite. The experiment eight-point bending plate (8PBP) test was selected to study the delamination behavior flax/epoxy composite under mixed-mode I+III. The specimen flax/epoxy composite was fabricated use staking method with manual hand lay-up and curing process by vacuum bagging at room temperature. The specimen flax/epoxy composite was tested in room temperature. During test, it was observed that the delamination propagates increase before peak load. The maximum load obtained from these test has been analyzed and compared with data available from published source. Result indicated that the force against displacement graph characteristic produced by flax/epoxy composite have similarity with published data. Therefore the objective of this experiment 8PBP mixed mode I+III delamination has been successfully conducted and proven with published experimental data.

# ABSTRAK

Kajian ini menerangkan delaminasi komposit flax / epoxy di bawah campuran-mod I + III. Tujuan penyelidikan ini adalah untuk mengkaji ciri-ciri mod campuran I + III untuk mengeliminasi komposit flax / epoxy. Ujian lapan point lenturan plat eksperimen (8PBP) telah dipilih untuk mengkaji delaminasi komposit flaks / epoksi campuran I + III. Spesimen flax / epoksi komposit telah difabrikasi menggunakan kaedah menyusun secara manual "hand lay-up" dan melalui proses pengeringan dengan pembungkusan vakum pada suhu bilik. Sampel flax / epoksi telah diuji dalam suhu bilik. Semasa ujian, telah diperhatikan bahawa penyimpangan delaminasi membesar sebelum mencapai beban maksimam. Beban maksimum yang diperoleh daripada ujian ini telah dianalisis dan dibandingkan dengan data yang didapati dari sumber yang diterbitkan. Keputusan menunjukkan bahawa ciri graf beban melawan anjakan yang dihasilkan oleh komposit flax /epoksi mempunyai persamaan dengan data yang diterbitkan. Oleh itu objektif ujian 8PBP percampuran mod I + III ini telah berjaya dilakukan dan terbukti dengan data eksperimen yang diterbitkan

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| 8PBP | - | Eight point bending plate |
| DCB | - | Double cantilever beam, |
| ENF | - | Mode-II end notched flexure |
| MMB | - | Mixed-mode bending |
| UD | - | Tests on unidirectional |
| MD | - | Multidirectional |
| PSCB | - | Prestressed split-cantilever beam |
| STB | - | Shear-torsion bending |
| K | - | Stress intensity factor |
| Kc | - | Values of the stress intensity factor |
| G | - | Strain energy release |
| Gc | - | Strain energy release rate |
| Gj (j = I, II, III) | - | Energy release rate component |
| L | - | Length |
| B | - | Width |
| P | - | Apply load |
| S | - | Span |
| N | - | Force |
| E | - | Young's modulus |
| m | - | Thickness |
| $\delta_1/ \delta_3$ | - | Ratio of imposed displacement |

# LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Research Background

In recent years, the use of flax fibers as reinforcement in composites has gained popularity in industry due to an increasing requirement for developing sustainable materials. The cost effective and offer have great tensile in specific mechanical properties besides environment friendly biodegradable comparable to syntactic fibers made the flax fiber composite most preferable used in the industry. In particular, flax fiber composite are employed in automotive industry especially produce car interior part, beside produce other product such as furniture, fabric and paneling.

However, recent industrial use of flax fiber composite is mostly limited to non-structural components due to delamination issues. Like most laminated composites, flax fiber composite laminates are susceptible to delamination. Delamination growth is sensitive to the application of fatigue loading. [1][2]. Hence, understanding of the fatigue delamination growth behavior in flax composite laminates is very useful for the design of structures.

Extensive research has been dedicated to characterization of delamination resistance of high performance laminate composite by using various standards nowadays. In composite structures, the delamination is generally subject to both tension (Mode I) and shear (Mode II and mode III) stresses. Extensive studies have been

performed on the combined Mode I and Mode II fatigue growth behavior in laminated but less study on mixed-mode fatigue delamination growth behavior involving in mode III [2]. Therefore, the understanding is required to investigate the delamination behavior under combined Mode I/III loading.

The present work is focusing on study of delamination of flax/epoxy composite mixed-mode I+III flax/epoxy behavior using experiment 8PBP (eight point bending plate).

