A STUDY ON IMPACT RESPONSE OF ADVANCED LAMINATE COMPOSITE

MOHD FAEZ BIN SAHARUDIN

This report is submitted as partial fulfillment of the requirements for the award of
Bachelor of Mechanical Engineering (Thermal Fluid)

Faculty of Mechanical Engineering
University Technical Malaysia Melaka

APRIL 2009

"I admit that had read this dissertation and in my opinion this dissertation is satisfactory in the aspect of scope and quality for the bestowal of Bachelor of Mechanical Engineering (Thermal Fluid)"

Signature :
Supervisor I Name : Pn Siti Hajar Binti Sheikh Md Fadzullah
Date :

Signature :
Supervisor II Name : Pn Nortazi Binti Sanusi
Date :

"I verify that this report is my own word except citation and quotation that the source has been clarify for each one of them"

Signature :
Writer Name : Mohd Faez bin Saharudin
Date :

For my beloved parent and siblings

ACKNOWLEDGEMENT

I would like to thank my supervisor, Pn Siti Hajar Binti Sheikh Md Fadzullah for her support, guidance and encouragement during completion of this Projek Sarjana Muda.

I also would like to thank all the lecturers, technician and laboratory assistant for assisting me in this project from the start. I would like to tell that their help are very much appreciated especially to En Azhar from FKP (UTeM) and En Wan Shahril from FKM (UTeM).

My thanks also go to my parents, friends and everyone that helped me in finishing my project. I hope this report would be beneficial for future student as a reference.

ABSTRACT

This research is focus on the study of impact response of advanced laminate composite. This research investigates the effect of different velocity on impact behavior of different types of advanced composite materials. Impact may be defined as the relatively sudden application of an impulsive force, to a limited volume of material or part of a structure. The effect of impacts are widely known and yet analyzing the phenomenon and relating effects to the forces acting and the materials properties. The specimen used in this project are uni-directional carbon fibre, woven carbon fibre and woven glass fibre. Three type of testing were carried out including Quasi-static compression test based on ASTM D695, surface analysis using scanning electron micrograph (SEM) and Finite Element Analysis using Cosmos Xpress. In this study, Quasi-static compression test were carried out at different loading rate ranging from 0.2mm/min to 0.6mm/min for each type of material. From the results, it is found that the mean load of woven type of carbon fibre and glass fibre process the highest load compared to uni-directional carbon fibre. During impact test, the highest velocities used have an effect on the structure of material. This is because load and energy are directly proportional. As the load increase, therefore the energy increased. Fractographic is use to study the fracture surface. This has proved to be extremely useful for failures in fibre reinforced plastic composites. The orientations of material have an effect on failure surface analysis of material. Several types of damages were observed under impact test and this includes upper failure, fractured failure, fragmentation failure and kind band failure.

ABSTRAK

Fokus penyelidikan ini adalah tentang reaksi impak bahan komposit berlapis. Penyelidikan ini adalah mengkaji kesan daripada perbezaan halaju pada kelakuan impak bahan komposit berlapis pelbagai jenis. Secara asasnya, impak membawa maksud satu perihal yang mengejut dari satu daya yang cenderung pada isipadu bahan yang terbatas atau pada bahagian strukturnya. Kesan impak adalah secara menyeluruh, namun demikian kesudahan atau keakhiran sesuatu perwujudan daya yang menyeluruh amat sukar diramalkan. Bahan contoh yang digunakan dalam projek ini adalah gentian karbon jenis searah, gentian karbon jenis fabrik tenun dan gentian kaca jenis fabrik tenun. Tedapat tiga jenis ujian dijalankan termasuk proses ujian kaedah mampatan kuasi-statik yang merujuk pada ASTM D695, analisis permukaan bahan menggunakan Mikroskop Imbasan Elektron (SEM) dan analisis unsur terhingga menggunakan perisian 'Cosmos Xpress'. Dalam kajian ini, ujian mampatan kuasi-statik bahan dijalankan pada halaju berbeza meliputi halaju mapatan pada 0.2mm/min sehingga 0.6mm/min. Berdasarkan hasil daripada kajian, didapati bahawa beban purata pada gentian karbon dan gantian kaca jenis fabrik tenun mempunyai nilai daya yang besar berdanding gantian karbon jenis searah. Melalui ujian hentaman, ketinggian nilai halaju yang dikenakan mempengaruhi kesan permukaan bahan. Ini semua berlaku kerana daya berkadar langsung dengan tenaga. Lebih banyak daya dikenakan maka nilai tenaga turut bertambah. Kajian pada kesan permukan bahan yang patah dibuktikan bagi kegunaan kajian terhadap kegagalan bahan komposit plastik bertetulang gentian. Arah hala bahan komposit turut mempengaruhi analisis kegagalan pada permukaan bahan. Terdapat beberapa jenis kerosakan bahan yang berlaku akibat dari ujian impak mampatan, antaranya patah atas bahan, patah penyerpihan, patah retakan dan patah jalur punding.

