THERMAL PROPERTIES OF BAMBOO/KENAF FIBER REINFORCED EPOXY HYBRID COMPOSITES AND NANOCOMPOSITES

Presented by

Dr. Mohammad Jawaid

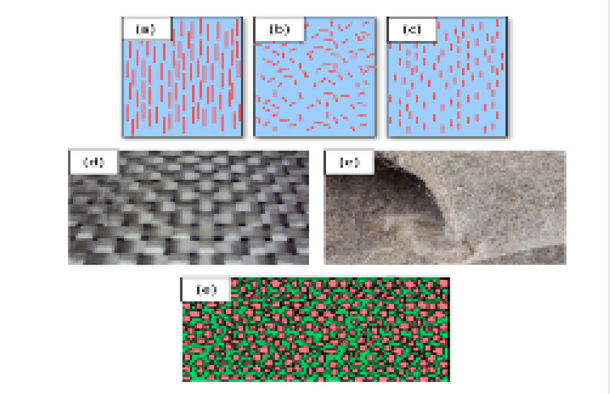
Department of Biocomposite Technology, Universiti Putra Malaysia, Malaysia

jawaid@upm.edu.my

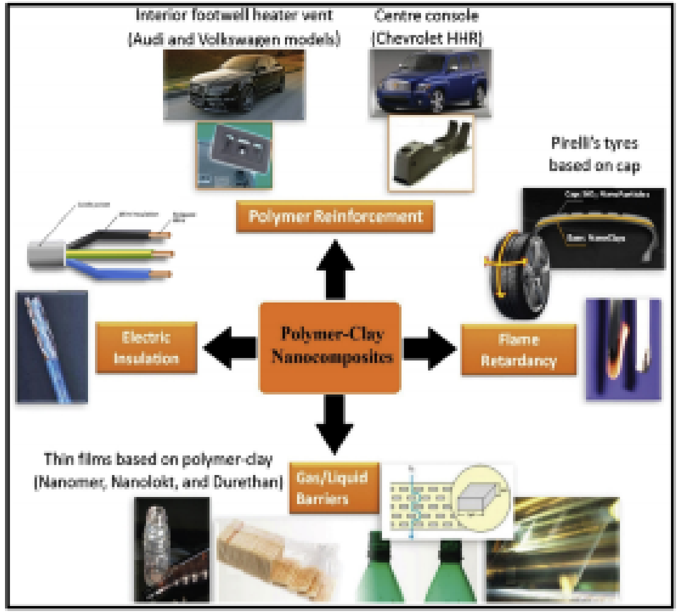
)06/03/2022 (03/08/1443

Introduction

- **Natural fiber polymer composites (NFPCs)** are a class of composite material comprising a polymer matrix reinforced with high-strength natural fibers. *(Atiqah et al., 2019)*.
- **Kenaf** and **bamboo** fibers reinforced polymer composites have many well-established applications in various segments such as automotive, construction, packaging material etc.
- Natural fibers can be incorporated into a polymer composites in different forms, such as **long align fibers, short random fibers, short align fibers, woven or non- woven mat form** and as **filler particulate.**
- **Woven/non-woven mat form provide excellent integrity** and **conformability** for advanced structural applications *(Singh et al., 2015)*.
- **Polymer nanocomposites (PNCs)** where nano size fillers were dispersed in polymer matrix ***(Wang et al., 2019).***
- **Polymer-Clay Nanocomposites** show enhanced properties in several perspective such as **mechanical properties, barrier properties, heat and fire performance. *(Suoware, Ezema, & Edelugo, 2017; Zabihi et al., 2018)***
- **Thermal analysis** provide valuable insight on the thermal properties of a composites such as:
  - ➢ Thermal expansion / shrinkage behaviour
  - ➢ Mechanical properties / viscous elastic behaviour
  - ➢ Thermal stability and oxidation stability



(a) long align fibers; (b) short random fibers; (c) short align fibers; (d) woven mat fibers; (e) non-woven mat fibers; (f) filler



جامعة الملك سعود
King Saud University
1957
عمادة البحث العلمي

Literature Survey

Recent reported work on kenaf based, bamboo based, natural fiber/ nanoclay base hybrid composites

No	Fiber	Matrix	Characterization	Reference
1	Non-woven kenaf /Oil palm EFB mat	Epoxy	Tensile, flexural and impact properties	(F. Hanan, Jawaid & Paridah, 2018)
2	Interwoven Kenaf/jute; Interwoven Kenaf/hemp	Epoxy	Water-resistant, tensile and flexural properties	(Maslinda et al., 2017)
6	Bamboo/PALF/Coir (powder form)	Polyester	Tensile and flexural	(Rihayat et al., 2018)
7	Bamboo/Salacca zalacca fruit skin	Epoxy	Density, water absorption, thickness swelling and flexural properties	(Yvonne et al., 2018)
9	Chopped kenaf fiber / OMMT (Nanomer 1.31PS)	polylactic acid	1% OMMT clay included PLA/treated kenaf fiber composites demonstrate superior tensile and flexural properties.	(Ramesh, Prasad, & Narayana 2019)
10	Bamboo yarn (unidirectional)/ OMMT (closite 20A)/	Unsaturated Polyester	1 wt.% nanoclay addition exhibited the optimized tensile and flexural strength.	(Patel et al., 2018)
11	Flax plain weave textile/ carbon fiber plain weave textile/ MMT (Closite Na⁻) /	Phenolic	Nanoclay addition improved overall fire behaviour. Peak heat release rate improved around 23% with addition of 4% nanoclay. Nanoclay addition also slow down mass loss rate and smoke generation.	(Monteriro et al., 2018)
12	Non-woven kenaf mat/ OPEFB/ MMT/ OMMT	Epoxy	Kenaf/Epoxy nanocomposites were prepared by adding 3 % of OPEFB, MMT and OMMT into epoxy, respectively. All hybrid nanocomposites reveal satisfactory flame retardancy in terms of LOI and UL 94.	(N. Saba et al., 2019)

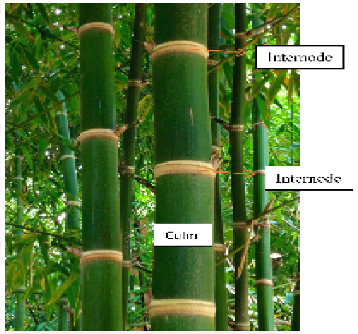
Literature Gap and Summary

- Natural fibers/nanofiller hybrid composites is a new raised engineering material with potential usage in various sector.
- Lack of work on hybridizing bamboo and kenaf fibers in mat forms.
- Lack of work on the study of thermal properties of bamboo/kenaf hybrid composites.
- Up to date there is still no work reported on bamboo/kenaf/nanoclay hybrid nanocomposites.