## 1.2 Research Objective

The objective of this research is to characterize the mixed-mode I+III delamination behavior of flax fabric reinforced epoxy composite laminate.

## 1.3 Problem statement

The use of flax fibers as reinforcement in composites has gained popularity due to an increasing requirement for developing sustainable materials. The good properties offer such as low density, high specific stiffness, low cost and environment friendly which is recyclable constitute the major incentives for flax fibers used in composites. It became an alternative of synthetic fiber in fiber-reinforced polymer composite. One of main issue concern in laminated composite material is their tendency to delaminate. The delamination of composite can be caused by expansion of moisture entrapped during the manufacturing of composites, mismatch of engineering properties between adjacent layers, non-optimum curing, etc, [6]. Delamination is also a common mode of damage when a composite structure is subjected to low velocity blunt object impact [6]. Initiation and growth of delamination can cause progressive reduction in the composite stiffness and it may substantially reduce the residual comprehensive strength of

composite. In recent days, many research test method has been conducted to study the delamination under mode 1, mode II, mode III and mixed mode I+III. However there is less study on delamination under mixed mode I+III. Therefore this research will focused on delamination behavior flax/epoxy composite form 8PBP experiment mixed mode I+III.

## 1.4 Scope of Research

The project will be completed according to following scopes:

a) The selected of material flax fabric and epoxy resin in order to produce flax/epoxy composite.
b) Selection of dimension flax/epoxy as sample for testing 8PBP (eight point bending plate)
c) Fabrication method manual hand lay-up stacking sequence unidirectional
d) Vacuum bagging and curing time of flax/epoxy after done hand lay-up rolled epoxy resin.
e) Conduct Experimental for Mixed-mode I+III using eight point bending plate method (8PBP) in order to know the characteristic of delamination behaviour.
f) Comparison the maximum load applied and graph pattern with previous established experimental data.

## 1.5 Research frame work

This study will determine the delamination of flax/epoxy composite through experimental 8PBP (eight point bending plate). Figure 1.1 summaries the frame work of this research.

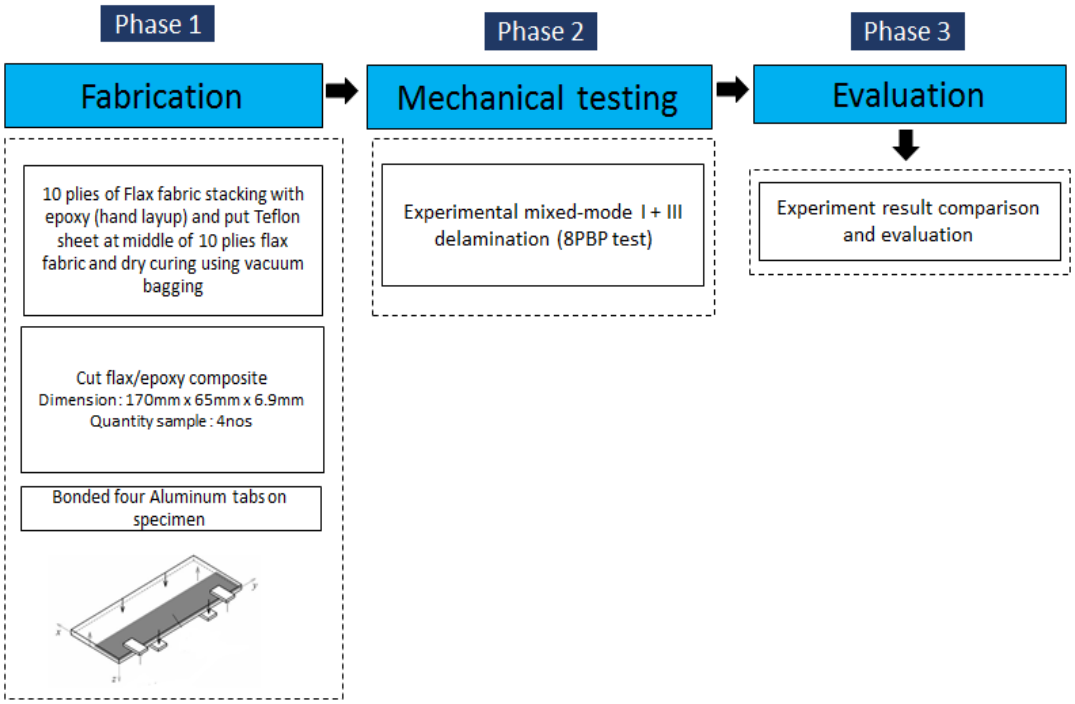


**Figure 1.1**: Research frame work

## 1.6 Thesis Outline

Chapter 1 presents on the research introduction. In this chapter, the research background, problem statement, objective, scope of this study and research methodology has been discussed.

