# MECHANICAL, PHYSICAL, THERMAL AND BIODEGRADABILITY STUDIES OF LOW DENSITY POLYETHYLENE/THERMOPLASTIC SAGO STARCH/KENAF CORE FLOUR BIOCOMPOSITES

by

#### NORSHAHIDA BINTI SARIFUDDIN

Thesis submitted in fulfillment of the requirements for the degree of Doctor of Philosophy

#### ACKNOWLEDGEMENT

First and foremost, my utmost gratitude and praise is to Allah, the Most Merciful and Most Compassionate for His blessings, that I was able to complete this research work. And, I feel so blessed for the given opportunity and granting the capability to proceed successfully. Completing my PhD degree is probably the most challenging activity of my 31 years of life. The best and worst moments of my doctoral journey have been shared with many people. I would like to express my sincere gratitude to all of them.

To my PhD supervisor, Prof. Dr. Hanafi Ismail, I am extremely grateful for his valuable guidance, scholarly inputs and consistent encouragement I received throughout the research work. It is a great opportunity to do my doctoral program under his supervision and to learn from his research expertise. I also would like to express my gratitude to the one who always has confidence in me, Assoc. Prof. Ir. Dr. Zuraida Ahmad. She was among those who kept me going at the beginning, who was the source of inspiration since the early days, and who taught me many things, including academic and career planning, personal related matters as well as life and spiritual conduct.

Most of the results described in this thesis would not have been obtained without a close collaboration with few laboratories. I owe a great deal of appreciation and gratitude to Mr. Shahril Amir Salleh and Mr. Suharuddin Sulong (Rubber Lab), Mr. Mohamed Hassan (Plastic Lab), Mr. Faizal (Latex Lab), Mr. Rashid and Mr. Khairi (SEM Lab), Mr. Shaarani and Mr. Sharizol (Workshop) as well as Mr. Azrul (Chemical Lab) for their help and support during my experimentation in those laboratories. Besides, I would like to thank administrative and technical staff members of the SMMRE, USM who has been kind enough to advise and help in

their respective roles. I am indebted to my research group colleagues for providing a stimulating and fun filled environment. Many thanks go in particular to Sam Sung Ting, Ragunathan, Mohd Kahar, Shazlin Shaari, Nabil, Nor Fasihah, Rohani, Ooi, Maryam Irani, Shamala Ramasamy, Shamila, Maryam Mansor, Pang Ai Ling, Dalina, Siti Zuliana and Hazwani Syaza for their personal and scholarly interaction. Words are short to express my deep sense of gratitude towards my following friends, Siti Shuhadah, Norhidayah, Nurfarahiyah, Siti Rohana, Khairul Arifah, Norhuda Hidayah, Syazwani and Syahriza who have been a part of my campus life journey and with whom I have enjoyed my past three years. Many thanks go to fellow friends who give their ears to listen to, their shoulder to cry on, their heart to care specially Afifah, Siti Noorbahiyah, Suhaily Mokhtar, Farah Diana, Nurul Hajar, Noor Khairushima, Muna Tasnim and Toibah as well as Rina, Liza, Azia, Jaimah, Analis Salleh, Nana, Ila and Mira for this ten years friendship and for their constant support in every way.

This thesis is dedicated to my beloved parents Mr. Sarifuddin Harun and Mrs. Norainun Mohd Usop for their non-stop encouragement and support to me through laugh and tears. Though they have not even attended university during their time, yet, they pray and wish to see their child passes through all the way of schooling has made me what I am now. I will never forget what we've gone through in some phase of life emotionally and financially, and that made me really appreciate this pathway. And my special thanks also dedicated to my siblings, Ayo, Wan as well as Adik for their care and love. Finally, I am also grateful to the financial support received through the IIUM funding as well as scholarship from International Islamic University Malaysia (IIUM).