Literature Survey

Kena
f

Bamboo



.**Kenaf** fall under **bast fiber** while **bamboo falls** under **grass family**

The chemical composition of kenaf and bamboo fibers mainly comprised of **cellulose**, .**hemicellulose** and **lignin**

Cellulose is the main constituent which **determine the strength** of the fibers and **supports the stem plant** wall stability

.**Bamboo fibers** contain **high lignin** content which may contribute to **high thermal stability**

Fibers	**Chemical Composition**			Reference
	(%)Cellulose	**(%)Hemicellulose**	**(%)Lignin**	
Kenaf	72	20	9	Faruk et al., 2012
Bamboo	26-43	30	21-31	

Fibers	**Mechanical Properties**		Reference
	Tensile Strength (MPa)	**Tensile Modulus (GPa)**	
Kenaf	930	53	Faruk et al., 2012
Bamboo	230 - 140	17 -11	

Fibers	**Thermal properties**			**Reference**
	Initial degradation temperature (°C)	**Final degradation temperature (°C)**	**(%)Char Residue**	
Kenaf	247	455	11.4	Khalil & Suraya, 2011
Bamboo	292	370	21.6	Zakikhani et al., 2015

Literature Survey

عمادة البحث العلمي

Epoxy/clay nanocomposites

Epoxy-based layered silicate (clay) nanocomposites have been widely reported, due to the ease of processing as well as its versatile .applications in various fields

:Commonly used nanoclay
Kaolinite (1:1): Halloysite
Smectite (2:1): Montmorillonite

Cryogenic tank fabrication with filament wound carbon fibers reinforced with epoxy/organically modified layered silicate nanocomposites. ***(Adapted from Campbell & Johnston (2004))***

Applications of epoxy nanoclay / epoxy nanoclay fibers composites.

Reinforcement	Application	Enhanced Properties	References
OMMT)Closite 30B(	Adhesives	Toughness, stress whitening	Sancaktar & Kuznicki (2011)
OMMT)Closite 30B(	Adhesives	Adhesion strength, thermal stability	Aradhana et al., 2019
Halloysite	Coating	Anti-corrosion, mechanical properties	Shi et al., 2009
Vermicullite	Coating	Improved resistant to oxygen and water vapor permeation	Mittal (2008)
Halloysite	Coating	Thermal stability, flame retardancy	Vahabi et al., 2018
Filament wound carbon fiber / nanoclay	Cryogenic tank	Mechanical, thermal, reduced gas permeability	Campbell & Johnston (2004)
OMMT)Closite 30B(	Neutron beam sheilding	Thermal neutron shielding	Kiani et al., 2017

Problem Statement

Polymer composites reinforced with **synthetic fibers** are widely used and displays enhanced mechanical and thermal stability .performance

Usage of synthetic fibers lead to severe problems such as **non-biodegradable**, **difficult to dispose**, **high manufacturing cost .and unhealthy working environment**

The inherent properties of **natural fibers polymer composites** are **low thermal stability**, **high flammability and release of .toxic gasses** during the combustion process

Hence, it is anticipated that **hybridisation of natural fiber** with **nanoclay modified epoxy matrix** will **provide enhanced properties** which cannot be obtained from either natural fiber .composites or nanoclay/epoxy nanocomposites

Significance of Study

Woven Kenaf Mat

Non-Woven Bamboo Mat

Nanoclay Powder

Bamboo/Kenaf/ Nanoclay Hybrid Nanocomposites

- This study will help us to gain insight on the thermal properties of a natural fiber base epoxy hybrid composites reinforced with **woven kenaf fiber mat** and **non-.woven bamboo fiber mat**

- It is anticipated that the **woven kenaf mat** would **render better dimensional stability** to the composite due to the **longitudinal fiber arrangement on both .horizontal and vertical direction**

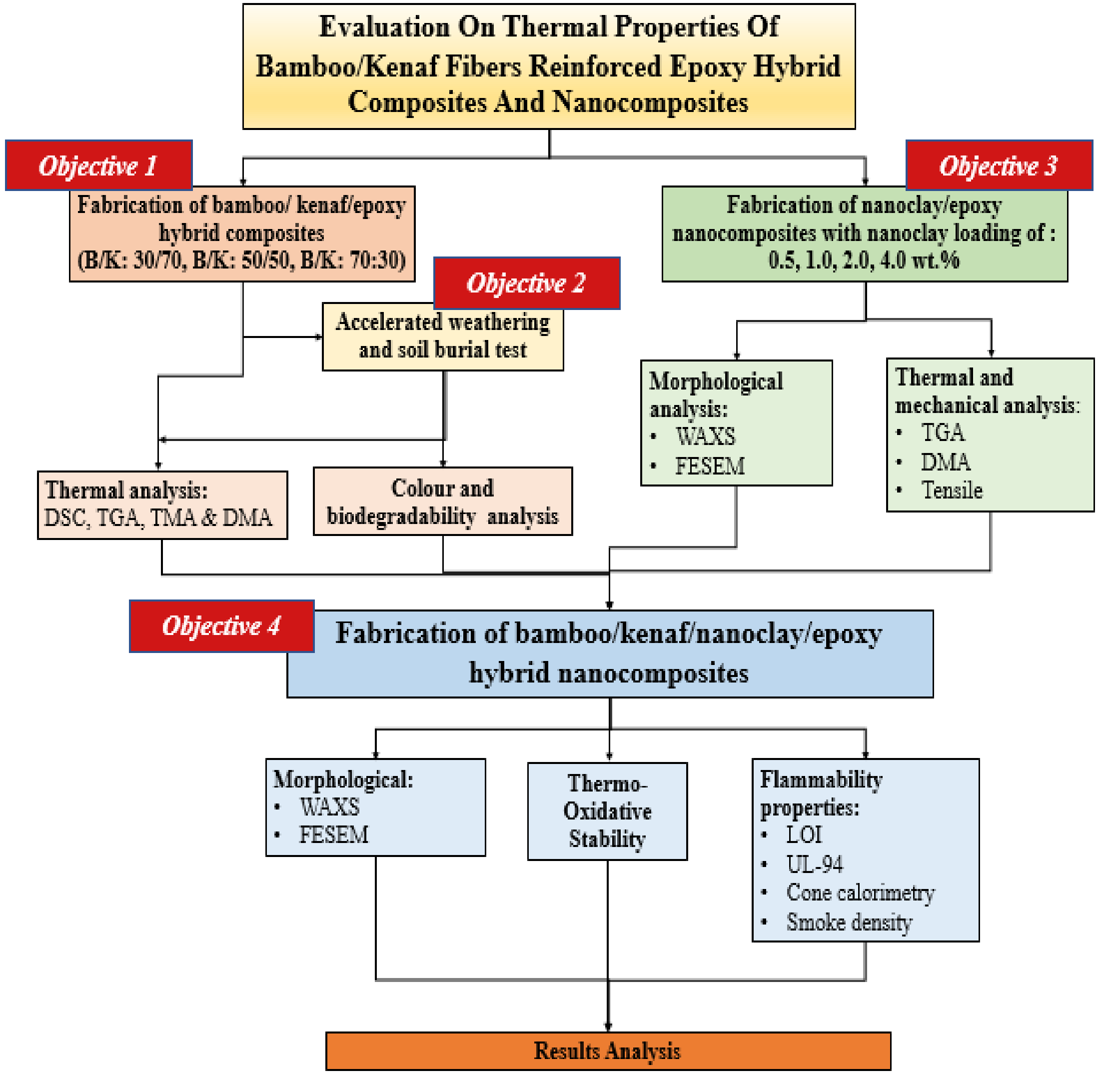
- In addition, the **thermal stability** of the kenaf fiber composites is **improved .with addition of bamboo fiber due to its high lignin content**