Chapter 2 presents the literature review related subjects concerning to the research done. In this chapter the extensive literature review has been done on flax/epoxy composite, delamination of flax/epoxy composite and type of testing method mixed mode I+III conducted related with delamination.

Chapter 3 presents methodology fabrication flax/epoxy composite and experimentation of 8PBP (eight point bending plate) mixed mode I+III flax/epoxy composite. Other than that, the experiment setup and apparatus used for this experiment has been discussed and described.

Chapter 4 presents the results obtained from conducted 8PBP experiment mixed mode I+III. The result data given in form of force and displacement and graph force against displacement been plotted, analyzed and discussed. Discussion on the delamination behavior from previous established data with regards the maximum force and displacement been discussed and compared.

Chapter 5 is the last chapter which will summarizes the work done in the entire research on this thesis. The directions and recommendations for future work research work are also has been described in this chapter.

## 1.7 Research Methodology and Flowchart

The methodology involved in this research has been shown in figure 1.2. Generally this project will be conducted in two phase which is project master 1 and project master 2. In the project master 1, this project will start with the literature review to understand the flax fabric characteristic and composite. A few testing method relate with mixed mode I + III was studied during literature review in order to find the suitable sample flax composite dimension for experimental purpose. The selection of number plies flax fabric was decided based on common experimental been conducted from previous published experimental by other researcher. Once dimension and method fabrication of flax/epoxy composite decided, the fabrication will started.

The fabrication of flax composite will be carried out by using stacking of plies manual hand lay-up rolled using epoxy 1006. The number of plies were selected based on common thickness used refer to the previous published experimental.

The characteristic of sample flax composite will be defined using experimental eight plate bending point (8PBP) method. A testing machine Shimadzu AG-X will be used for conduct 8PBP experimental. The Shimadzu AG-X with load cell will connected with two numbers of jigs which is upper jig and lower jig. The sample flax/epoxy plate will place at lower jig while experimental setup. The rate load applied to the specimen is 2mm per minute. The data obtained from the experimental 8PBP will be analyzed and showed in monitor computer connected from Shimadzu AG-X machine. Graph force versus displacement will be produced during the execution of 8PBP experimental.

Several samples were tested during experimental in order to get the graph pattern, maximum load and comparison maximum between all samples. The result experimental will be compare with previous result from previous published experimental [5].