## TABLE OF CONTENTS

Acknow	edgementii
Table of	Contentsiv
List of T	ablesxii
List of F	guresxvii
List of A	breviationsxxxvii
List Of S	ymbolsxxxix
Abstrak .	xli
Abstract	xliii
CHAPTI	ER 1 - INTRODUCTION
1.1	Background1
1.2	Problem statement
1.3	Research objectives
1.4	Thesis outline6
CHAPTI	ER 2 - LITERATURE REVIEW
2.1	Introduction
2.2	Environmental Issues and Degradation
2.3	Biodegradable Polymer
	2.3.1 Starch
	2.3.2 Thermoplastic starch

2.4	Synth	etic Polymer/Biodegradable Polymer Blends	20
	2.4.1	Low Density Polyethylene (LDPE)	20
	2.4.2	Low Density Polyethylene (LDPE)/Thermoplastic Starch (TPS	3)
		Blend	22
	2.4.3	Properties of Low Density Polyethylene (LDPE)/Thermoplastic	.c
		Starch (TPS) Blend	24
2.5	Natura	al Fiber Reinforced Synthetic Polymer/Biodegradable Polymer	
	Blend	<b></b>	26
	2.5.1	Natural Fiber as Reinforcement	27
	2.5.2	Kenaf Fiber	35
	2.5.3	Kenaf and Its Composites	40
	2.5.4	Natural Fibers Reinforced Thermoplastic Starch	43
		2.5.4.1 Properties of Natural Fibers Reinforced Thermoplastic	c
		Starch	45
	2.5.5	Natural Fibers Reinforced Synthetic Polymer/Thermoplastic S	tarch
		Blend	49
2.6	Fiber/	Matrix Adhesion: Challenges	51
2.7	Chem	ical Modification of Natural Fibers	52
2.8	Hybri	dization of Polymer Composites with the Addition of Inorganic	
	Miner	al Fillers	60
	2.8.1	Inorganic Mineral Fillers	62
	2.8.2	Properties of Hybrid Composites	66
2.9	Degra	dation	71
	2.9.1	Natural Weathering	71
	2.9.2	Soil burial	75

## CHAPTER 3 - METHODOLOGY

3.1	Introd	uction	79
3.2	Raw r	naterials	79
	3.2.1	Low Density Polyethylene (LDPE)	79
	3.2.2	Sago starch	80
	3.2.3	Kenaf Core Fillers	80
	3.2.4	Halloysite Clay	81
3.3	Chem	icals	81
	3.3.1	Glycerol	81
	3.3.2	Sodium Hydroxide	82
	3.3.3	Methyl Methacrylate	83
	3.3.4	Benzoyl Peroxide	83
	3.3.5	Acetone	84
3.4	Outlin	ne of the study	84
3.5	Samp	le Preparation	88
	3.5.1	Preparation of Thermoplastic Sago Starch	88
	3.5.2	Preparation of LDPE/KCF Composites with the Addition of	
		TPSS	89
	3.5.3	Preparation of LDPE/TPSS Blends Reinforced with Kenaf Cor	e
		Fillers	91
	3.5.4	Preparation of LDPE/TPSS Blend Reinforced with MMA-Trea	ited
		Kenaf Core Fillers (KCF)	91
	3.5.5	Preparation of LDPE/TPSS Blends Reinforced KCF with the	
		Addition of Halloysite Clay	93
3.6	Degra	dation Test	94

	3.6.1	Natural Weathering	94
	3.6.2	Soil Burial	96
3.7	Measu	rement and Analysis	97
	3.7.1	Tensile Properties	97
	3.7.2	Fourier Transform Infra-Red (FTIR) Analysis	98
	3.7.3	Thermogravimetric Analysis (TGA)	99
	3.7.4	Differential Scanning Calorimetry (DSC)	99
	3.7.5	Scanning Electron Microscopy (SEM)	100
	3.7.6	Water Absorption	100
	3.7.7	Weight Loss	101
LDPE/T	PSS/KC	PREPARATION AND CHARACTERIZATION OF COMPOSITES	
4.1		uction	
4.2	Effect	of TPSS Loading	
	4.2.1	Processing Characteristics	102
	4.2.2	Fourier Transform Infra-Red (FTIR) Analysis	105
	4.2.3	Tensile Properties	112
	4.2.4	Thermogravimetric Analysis (TGA)	117
	4.2.5	Differential Scanning Calorimetry (DSC)	121
	4.2.6	Morphological Properties	124
	4.2.7	Water Absorption	128
4.3	Effect	of Natural Weathering on the Properties of LDPE/TPSS/KCF	
	Comp	osites at Different TPSS Loading	130
	4.3.1	Visual Observation	130