- To further enhance the **thermal stability and flammability** of the natural fiber-based hybrid composites, **nanoclay** was added to modify the epoxy matrix to prepare a **novel hybrid nanocomposites** – **Bamboo/Kenaf/Nanoclay/Epoxy !Hybrid Nanocomposites**

Objectives

- To explore the effect of hybridizing bamboo and kenaf fibers on the thermal properties of bamboo/kenaf fibers reinforced .epoxy hybrid composites
- To evaluate the morphology, thermal stability, viscous elastic behavior and tensile properties of nanoclay modified epoxy .nanocomposites
- To investigate the effect of nanoclay on the morphological, thermo-oxidative stability and flammability properties of the .bamboo/kenaf fibers reinforced epoxy hybrid composites

Methodology

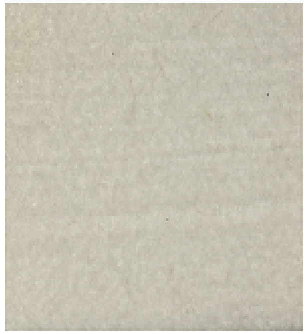


Research Methodology Flow Chart

TESTING	STANDARDS
Differential Scanning Calorimetry (DSC) Analysis	ASTM D 2009-02
Thermogravimetry (TGA) Analysis	ASTM E 1131-03
Thermomechanical (TMA) Analysis	ASTM E 831-03
Dynamic Mechanical (DMA) Analysis	ASTM D 5023-01
Accelerated Weathering Test	ASTM G 154-00
Tensile Testing	ASTM D 3039
UL-94HB	ASTM D 653
Limiting Oxygen Index (LOI)	ASTM D 2863
Cone Calorimetry	ISO 5660
Smoke Density	ASTM E 662

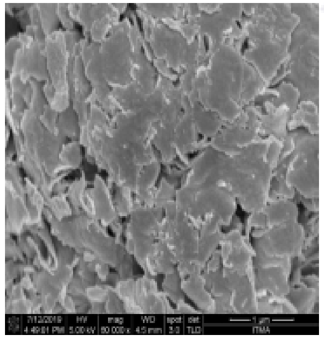
Materials

Non-woven bamboo mat
Woven kenaf mat
Epoxy resin (Diglycidyl ether of bisphenol A)
,Nanoclay: Montmorillonite (MMT), Halloysite nanotube (HNT)
Organically modified MMT (OMMT)

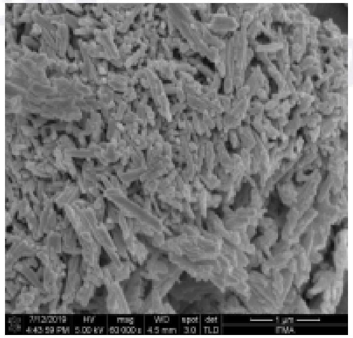


Non-woven bamboo mat

Woven kenaf mat



FESEM image of MMT



FESEM image of HNT

Chemical composition of kenaf and bamboo fiber mats

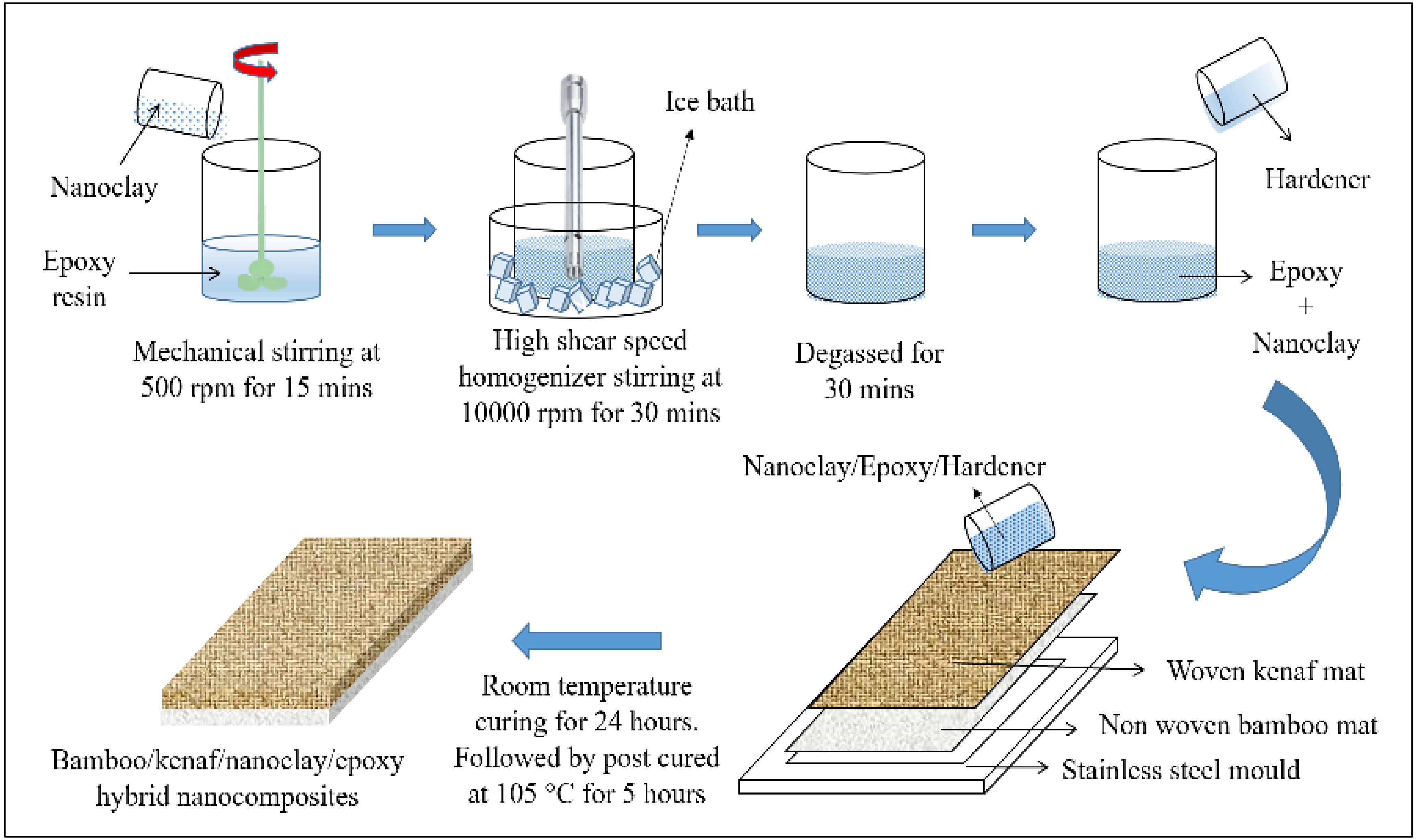
Chemical Composition	Kenaf fiber mat	Bamboo fiber mat
Cellulose Content (%)	65.7	72.6
Hemicellulose Content (%)	17.8	11.1
Lignin Content (%)	6.0	9.5