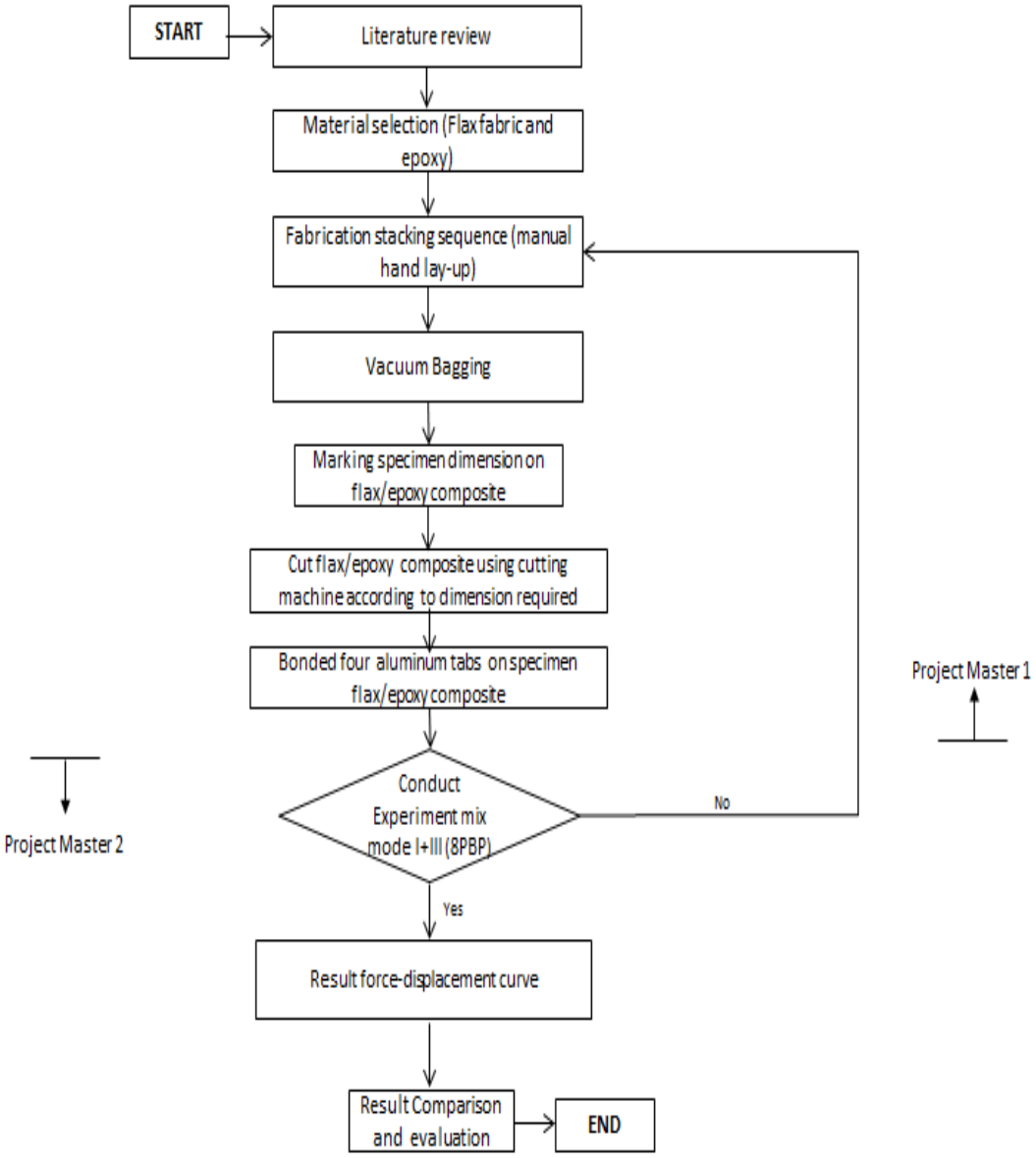


**Figure 1.2**: Flowchart of research

## REFERENCES

1. Sparnins, Edgars.” Mechanical properties of flax fibers and their composites*”*. Diss. Luleå tekniska universitet, 2009.

2. Brunner AJ, Murphy N and Pinter G. “Development of a standardized procedure for the characterization of interlaminar delamination propagation in advanced composites under fatigue mode I loading conditions.” Eng Fract Mech 2009; 76: 2678–2689.

3. Masaya Miura, Yasuhide Shindo, Tomo Takeda and Fumio Narita. “Mixed-mode I/III fatigue delamination growth in woven glass/epoxy composite laminates at cryogenic temperatures”. *Journal of Composite Materials 2014 Vol 48(10) 1251-1259.*

4. Kenane M and Benzeggagh ML. “Mixed-mode delamination fracture toughness of unidirectional glass/epoxy composites under fatigue loading.” Compos Sci Technol 1997; 57: 597–605.

5. A.B. Pereira, A.B. de Morais. "Mixed mode I+ III interlaminar fracture of carbon/epoxy laminates." Composites *: Part A 40 (2009) 518-523.*

6. Andr´as Szekr´Enyes “overview on the experimental investigations of the fracture toughness in composite materials” Submitted to HEJ. Manuscript no.: MET-020507-A

7. Madhu S. Maghukar and Laurence T. Drzal. “Fiber-Matrix Adhesion and Its Effect on Composite Mechanical Properties: IV. Mode I and Mode II Fracture Toughness of Graphite/Epoxy Composites” Composite Materials and Structures Center Michigan State University East Lansing, MI 48824.

8. Aslan, Mustafa; Sørensen, Bent F.; Madsen, Bo “Characterisation of Flax Fibres and Flax Fibre Composites. Being cellulose based sources of materials” Technical University of Denmark, Publication date: 2012.