TABLE OF CONTENT

CHAPTER	TOPIC	PAGE
	CONFESSION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENT	vii
	LIST OF TABLE	xi
	LIST OF FIGURE	xiii
	LIST OF SYMBOL	xviii
	LIST OF APPENDIX	xix
CHAPTER I	**INTRODUCTION**	1
	1.0 Introduction	1
	1.1 Objective of this research	2
	1.2 Problem Statement	2
	1.3 Scope of the research	2
	1.4 Planning and execution – PSM 1 and PSM 2	3
CHAPTER II	**LITERATURE REVIEW**	5
	2.1 Introduction	5
	2.1.1 Failure of Composites	6

CHAPTER	TOPIC	PAGE

2.2 Compression Fatigue Failure of CFRP Laminates with Impact Damage

2.2.1 Experimental of Compression Fatigue Failure of CFRP Laminates. 7

2.2.2 Result and Discussion of Experimental For Compression Fatigue Failure of CFRP Laminates Test. 8

2.3 Impact Response of Advance Laminate Composite 12

2.3.1 Experimental tests 13

2.4 An experimental study on the Charpy impact response of cracked aluminum plates repaired with GFRP or CFRP composite patches 17

2.4.1 Investigation of Charpy impact response of cracked with GFRP or CFRP composite patches 18

2.5 Impact Behavior of Laminated Composite Plates 21

CHAPTER III **METHODOLOGY** 26

3.1 Overview 26

3.2 Material and Specimen Preparation 28

3.2.1 Material 28

3.2.1.1 Carbon Fiber 29

3.2.1.2 Glass Fiber Reinforced Plastic (GFRP) 31

3.2.2 Specimen Preparation 32

3.2.3 Fabrication Specimen Compression Test 33

CHAPTER	TOPIC	PAGE

3.3 Experimental Condition 35

3.3.1 Quasi – Static Compression Test. 35

3.4 Quasi Static Compression Test 36

3.4.1 Compression Test 37

3.5 Fractograhic Analysis Using SEM 38

3.5.1 Procedure for failure analysis component 39

3.5.2 Surface Analysis via Scanning Electron Microscope (SEM) 40

3.5.3 Impact Damage 41

3.5.3.1 SEM Examination 41

3.6 Finite Element Analysis (FEA). 42

3.6.1 Finite Element Analysis via Solid Work COSMOS Xpress. 42

3.6.2 Simulation Analysis vis Cosmos Xpress under Finite Element Analysis. 44

CHAPTER IV RESULT AND DISCUSSION 45

4.1 Result of Mechanical Testing of Quasi - Static Compression Test. 45

4.1.1 Compression Test of Uni-directional Carbon Fibre Reinforced Plastic (CFRP) of Laminate Composite. 45

4.1.1 Compression Test of Woven Carbon Fibre Reinforced Plastic (CFRP) of Laminate Composite. 52

4.1.3 Compression Test of Woven Glass Fibre Reinforced Plastic (GFRP) of Laminate Composite. 58

4.2 Comparison of Compression Properties for Different Material and Orientation. 65

CHAPTER	TOPIC	PAGE

4.3 Scanning Electron Micrograph, (SEM) Analysis 72
4.3.1 Comparison of Uni-Directional Carbon Fibre 72
4.3.2 Comparison of Woven Carbon Fibre 74
4.3.3 Comparison of Woven Glass Fibre(GFRP) 76
4.4 Finite Element Analysis (FEA) under Cosmos Express 78
4.4.1 FEA Analysis for Uni-Directional Carbon Fibre at Maximum and Minimum Velocity under Compression Test. 79
4.4.1.1 FEA Simulation Analysis and Result for Uni-Directional Carbon Fibre. 81
4.4.2 FEA Analysis for Woven Carbon Fibre at Maximum and Minimum Velocity under Compression Test. 86
4.4.2.1 FEA Simulation Analysis and Result for Woven Carbon Fibre. 87
4.4.3 FEA Analysis for Woven Glass Fibre at Maximum and Minimum Velocity under Compression Test. 92
4.4.2.1 FEA Simulation Analysis and Result for Woven Carbon Fibre. 93