.The test is carried out by MARDI according to NDF, ADF and lignin method*

Specifications of MMT, HNT and OMMT used in this study

	MMT	HNT	OMMT
Mean particle size (μm)	≤ 25	-	14 – 18
Diameter (nm)	-	30 -70	-
Length (μm)	-	1 – 3	-
Surface Modifier (%):			
- Octadecyl ammonium	-	-	15 – 35
- 3-aminopropyltriethoxy silane	-	-	0.5 – 5

Fabrication



Schematic illustration on the preparation of bamboo/kenaf/nanoclay reinforced epoxy hybrid nanocomposites.

Formulation

Formulation of kenaf, bamboo, hybrid and epoxy composites

Composites	(%)Weight Ratio		
	Bamboo fiber mat	Kenaf fiber mat	Epoxy
B:K:70:30	28	12	60
B:K:50:50	20	20	60
B:K:30:70	12	28	60
Kenaf/epoxy	0	40	60
Bamboo/epoxy	40	0	60
Pure epoxy	0	0	100

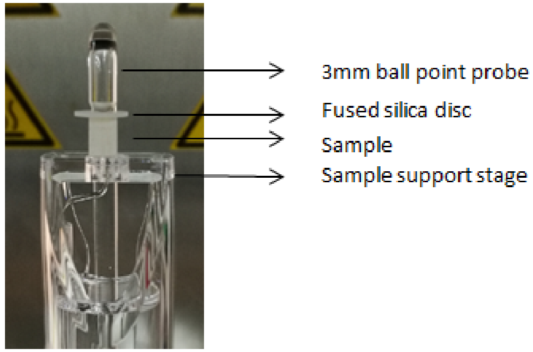
Formulation of bamboo/kenaf/epoxy hybrid composites and bamboo/ kenaf / nanoclay / epoxy hybrid nanocomposites

Hybrid Composites	Bamboo fibers (wt. %)	Kenaf fibers (wt. %)	Epoxy matrix . %)wt(	Nanoclay . %)wt(
B/K/Epoxy	20	20	60	0
B/K/MMT	20	20	59	1
B/K/HNT	20	20	59	1
B/K/OMMT	20	20	59	1

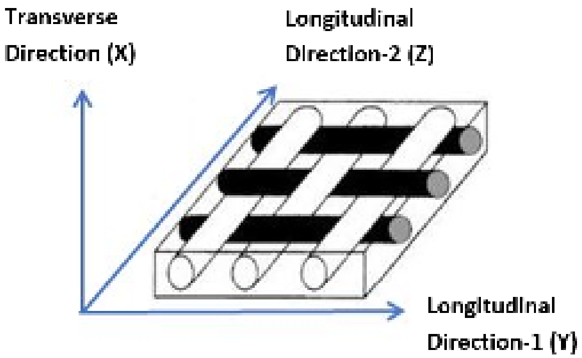
Results and Discussion

Objective 1: Thermal Expansion of Bamboo/Kenaf/Epoxy Hybrid Composites

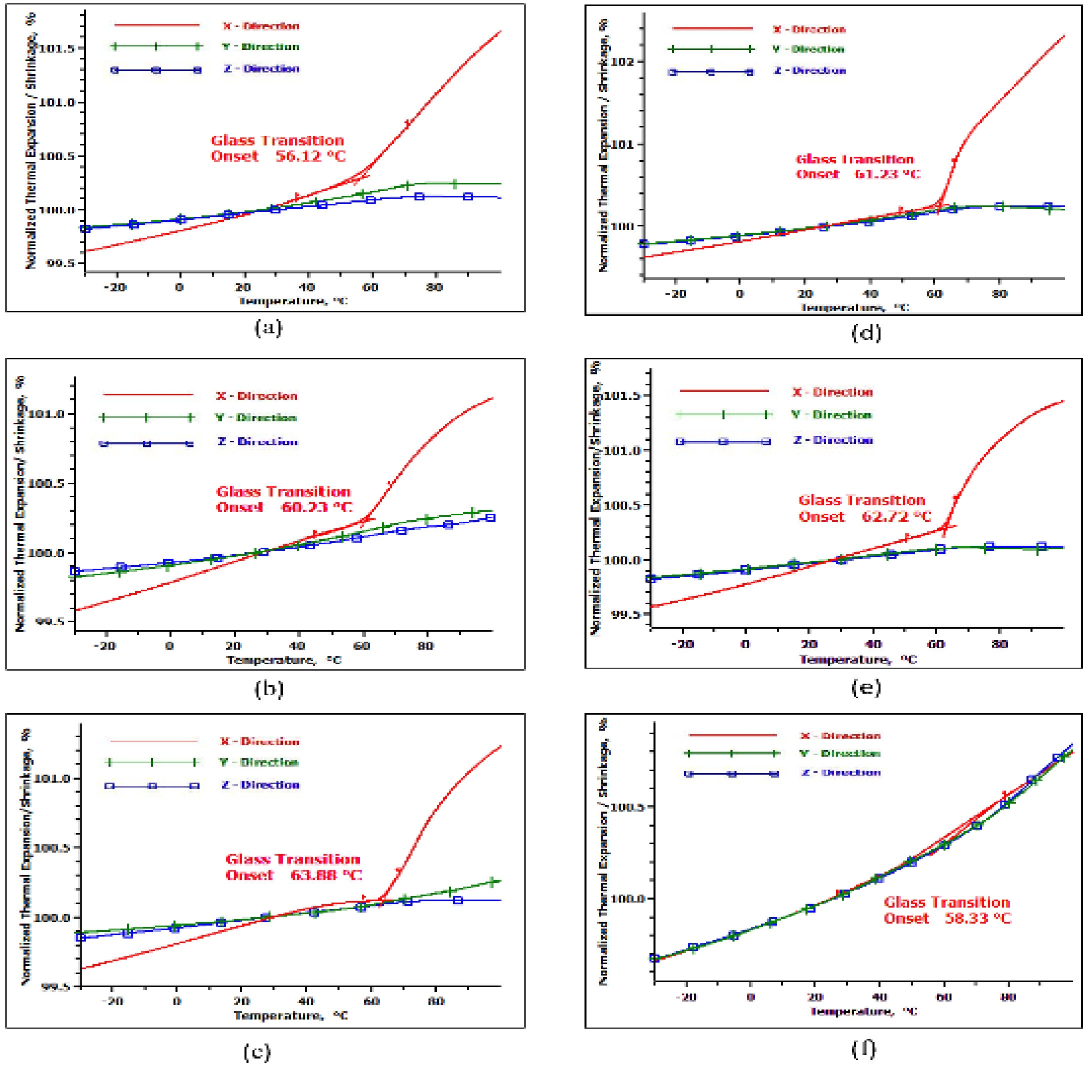
عمادة البحث العلمي



Measurement with dilatometric mode on TMA



Thermal expansion of a woven fiber reinforced composite in longitudinal fibers direction (Y and Z) and .transversal fibers direction (X)