	4.3.2	Tensile Properties	132
	4.3.3	Fourier Transform Infra-Red (FTIR)	138
	4.3.4	Differential Scanning Calorimetry (DSC)	141
	4.3.5	Morphological Properties	144
	4.3.6	Weight Loss	148
4.4	Effect	of Soil Burial on the Properties of LDPE/TPSS/KCF Composit	es at
	Differ	ent TPSS Loading	150
	4.4.1	Visual observation	150
	4.4.2	Tensile Properties	151
	4.4.3	Fourier Transform Infra-Red (FTIR) Analysis	156
	4.4.4	Differential Scanning Calorimetry (DSC)	159
	4.4.5	Morphological Properties	161
	4.4.6	Weight Loss	164
4.5	Effect	of KCF Loading	166
	4.5.1	Processing Characteristics	166
	4.5.2	Fourier Transform Infra-Red (FTIR) Analysis	168
	4.5.3	Tensile Properties	170
	4.5.4	Thermogravimetric Analysis (TGA)	174
	4.5.5	Differential Scanning Calorimetry (DSC)	177
	4.5.6	Morphological Properties	179
	4.5.7	Water Absorption	183
4.6	Effect	of Natural Weathering on the Properties of LDPE/TPSS/KCF	
	Comp	osites at Different KCF Loading	185
	4.6.1	Visual observation	185
	4.6.2	Tensile Properties	186

	4.6.3	Fourier Transform Infra-Red (FTIR) Analysis	192
	4.6.4	Differential Scanning Calorimetry (DSC)	196
	4.6.5	Morphological Properties	198
	4.6.6	Weight Loss	202
4.7	Effect	of Soil Burial on the Properties of LDPE/TPSS/KCF Comp	osites at
	Differ	ent KCF Loading	204
	4.7.1	Visual observation	204
	4.7.2	Tensile Properties	205
	4.7.3	Fourier Transform Infra-Red (FTIR) Analysis	209
	4.7.4	Differential Scanning Calorimetry (DSC)	212
	4.7.5	Morphological Properties	215
	4.7.6	Weight Loss	218
		EFFECT OF FILLER TREATMENT ON THE PROPERTIE	ES OF
LDPE/T	PSS/KC	CF COMPOSITES	
5.1	Introd	uction	220
5.2	Effect	of Filler Treatment	220
	5.2.1	Processing Characteristics	220
	5.2.2	Fourier Transform Infra-Red (FTIR) Analysis	223
	5.2.3	Tensile Properties	228
	5.2.4	Thermogravimetric Analysis (TGA)	234
	5.2.5	Differential Scanning Calorimetry (DSC)	237
	5.2.6	Morphological Properties	240
	5.2.7	Water Absorption	244

5.3	Effect	Effect of Natural Weathering on the Properties of LDPE/TPSS/Treated		
	KCF (	Composites	246	
	5.3.1	Visual observation	246	
	5.3.2	Tensile Properties	247	
	5.3.3	Fourier Transform Infra-Red (FTIR) Analysis	252	
	5.3.4	Differential Scanning Calorimetry (DSC)	256	
	5.3.5	Morphological Properties	259	
	5.3.6	Weight Loss	261	
СНАРТ	ΓΕ <b>R</b> 6 - F	EFFECT OF INORGANIC MINERAL FILLERS ADDITI	ON ON	
		TIES OF LDPE/TPSS/KCF COMPOSITES	011 011	
			262	
6.1		luction		
6.2	Effect	t of Halloysite Clay Loading	264	
	6.2.1	Processing Characteristics	264	
	6.2.2	Tensile Properties	266	
	6.2.3	Fourier Transform Infra-Red (FTIR) Analysis	272	
	6.2.4	Thermogravimetric Analysis (TGA)	274	
	6.2.5	Differential Scanning Calorimetry (DSC)	278	
	6.2.6	Morphological Properties	280	
	6.2.7	Water Absorption	285	
6.3	Effect	t of Natural Weathering on the Properties of LDPE/TPSS/	KCF	
	Comp	posites with the Addition of Halloysite Clay	287	
	6.3.1	Visual observation	287	
	6.3.2	Tensile Properties	288	
	6.3.3	Fourier Transform Infra-Red (FTIR) Analysis	293	