CHAPTER V **CONCLUSION** 98
CHAPTER VI **RECOMMENDATION FOR FUTURE WORK** 99

REFERENCES 100
BIBLIOGRAPHY 103
APPENDIX 104

LIST OF TABLE

NO	TITLE	PAGE
1.1	Gantt Chart of The Research for PSM I-2008	3
1.2	Gantt Chart of The Research for PSM II -2009	4
3.1	Carbon Fiber Properties.	30
3.2	The Fibre Orientation, Compression Modulus and Strength Data.	31
3.3	Compression Modulus and Strength Data for Different Lay-Ups of GFRP	32
3.6	Dimensions for compression test follow ASTM D695.	33
3.10	Uni-Directional (UD) Carbon Fibre Reinforced Plastic. (CFRP)	35
3.11	Woven Carbon Fibre Reinforced Plastic. (CFRP)	36
3.12	Woven Glass Fibre Reinforced Plastic. (GFRP)	36
4.1	Data of Experiment for Compressive Test for Uni-directional Carbon Fiber Reinforce. (CFRP)	47
4.2	Data of Maximum and Minimum Energy at Different Velocity for Uni-directional Carbon Fibre.	49
4.3	Data of Maximum and Minimum Load (kN) at Different Velocity for Uni-directional Carbon Fibre.	51
4.4	Mean Load, kN at Different Loading Rate.	52
4.5	Experiment Data for Woven Carbon Fiber Reinforce (CFRP) Under Quasi-Static Compression Test.	54
4.6	Maximum Energy and Minimum Energy at Maximum Compression Load.	55
4.7	Maximum Load and Minimum Load For Woven Carbon Fibre.	57
4.8	Mean Load, kN at Different Loading Rate For Woven Carbon Fibre	58

4.9	Experiment Data for Woven Glass Fiber Reinforce (CFRP) Under Quasi-Static Compression Test.	60
4.10	Data of Maximum and Minimum Energy at Different Velocity for Woven Glass Fibre.	62
4.11	Data of Maximum and Minimum Load (kN) at Different Velocity for Woven Glass Fibre.	64
4.12	Mean Load, kN at Different Loading Rate.	65
4.13	Comparison Different Material and Orientation Laminate Composite under Compression Test.	67
4.14	Visual Observation for Uni-directional Carbon Fibre under Compression Test.	70
4.15	Visual Observation for Woven Carbon Fibre under Compression Test.	71
4.16	Visual Observation for Woven Glass Fibre under Compression Test.	72
4.17	Data Analysis of Uni-Directional Carbon Fibre at maximum velocity.	81
4.18	Data Analysis of Uni-directional Carbon Fibre at minimum velocity.	82
4.19	Result of Stress Analysis of Specimen at 0.2mm/min.	84
4.20	Data Analysis at Loading Rate 0.6mm/min for Woven Carbon Fibre via Cosmos Xpress.	87
4.21	Data Analysis at Loading Rate 0.6mm/min for Woven Carbon Fibre via Cosmos Xpress.	88
4.22	Result of Stress Analysis of Specimen at 0.6mm/min.	90
4.23	Result of Stress Analysis of Specimen at 0.2mm/min.	90
4.24	Data Analysis of Woven Glass Fibre via Cosmos Xpress.	93
4.25	Data Analysis of Woven Glass Fibre via Cosmos Xpress.	94
4.26	Analysis of Von Mises stress at Maximum Velocity.	96
4.27	Analysis of Von Mises stress at Minimum Velocity.	96

LIST OF FIGURE

NO	TITLE	PAGE
2.1	Properties of patch materials and adhesive	8
2.2	Specimen codes and patches types	9
2.3	Photographs of an unimpacted AS4/PEEK specimen in fatigue	10
2.4	Photographs of an impacted UT500/Epoxy specimen with De /b =0.55	10
2. 5	Photographs of an impacted AS4/PEEK specimen	11
2.6	SEM photographs showing kink band occurred	12
2.7	Size and stitching pattern of unstitched and stitched samples	14
2.8	Typical force versus time curves of impacted	15
2.9	Typical force versus displacement curves of impacted	15
2.10	X-radiographs of unstitched [03/903]s laminates impacted	16
2.11	X-radiographs of stitched [03/903] s laminates impacted	16
2.12	Specimen with different crack lengths	18
2.13	Specimen with patch before impact test	20
2.14	Specimen 10 after impact test	20
2.15	Specimen 12 after impact test.	21
2.16	Compression after impact (CAI) test fixture.	22
2.17	(a) Horizontal and (b) Vertical damage according to loading directions.	23
2.18	CAI Damage propagations	23
2.19	Direction of CAI damage propagation	23
2.20	Effect of impact damages on CAI damage propagation	24
2.21	CAI damage propagations	24
3.1	Process Flow Chart of Research	27