TMA graph in normalized thermal expansion / shrinkage (%) versus temperature (℃) for composites: (a) B:K:70:30; (b) B:K:50:50; (c) B: .K:30:70; (d) Bamboo/epoxy; (e) Kenaf/epoxy; (f) Pure Epoxy

جامعة الملك سعود
King Saud University
عمادة البحث العلمي

Objective 1: Thermal Expansion of Bamboo/Kenaf/Epoxy Hybrid Composites

Composites	Total Shrinkage from 25 °C to -30°C, %			Total Expansion from 25 °C to 100°C, %			Mean CTE from -30°C to 100 °C, ppm/°C		
	X	Y	Z	X	Y	Z	X	Y	Z
Pure epoxy	0.33	0.32	0.32	0.80	0.81	0.85	87.39	87.82	90.11
Bamboo/epoxy	0.41	0.21	0.21	2.33	0.20	0.25	208.9	31.92	35.36
Kenaf/epoxy	0.36	0.15	0.16	1.47	0.11	0.13	145.5	20.24	17.48
B:K:70:30	0.37	0.16	0.16	1.66	0.24	0.13	162.7	30.99	22.44
B:K:50:50	0.39	0.17	0.13	1.14	0.31	0.26	118.2	30.94	36.78
B:K:30:70	0.34	0.10	0.14	1.26	0.27	0.13	123.2	30.06	20.78

Mean CTE of woven kenaf/epoxy is lower compare to non-woven bamboo/ .epoxy

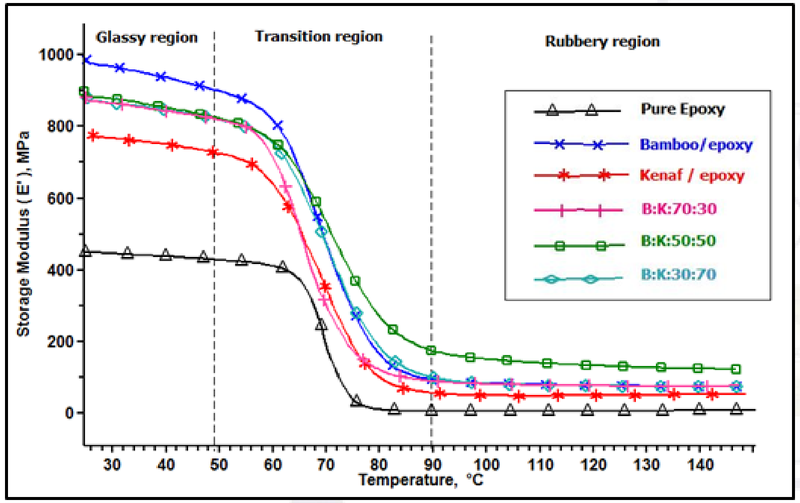
The decrease in CTE correspond to the decreased of polymeric segmental motion due to the interlocking mechanism between the fibers and epoxy .matrix ***(N. Saba et al., 2016c)***

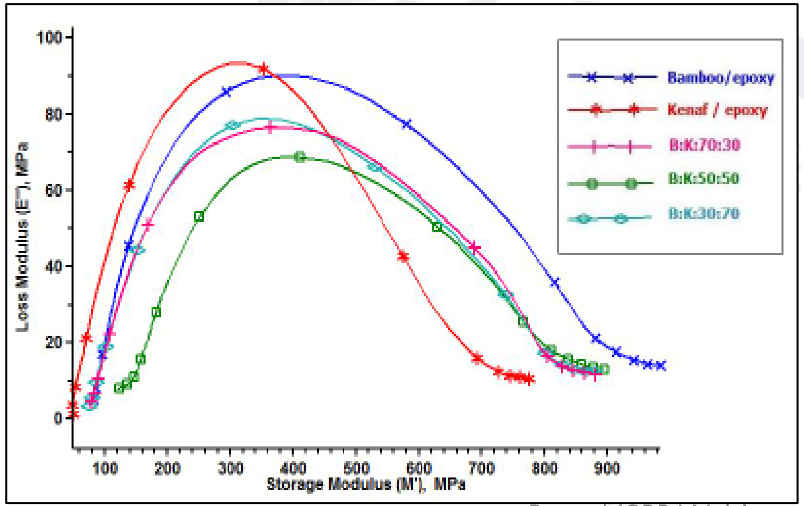
B:K:70:30 shows the highest CTE among all the 3 hybrid composites with .CTE of 162.7 ppm/°C and total expansion of 1.66% from 25 to 100 °C

This follow by **B:K:30:70 with CTE of 123 ppm/°C** and total expansion of .1.26%

Objective 1: Dynamic Mechanical Properties of Bamboo/ Kenaf/Epoxy Hybrid Composites

Viscous elastic behaviour from 25 °C to 150 °C





Cole-cole plot

Storage modulus (E') represents the elastic portion of a viscous elastic material and is the most significant property to evaluate the load bearing capacity of a .composite ***(Anand et al., 2017)***

The storage modulus of the composites follow the sequence series of bamboo/epoxy > B: K: 50:50 > B: K: .70:30> B: K: 30:70 > kenaf/epoxy > pure epoxy

The effective coefficient (C) is used to evaluate the effectiveness of the interfacial adhesion strength ***(Idicula et al., 2005; Senturk, Senturk, & Palabiyik, .2018)***

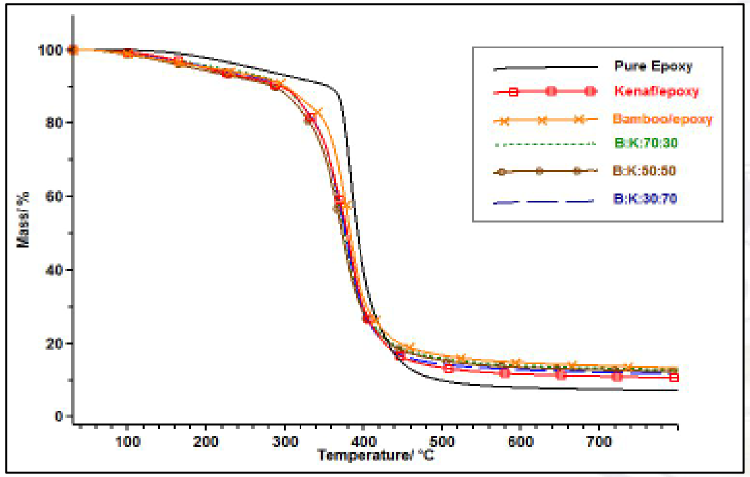
$$C = \frac{(E'_G/E'_R)composite}{(E'_G/E'_R)\ matrix}$$