	6.3.4	Differential Scanning Calorimetry (DSC)	296
	6.3.5	Morphological Properties	298
	6.3.6	Weight Loss	301
6.4	Effect	of Soil Burial on the Properties of LDPE/TPSS/ KCF Composi	ites
	with tl	he Addition of Halloysite Clay	302
	6.4.1	Visual observation	302
	6.4.2	Tensile Properties	303
	6.4.3	Fourier Transform Infra-Red (FTIR) Analysis	307
	6.4.4	Differential Scanning Calorimetry (DSC)	310
	6.4.5	Morphological Properties	313
	6.4.6	Weight Loss	316
CHAPTE		CONCLUSIONS AND RECOMMENDATIONS FOR FUTURI	E
7.1	Concl	usions	318
7.2	Recon	nmendations for future works	320
REFERE	ENCES.		322
LIST OF	PUBL	ICATIONS	346
APPENI	DICES		

## LIST OF TABLES

		Page
Table 2.1	Physical properties and chemical composition of different starch (adapted from Averous & Halley, 2009 and Singhal et al., 2008)	17
Table 2.2	Summary of the works done related to the LDPE and starch blends in a chronological order	23
Table 2.3	Recent reported work on natural fibers and polymer composites	28
Table 2.4	Chemical compositions of various natural fibers (Majeed et al., 2013; Faruk et al., 2012)	32
Table 2.5	Mechanical and physical properties of various natural fibers (Abdul Khalil & Suraya, 2011; Majeed et al., 2013)	34
Table 2.6	Mean value of fiber length, fiber diameter and fiber cell wall thickness of V36 type kenaf (H`ng et al. 2009)	38
Table 2.7	Chemical composition of different fractions of kenaf fibers (Abdul Khalil et al., 2010)	39
Table 2.8	The development of kenaf fiber reinforced polymer composites in chronological order	40
Table 2.9	Biocomposites based on thermoplastic starch	44

Table 2.10	Chronological development of the MMA-grafted fiber reinforced polymer composites	59
Table 2.11	Chronological development of hybrid composites	63
Table 3.1	Product information (Titan-data sheet)	79
Table 3.2	Chemical Composition of Halloysite clay (Ismail et al., 2008)	81
Table 3.3	Product information (Merck-data sheet)	82
Table 3.4	Product information (Merck-data sheet)	82
Table 3.5	Product information (Sigma Aldrich-data sheet)	83
Table 3.6	Product information (Merck-data sheet)	83
Table 3.7	Details of experiment by stages	84
Table 3.8	Composite formulation	88
Table 3.9	Composite formulation	90
Table 3.10	Composite formulation	91
Table 3.11	Composite formulation	93
Table 3.12	Climatic conditions during the test	94
Table 4.1	TGA results for LDPE/KCF (80/20) composites with various	121

# TPSS loadings

Table 4.2	DSC results for LDPE/KCF (80/20) composites with various	123
	TPSS loadings	
Table 4.3	Tensile properties retention ratios of LDPE/KCF (80/20) composites with different TPSS loadings after exposed to outdoor natural weathering for 3 and 6 months	138
Table 4.4	Representative DSC results of composites after exposed to outdoor natural weathering for 3 and 6 months	142
Table 4.5	Tensile properties retention ratios of LDPE/KCF (80/20) composites with different TPSS loadings after being subjected to soil burial for 3 and 6 months	155
Table 4.6	Representative DSC results of composites after being subjected to soil burial test for 3 and 6 months	160
Table 4.7	TGA results of LDPE/TPSS (90/10) blends with different KCF loadings	177
Table 4.8	DSC results for LDPE/TPSS (90/10) blends with different KCF loadings	178
Table 4.9	Retention ratio of tensile properties of LDPE/TPSS (90/10) blends with different KCF loadings after exposed to natural weathering for 3 and 6 months	191