NO **TITLE** **PAGE**

NO	TITLE	PAGE
3.2	Flow of Material Preparation for Different Type of Composite Material	28
3.3	Uni-directional Carbon Fiber Reinforced Plastic (CFRP)	29
3.4	Woven Carbon Fiber Reinforced Plastic (CFRP)	29
3.5	Uni-Directional Glass Fiber Reinforced Plastic (GFRP)	32
3.9	A schematic diagram shows dimensions for 0º plies.	34
3.10	Process fabrication of compression test specimen for woven carbon.	34
3.11	Specimen of carbon and glass fiber reinforced plastic after cutting process.	34
3.12	Universal Testing Machine (UTM).	37
3.13	The position of Specimen Stating Compression Test.	38
3.14	Specimen Condition during Compression Testing Running	38
3.15	Procedure for failure analysis of composites	40
3.16	SEM Machine	41
3.17	Impact Damage Growth Prior of compression failure in a Composite.	42
3.18	Diagram of specimen before analysis via cosmos Xpress.	44
3.19	Position of load applies to specimen under simulation analysis.	44
3.20	Cosmos Xpress process via the finite element analysis.	45
4.1	Load extension relationship for specimen under quasi static compression test for uni-directional carbon fibre.	48
4.2	Graph of maximum energy versus different loading rate.	49
4.3	Graph of minimum energy versus different loading rate.	50
4.4	Graph of maximum loads versus difference loading rate for uni-directional carbon fibre.	51
4.5	Graph of minimum loads versus difference loading rate for uni-directional carbon fibre.	52
4.6	Graph of mean load (kN) versus different loading rate for uni-directional carbon fibre.	53

NO	TITLE	PAGE

NO	TITLE	PAGE
4.7	Load extension relationship for specimen under quasi static compression test for uni-directional carbon fibre.	54
4.8	Maximum energy versus different loading rate for woven carbon fibre.	55
4.9	Graph of minimum energy versus different loading rate for woven carbon fibre	56
4.10	Graph of maximum load, kN versus loading rate (mm/min) for woven carbon fibre	57
4.11	Graph of minimum load, kN versus loading rate (mm/min) for woven carbon fibre..	58
4.12	Graph of mean load versus different loading rate for woven carbon fibre	59
4.13	Compressive load versus extension for woven glass fibre.	61
4.14	Maximum energy versus different loading rate of woven glass fibre.	62
4.15	Minimum energy versus different loading rate of woven glass fibre	63
4.16	Maximum loads versus different loading rate of woven glass fibre.	64
4.17	Minimum loads versus different loading rate of woven glass fibre	65
4.18	Mean load versus different loading rate for woven glass fibre.	66
4.19	Mean energy, J versus loading rate, mm/min for every laminate composite under compression test.	68
4.20	Mean load, kN versus loading rate, mm/min for every laminate composite under compression test	69
4.21	SEM Micrograph of UD carbon fibre at loading rate 0.2mm/min	74
4.22	SEM Micrograph of UD carbon fibre at loading rate 0.6mm/min	74

NO	TITLE	PAGE
4.23	SEM Micrograph of UD carbon fibre at loading rate 0.4mm/min	75
4.24	SEM Micrograph of Woven carbon fibre at loading rate 0.2mm/min	76
4.25	SEM Micrograph of Woven carbon fibre at loading rate 0.4mm/min	76
4.26	SEM Micrograph of Woven carbon fibre at loading rate 0.6mm/min	77
4.27	SEM Micrograph of Woven Glass fibre at loading rate 0.2mm/min	78
4.28	SEM Micrograph of Woven Glass fibre at loading rate 0.4mm/min	78
4.29	SEM Micrograph of Woven Glass fibre at loading rate 0.6mm/min	79
4.30	Analysis of uni-directional carbon fibre at maximum velocity data	83
4.31	Analysis of uni- directional carbon fibre at minimum velocity data	83
4.32	Check analysis simulation process for UD carbon fibre under	85
4.33	Result of simulation for UD carbon fibre under maximum loading rate.	85
4.34	Check analysis simulation process for UD carbon fibre under 0.2mm/min	86
4.35	Result of simulation for UD carbon fibre under minimum loading rate.	86
4.36	Analysis of woven carbon fibre at maximum velocity (0.6mm/min)	89
4.37	Analysis of woven carbon fibre at minimum velocity (0.2mm/min) under compression test.	89
4.38	Check analysis simulation process for woven carbon fibre at loading rate 0.6mm/min	91