The lower the value of effectiveness coefficient indicates the higher interfacial adhesion strength

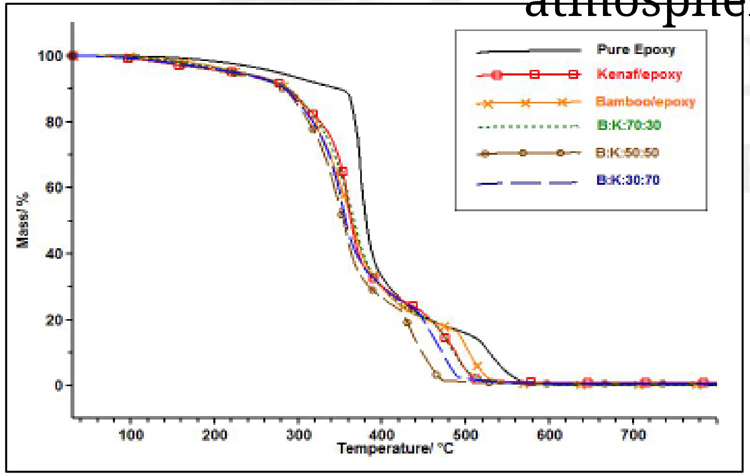
Coefficient Effectiveness	Bamboo /Epoxy	/Kenaf Epoxy	:B:K 70:30	:B:K 50:50	:B:K 30:70
	0.17	0.21	0.15	0.09	0.15

The cole-cole plot also shows evidence of positive hybridization effects whereby the hybrid composites shows relatively more perfect semi-circular peak

Objective 1: Thermal and Thermo-oxidative (TOD) Stability of Bamboo/Kenaf/Epoxy Hybrid Composites



Decomposition under nitrogen atmosphere



Decomposition under oxygen atmosphere

Thermal stability was study with TGA under nitrogen atmosphere while TOD stability was study under .oxygen atmosphere

Decomposition under nitrogen atmosphere reveal in a single step while decomposition under oxygen atmosphere follow a 2 steps .decomposition

Presence of oxygen can cause changes in the chemical decomposition process in natural fibers ***(Rachini et al., 2009)*** as well as epoxy polymer ***(L.Beyler, 2002; X. .Zhang et al., 2018)***

According to ***Dorez et al. (2014***), the second mass loss in oxidative

UPM
UNIVERSITI PUTRA MALAYSIA

Objective 1: 1:Thermal and Thermo-oxidative Stability of Bamboo/Kenaf/Epoxy Hybrid Composites

جامعة الملك سعود
King Saud University
عمادة البحث العلمي

Composites	T_O/ °C		T_M/ °C		T_E/ °C	
	N_2	O_2	N_2	O_2	N_2	O_2
Pure epoxy	365.2	356.0	382.9	378.2	459.8	395.8
Kenaf/epoxy	274.1	261.8	380.2	363.3	447.7	382.1
Bamboo/epoxy	294.1	273.3	384.3	365.3	453.7	388.1
B:K:70:30	285.1	271.5	379.9	365.7	450.6	386.7
B:K:50:50	278.7	268.1	372.8	359.2	445.3	375.9
B:K:30:70	276.7	265.6	371.0	354.1	442.3	379.9

Oxidative atmosphere fastened the decomposition process shifting the decomposition temperature to lower in comparison to those measured in nitrogen atmosphere.

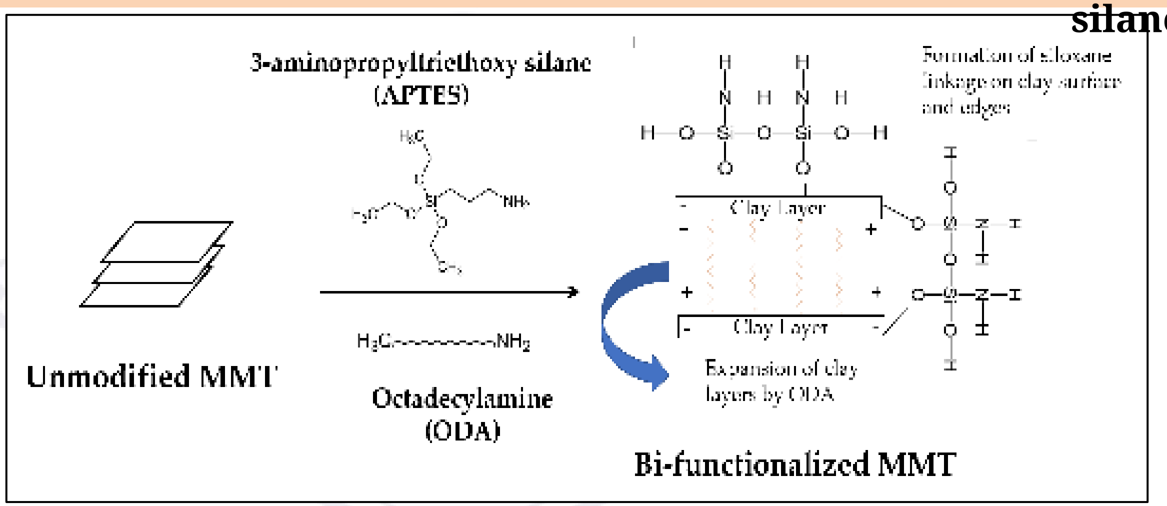
•**Bamboo/epoxy shows higher thermal stability** compare to kenaf/epoxy due to **higher cellulose and lignin content in bamboo fiber**.

•With increasing bamboo fiber content, increase thermal and TOD stability. Thermal and TOD stability of the hybrid composites following sequence: **B:K:70:30 > B:K:50:50 > B: K:30:70**

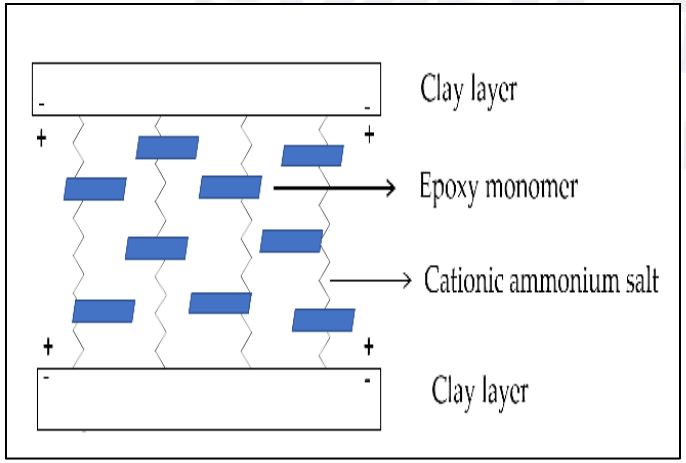
Objective 2: Morphology, thermal stability, viscous elastic behavior and tensile properties of nanoclay modified epoxy nanocomposites