Table 4.10	Representative DSC results of composites after exposed to natural weathering for 3 months and 6 months	197
Table 4.11	Retention ratios of tensile properties of LDPE/TPSS (90/10) blends with different KCF loadings after being subjected to soil burial test for 3 and 6 months	208
Table 4.12	Representative DSC results of composites after being subjected to soil burial test for 3 and 6 months	213
Table 5.1	TGA results of untreated and MMA-treated KCF reinforced LDPE/TPSS blends	237
Table 5.2	DSC results of untreated and MMA-treated KCF reinforced LDPE/TPSS blends	238
Table 5.3	Retention ratios of LDPE/TPSS blend reinforced with MMA-treated KCF at different filler loading after exposure to natural weathering for 3 and 6 months	252
Table 5.4	Representative DSC results of composites with 10 phr MMA-treated KCF after exposed to outdoor natural weathering for 3 and 6 months	257
Table 6.1	TGA results for pristine halloysite clay and LDPE/TPSS/KCF composites with incorporation of halloysite clay at various loading	276
Table 6.2	DSC results for LDPE/TPSS/KCF composites with the addition	279

# of halloysite

Table 6.3	Retention ratios of LDPE/TPSS blend reinforced KCF/HC	293
	hybrid fillers at different HC loading after exposed to natural	
	weathering for 3 and 6 months	
Table 6.4	Representative DSC results of composites with the addition of	297
	12 phr halloysite clay after exposed to outdoor natural	
	weathering for 3 and 6 months	
Table 6.5	Retention ratios of LDPE/TPSS blend reinforced KCF/HC	307
	hybrid fillers at different HC loading after being subjected to	
	soil burial test for 3 and 6 months	
Table 6.6	Representative DSC results for LDPE/TPSS/KCF composites	311
	with the addition of 12 phr halloysite after being subjected to	
	soil burial test for 3 and 6 months	

#### LIST OF FIGURES

		Page
Figure 2.1	Classification of degradation reactions (adapted from Andrady, 2000)	13
Figure 2.2	Chemical structure of starch (adapted from Flieger et al. 2003)	15
Figure 2.3	Molecular structure of starch (adapted from Lu et al., 2009)	16
Figure 2.4	Schematic representation of the starch granule structure (adapted from Jenkins & Donald, 1995)	17
Figure 2.5	SEM observations of native sago starch	18
Figure 2.6	Number of journals published on the natural fibers and polymer composites. Source: www.sciencedirect.com; keywords: natural fiber, polymer composites	28
Figure 2.7	Classification of natural fibers (adapted from Kalia et al., 2009 and Pandey et al., 2010)	30
Figure 2.8	Structural constitution of a natural fiber cell (adapted from Rong et al., 2001)	31
Figure 2.9	SEM micrographs of TPS, 250 X (a), luffa fiber, 50 X (b), 500 X (c), and TPS/luffa fiber composites (20 wt. % luffa fiber, 250 X (d), 500 X (e) (adapted from Kaewtatip &	48