NO	TITLE	PAGE
4.39	Simulation result of woven carbon fibre using loading rate of 0.6mm/min under compression test.	91
4.40	Check analysis simulation process for woven carbon fibre at loading rate 0.2mm/min	92
4.41	Simulation result of woven carbon fibre using loading rate of 0.6mm/min under compression test.	92
4.42	Analysis of woven glass fibre at maximum velocity data under compression test.	95
4.43	Analysis of woven glass fibre at minimum velocity data under compression test.	95
4.44	Check analysis simulation process for woven glass fibre at loading rate 0.6mm/min	97
4.45	Simulation result of woven g;ass fibre using loading rate of 0.6mm/min under compression test.	97
4.46	Check analysis simulation process for woven glass fibre at loading rate 0.2mm/min	98
4.47	Simulation result of woven glass fibre using loading rate of 0.2mm/min under compression test.	98

LIST OF SYMBOL

σ	=	Engineering stress
Δ*l*	=	Elongation
ε.	=	Engineering strain
*l*o	=	initial length
Ao	=	cross section area
F	=	uniaxial tensile force
ºC	=	Degree celcius

APPENDIX LIST

BIL **TITLE** **PAGE**

BIL	TITLE	PAGE
1	ASTM D695- compression test	104
2	Compression Test Data – mechanical testing	105

CHAPTER I

INTRODUCTION

1.0 Introduction

Impact may be defined as the relatively sudden application of an impulsive force, to a limited volume of material or part of a structure. The effect of impacts are widely known and yet analyzing the phenomenon and relating effects to the forces acting and the materials properties, in order to predict the outcome of a particular event, can be very difficult. The impact responses of the laminate specimens with different geometry were very different in fine details in terms of the magnitude of maximum impact force, impact duration and energy absorption, some features were common throughout.

Impact test can be applied by using advanced composites material. They are composite materials which traditionally used in the aerospace industries. These composites have high performance reinforcements of a thin diameter in a matrix material such as epoxy and aluminum. The most common advanced composites are polymer matrix composites (PMC).

1.1 Objectives

The objectives of this research are to study and discuss the effects of different velocity on impact behavior of different types of advanced composite materials.

1.2 Problem Statement

This research has been carried out due to impact problem. Impact damage is the type of damage, which most significantly affects the structural strength. Therefore, primarily the level of impact damage that is significant to be tolerated and that has to be reliable detected needs to be specified.

1.3 Scope of the research

This research comprises of the following scope:-

a) To do literature study on composite material particularly related to impact.
b) To carry out mechanical testing for different type of composite materials at different velocity.
c) To carry out surface analysis after testing via 'SEM'.
d) To compare the data using 'Finite Element.

1.4 Planning and execution

The research activity that is carried out in this project is tabulated in the Table 1.1 and Table 1.2 for PSM I and PSM II respectively.

Table 1.1: GANTT CHART OF THE RESEARCH FOR PSM I-2008

RESEARCH ACTIVITY/TIME	JULY				AUGUST				SEPTEMBER				OCTOBER	
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1) Proposal														
2) Literature Review														
a) Impact Response														
b) Advanced laminate composites														
3) Research Methodology														
a) Research of experiment/ Design Experiment														
b) Mechanical testing -Quasi-static test - Drop weight impact - Fractograhic analysis using SEM - FEA analysis														
4) Report writing for PSM 1														
5) Preparation for Seminar 1														
6) Submission of report and log book														

Table 1.2: GANTT CHART OF THE RESEARCH FOR PSM II -2008

	JANUARY				FEBRUARY				MARCH				APRIL	
RESEARCH ACTIVITY/TIME	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1) Literature review														
a) Impact Response														
b) Advance Laminate composite														
2) Research Methodology														
a) Experiment Activities														
i. Quasi Static test														
b) Mechanical Testing														
i. Compression test														
c) Fractographic Analysis using SEM														
d) Compare data using Finite Element analysis														
3) Result and Analysis														
4) Report writing for PSM II														
5) Preparation for PSM Seminar II														
6) Submission of report & log book														