عمادة البحث العلم

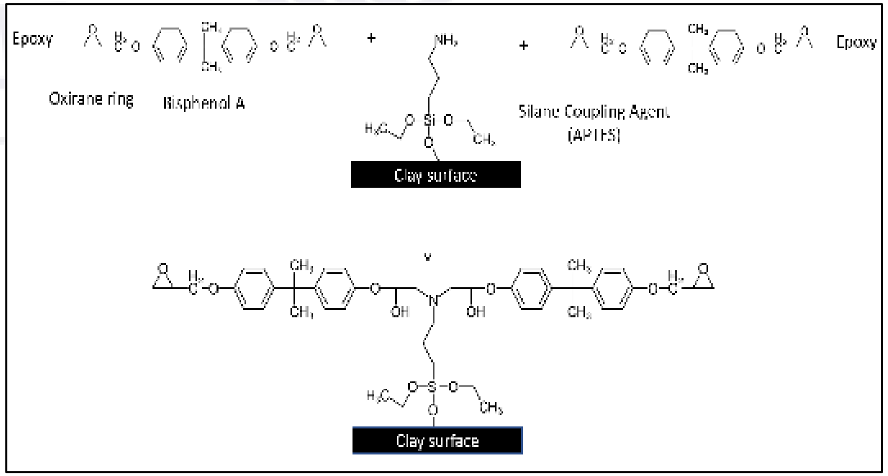
Interaction between unmodified Montmorillonite (MMT) with cationic ammonium salt and silane coupling agent



Interaction between bi-functionalized MMT with epoxy resin

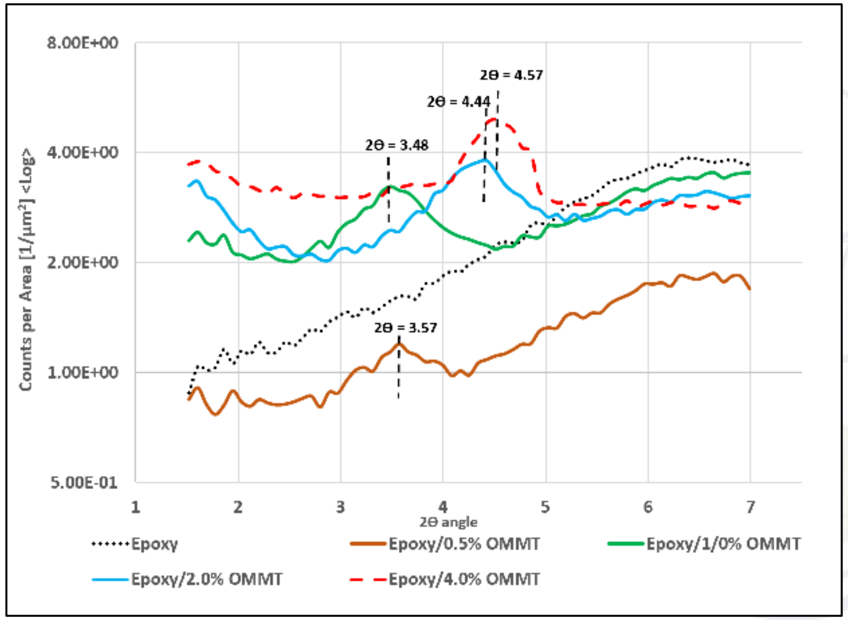


Diffusion of epoxy monomer into the clay galleries



Chemical reaction between clay layer, silane coupling agent and epoxy monomer.

Objective 2: Structural and Morphological of Epoxy/OMMT Nanocomposites



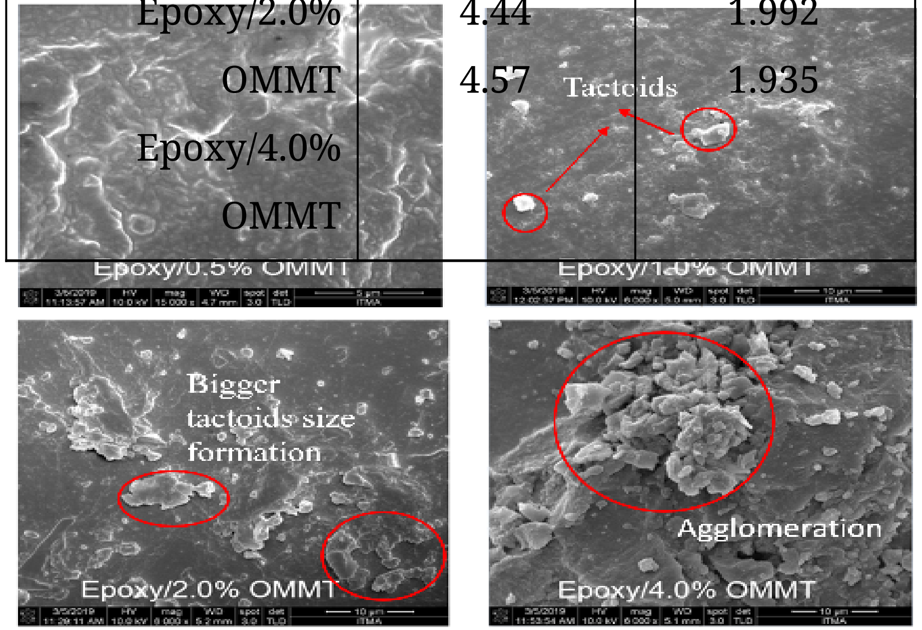
WAXS pattern of epoxy/OMMT nanocomposites with different concentration of OMMT

Specimens		d Spacing (nm)
OMMT	4.34	2.038
Epoxy/0.5% OMMT	3.57	2.476
Epoxy/1.0% OMMT	3.48	2.540
Epoxy/2.0% OMMT	4.44	1.992
Epoxy/4.0% OMMT	4.57	1.935

Bragg's Law:

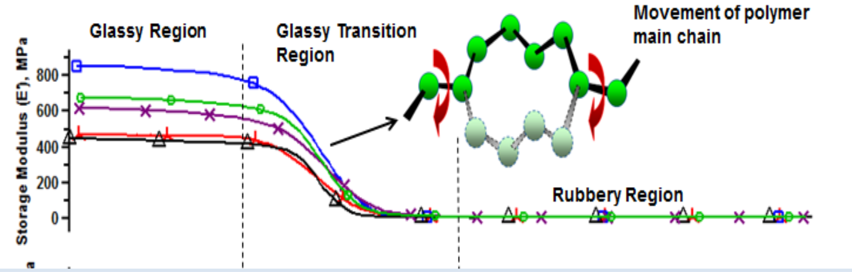
$$d\ spacing\ (d001) = \frac{n\lambda}{sin2\theta}$$