Figure 2.10	FTIR spectrum of (a) TPS and (b) TPS/luffa fiber composites	49
	with 20 wt. % of luffa fiber (adapted from Kaewtatip &	
	Thongmee, 2012)	
Figure 2.11	Mechanical properties of TPMBS samples with different	50
	ratios of cotton fiber/LDPE (adapted from Prachayawarakorn	
	et al., 2010a)	
Figure 2.12	Mechanism of grafting MMA on fiber (Ibrahim et al., 2003)	58
Figure 2.13	Schematic representation of fabricating the hybrid	60
	composites: newspaper fibers and talc in the polymer matrix	
	(adapted from Huda et al., 2007)	
Figure 2.14	Structure of Halloysite clays (adapted from Pasbakhsh et al.,	65
	2010)	
Figure 2.15	Schematic illustration of terminology used to describe	66
	nanocomposites formed from clays	
Figure 2.16	SEM micrographs of the fractured surface of impacted	69
	specimens of PLA/RNCF/silane treated talc composites: (A)	
	$10~\mu m$ and (B) 5 $\mu m$ (adapted from Huda et al. 2007)	
Figure 2.17	Typical photo-degradation process of polymer (Singh &	72
	Sharma, 2008)	

Figure 2.18	Typical UV degradation on natural fiber/polymer composites and its component (Azwa et al., 2013)	75
Figure 2.19	A schematic diagram showing microbial degradation mechanism	77
Figure 3.1	Experimental flow chart	87
Figure 3.2	Schematic diagram of composite's fabrication method (via melt-mixing and compression molding)	90
Figure 3.3	Experimental set up of natural weathering test	96
Figure 3.4	Schematic diagram of soil burial test assemblies	97
Figure 3.5	Tensile test specimens	98
Figure 4.1	Processing torques of LDPE/KCF (80/20) composites with different TPSS loading	104
Figure 4.2	Stabilization torques of LDPE/KCF (80/20) composites with different TPSS loading	105
Figure 4.3	IR spectra of raw materials (pristine LDPE, TPSS and KCF)	107
Figure 4.4	IR spectra of LDPE/KCF (80/20) composites with different TPSS loading with closer examination in region (i) O-H peaks (ii) O-H bonding and (iii) C-O-C and C-O-H stretching	110
Figure 4.5	Proposed interaction between starch and kenaf core filler	111

Figure 4.6	Tensile strength of LDPE/KCF (80/20) composites with different TPSS loading	115
Figure 4.7	Young's modulus of LDPE/KCF (80/20) composites with different TPSS loading	115
Figure 4.8	Elongation at break of LDPE/KCF (80/20) composites with different TPSS loading	117
Figure 4.9	TG thermograms of LDPE/KCF (80/20) composites with different TPSS loading	120
Figure 4.10	DTG thermograms of of LDPE/KCF (80/20) composites with different TPSS loading	120
Figure 4.11	DSC thermograms (melting) of LDPE/KCF (80/20) composites with different TPSS loading	123
Figure 4.12	DSC thermograms (cooling) of LDPE/KCF (80/20) composites with different TPSS loading	124
Figure 4.13	SEM morphology of tensile fracture surface of LDPE/KCF (80/20) composites with (a) 0 wt. % TPSS (b) 10 wt. % TPSS (c) 20 wt. % TPSS and (d) 40 wt. % TPSS loading (at 150X magnification)	127
Figure 4.14	Water absorption of LDPE/KCF (80/20) composites with different TPSS loading	130

Figure 4.15	Visual observation of LDPE/KCF (80/20) composites with	131
	different TPSS loadings retrieved after outdoor natural	
	weathering test for 6 months	
E: 4.16	Tancile atmosph of LDDE/VCE (90/20) composites with	125
Figure 4.16	Tensile strength of LDPE/KCF (80/20) composites with	135
	different TPSS loadings after exposed to outdoor natural	
	weathering for 3 and 6 months	
Figure 4.17	Young's modulus of LDPE/KCF (80/20) composites with	137
	different TPSS loadings after exposed to outdoor natural	
	weathering for 3 and 6 months	
Figure 4.18	Elongation at break of LDPE/KCF (80/20) composites with	137
	different TPSS loadings after exposed to outdoor natural	
	weathering test for 3 and 6 months	
F: 4.10		1.40
Figure 4.19	(a) Representative FTIR spectra of composites after exposed	140
	to outdoor natural weathering test for 3 and 6 months and (b)	
	a close examination of IR spectra indicating shoulder peak of	
	carbonyl	
Figure 4.20	Carbonyl index of LDPE/KCF (80/20) composites with	141
11801020	different TPSS loadings after exposed to outdoor natural	
	weathering test for 3 and 6 months	
Figure 4.21	Representative DSC thermograms (melting) of composites	143
	after exposed to outdoor natural weathering for 3 months and	
	6 months	