9. Masaya Miura, Yasuhide Shindo, Tomo Takeda and Fumio Narita. “Cryogenic Interlaminar fracture properties of Woven Glass/Epoxy Composite Laminates Under Mixed-mode I/III loading condition”. Appl Compos Mater (2013) 20:587-599

10. Davidson BD and Sediles FO. “Mixed-mode I-II-III delamination toughness determination via a sheartorsion- bending test.” Compos A 2011; 42: 589–603.

11. Szekre´nyes A. “Interlaminar fracture analysis in the GI-GIII plane using prestressed transparent composite beams.” Compos A 2009; 40: 1621–1631.

12. Precision Universal Tester Autograph AGS-X Series Shimadzu Corporation. “www.Shimadzu.com/am/Precision” © Shimadzu Corporation, 2013

13. Farhad Asgari Mehrabadi and Mohammadreza Khoshravan. “Mode III Interlaminar fracture and damage characterization in woven fabrix-reinforced glass/epoxy composite laminate”. Journal composite materials 47(13) 1583-1592. (2012).

14. András Szekrényes “Interlaminar fracture analysis in the GI–GIII plane using prestressed transparent composite beams” Department of Applied Mechanics, Budapest University of Technology and Economics, H-1111 Budapest, Muegyetem rkp. 5, Building MM, Hungary, 17 July 2009.

15. Edmund F. Rybicki, Tony D. Hernandez, John E. Deibler, Ronald C. Knight and Steven S. Vinson. “ Mode I and Mixed Mode Energy release rate value for delamination of graphite/epoxy test specimens.” Journal of composite material, vol 21 - Febuary 1987

16. Edgars Sparnins, Janis Modniks, Janis Andersons. “ Experiment Study of the Mechanical Properties of Unidirectional Flax Fiber Composite” 15th International Conference on Experimental Mechanics. (2012).

17. Marat-Mendes, Rosa, and M. De Freitas. "Characterisation of the edge crack torsion (ECT) test for the measurement of the mode III interlaminar fracture toughness." Engineering Fracture Mechanics 76.18 (2009): 2799-2809.

18. Camelia Cerbu. “ Mechanical characterization of the flax/epoxy composite material”. 8th International conference interdisciplinarity in Engineering, INTER-ENG 2014, 9-10 October 2014, Tirgu-Mures, Romania.

19. A Lopez-Menendez, J Vina, A Arguelles, S Rubiera. “ A new method for testing composite material under mode III fracture”. Journal of Composite Materials 2016 vol. 50(28) 3973-3980.

20. ASTM International. “Standard test method for Mode 1 Interlaminar Fracture Toughness of Unidirectional Fibre-reinforced polymer matrix composite”. Designation : D 5528 – 01 (Reapproved 2007).

21. C. Baley. “Analysis of the flax fibres tensile behaviour and analysis of the tensile stiffness increase”. Composites: Part A 33 (2002) 939–948.

22. Ueki, Yosuke ; Lilholt, Hans; Madsen, Bo”. Fatigue behaviour of uni-directional flax fibre/epoxy composites”. Proceedings of the 20th International Conference on Composite Materials. (2015).

23. Hessam Ghasemnejad*, Hossein Mirzaii " To Improve Mixed-Mode Interlaminar Fracture Toughness of Composite Sub-Structures*"* 2014

24. Ripling EJ, Santner JS, Crosley PB. "Fracture toughness of composite adherend adhesive joints under mixed mode I and III loading." J Mater Sci 1983;18:2274–82.

25. Vintilescu I, Spelt JK. "Mixed mode I, II, and III fracture characterization of adhesive joints*".* J Compos Sci Technol Res 1998;20:129–39.

26. Robinson P, Song DQ. "The development of an improved mode III delamination test for composites". Compos Sci Technol 1994:217–33.

27. O'Brien TK. "Characterization of delamination onset and growth in a composite laminate". In: Reifsnider KL, editor. "Damage in composite materials, ASTM STP 775 ". Philadelphia: American Society for Testing and Materials; 1982. p.140–67.

28. O'Brien TK, Raju IS. "Strain energy release rate analysis of delamination around an open hole in composite materials". 25th AIAA/ASME/ASCE/AHS Structures, Structural Dynamics and Materials Conference," Palm Springs, CA, 1984, p. 526–36.