Figure 4.22	Representative DSC thermograms (cooling) of composites	143
	after exposed to outdoor natural weathering for 3 months and	
	6 months	
Figure 4.23	SEM morphology of LDPE/KCF (80/20) composites with (a)	147
	0 wt. % (b) 10 wt. % (c) 40 wt. % of TPSS after 3 months	
	weathering and (d) 0 wt. % (e) 10 wt. % (f) 40 wt. % of TPSS	
	after 6 months weathering (300 X magnification)	
Figure 4.24	Weight loss of LDPE/KCF (80/20) composites with different	150
	TPSS loadings after exposed to outdoor natural weathering	
	for 3 and 6 months	
Figure 4.25	Visual observation of LDPE/KCF (80/20) composites with	151
	different TPSS loadings retrieved after being subjected to soil	
	burial test for 6 months	
F' 4.26	To the state of the transfer o	152
Figure 4.26	Tensile strength of LDPE/KCF (80/20) composites with	153
	different TPSS loadings after being subjected to soil burial	
	test for 3 and 6 months	
Figure 4.27	Tensile strength of LDPE/KCF (80/20) composites with	154
	different TPSS loadings after being subjected to soil burial	
	test for 3 and 6 months	
Figure 4.28	Elongation at break of LDPE/KCF (80/20) composites with	155
	different TPSS loadings after being subjected to soil burial	
	test for 3 and 6 months	

Figure 4.29	(a) Representative FTIR spectra of composites after being	158
	subjected to natural soil burial test for 3 and 6 months and	
	(b) a close examination of IR spectra indicating shoulder	
	peak of carbonyl	
Figure 4.30	Carbonyl index of LDPE/KCF (80/20) composites with	159
Tiguic III	different TPSS loadings after being subjected to natural soil	137
	burial test for 3 and 6 months	
	buriar test for 3 and 6 months	
Figure 4.31	Representative DSC thermograms (melting) of composites	160
	after being subjected to natural soil burial test for 3 months	
	and 6 months	
Figure 4.32	Representative DSC thermograms (cooling) of composites	161
	after being subjected to natural soil burial test for 3 months	
	and 6 months	
Figure 4.33	SEM morphological of LDPE/KCF (80/20) composites with	163
	(a) 0 wt. % (b) 10 wt. % (c) 40 wt. % of TPSS after being	
	buried in soil for 3 months and (d) 0 wt. % (e) 10 wt. % (f)	
	40 wt. % of TPSS after being buried in soil for 6 months	
	(300 X magnification)	
Figure 4.34	Weight loss of LDPE/KCF (80/20) composites with different	166
	TPSS loadings after being subjected to natural soil burial test	
	for 3 and 6 months	
Figure 4 35	Processing torques of LDPE/TPSS (90/10) blends with	167

# different KCF loadings

Figure 4.36	Stabilization torques of LDPE/TPSS (90/10) blends with different KCF loadings	168
Figure 4.37	IR spectra of LDPE/TPSS (90/10) blends with different KCF loadings	170
Figure 4.38	Tensile strength of LDPE/TPSS (90/10) blends with different KCF loadings	172
Figure 4.39	Young's modulus of LDPE/TPSS (90/10) blends with different KCF loadings	173
Figure 4.40	Elongation a break of LDPE/TPSS (90/10) blends with different KCF loadings	174
Figure 4.41	TGA thermograms of LDPE/TPSS (90/10) blends with different KCF loadings	176
Figure 4.42	DTG thermograms of LDPE/TPSS (90/10) blends with different KCF loadings	176
Figure 4.43	DSC thermograms (melting) of LDPE/TPSS (90/10) blends with different KCF loadings	178
Figure 4.44	DSC thermograms (cooling) of LDPE/TPSS (90/10) blends with different KCF loadings	179