Fu et al., 2019; Junior et al., 2015;( )Poletto et al., 2014



FESEM images of epoxy/OMMT nanocomposites

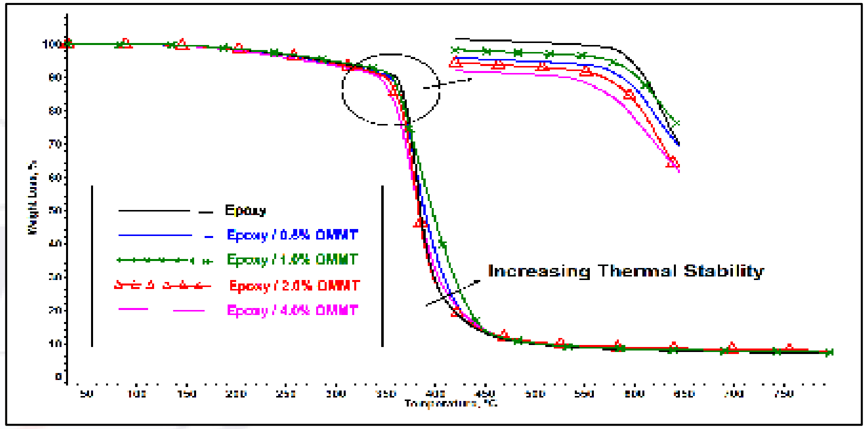
Objective 2: Dynamic Mechanical, Thermal Stability and Tensile Properties of Epoxy/OMMT Nanocomposites

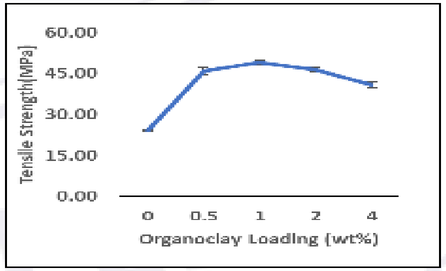


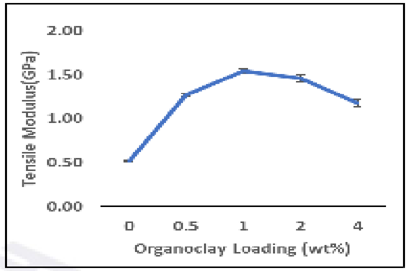
Crosslink density :

$$\nu_e = \frac{\grave{E}}{3RT}$$

(Miyagawa et al., 2005)



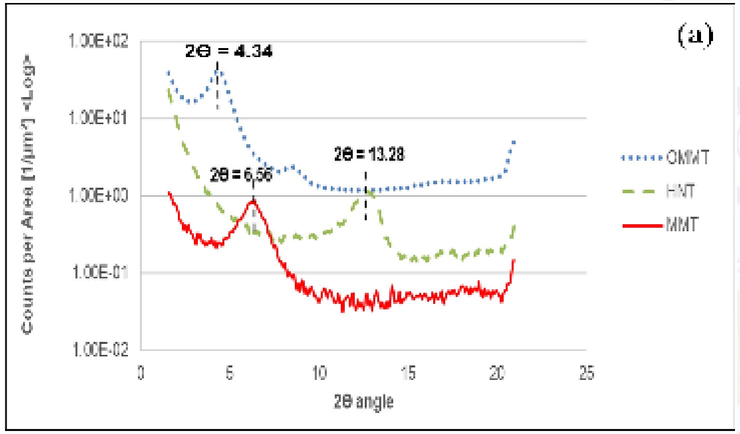




Composites	Storage Modulus (E') at 25 °C (MPa)	Storage Modulus (Ė) at T_g + 30 °C (MPa)	Crosslink Density ([illegible]) (× [illegible] mol/m³)	T_g by peak of Tan delta ([illegible])	T_{IDT}/°C	T_{MAX}/°C	T_{FDT}/°C
Epoxy	449	6.0	6.1	77.8	365	383	425
Epoxy/0.5% OMMT	675	9.0	9.2	81.0	353	387	449
Epoxy/1.0% OMMT	850	10.0	10.2	82.6	356	394	461
Epoxy/2.0% OMMT	615	8.4	8.6	78.4	347	381	446
Epoxy/4.0% OMMT	466	7.8	8.0	76.6	336	381	458

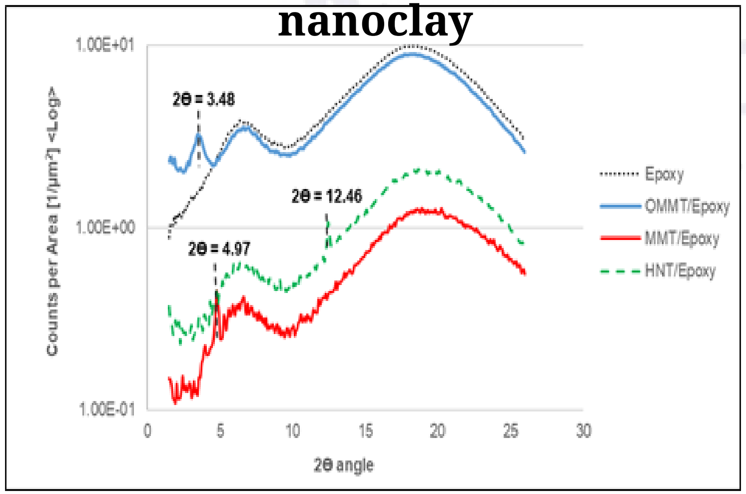
عمادة البحث العلمي

Structural and Morphological Study on Nanoclay/Epoxy Composites

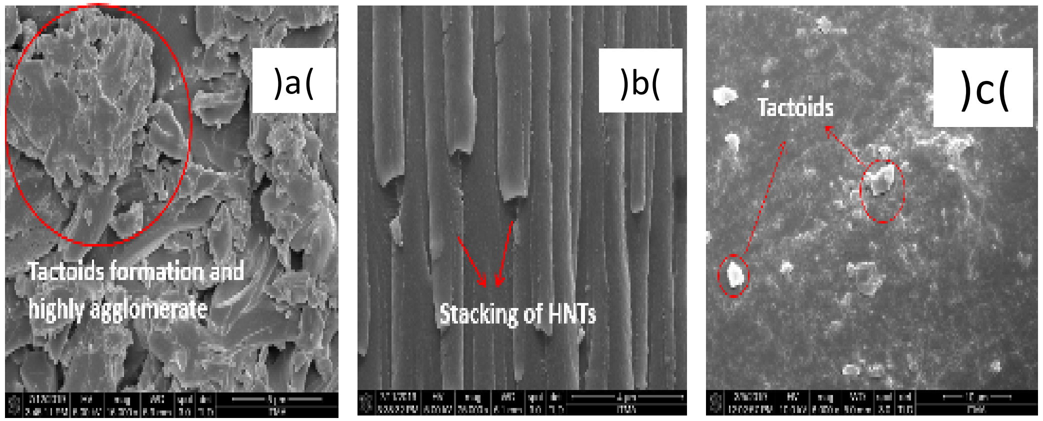


WAXS analysis on pristine nanoclay

Specimens	Peak in 2θ (°)	d spacing (nm)
MMT	6.56	1.35
HNT	13.28	0.67
OMMT	4.34	2.04
MMT/Epoxy	4.97	1.78
HNT/Epoxy	12.46	0.72
OMMT/Epoxy	3.48	2.54



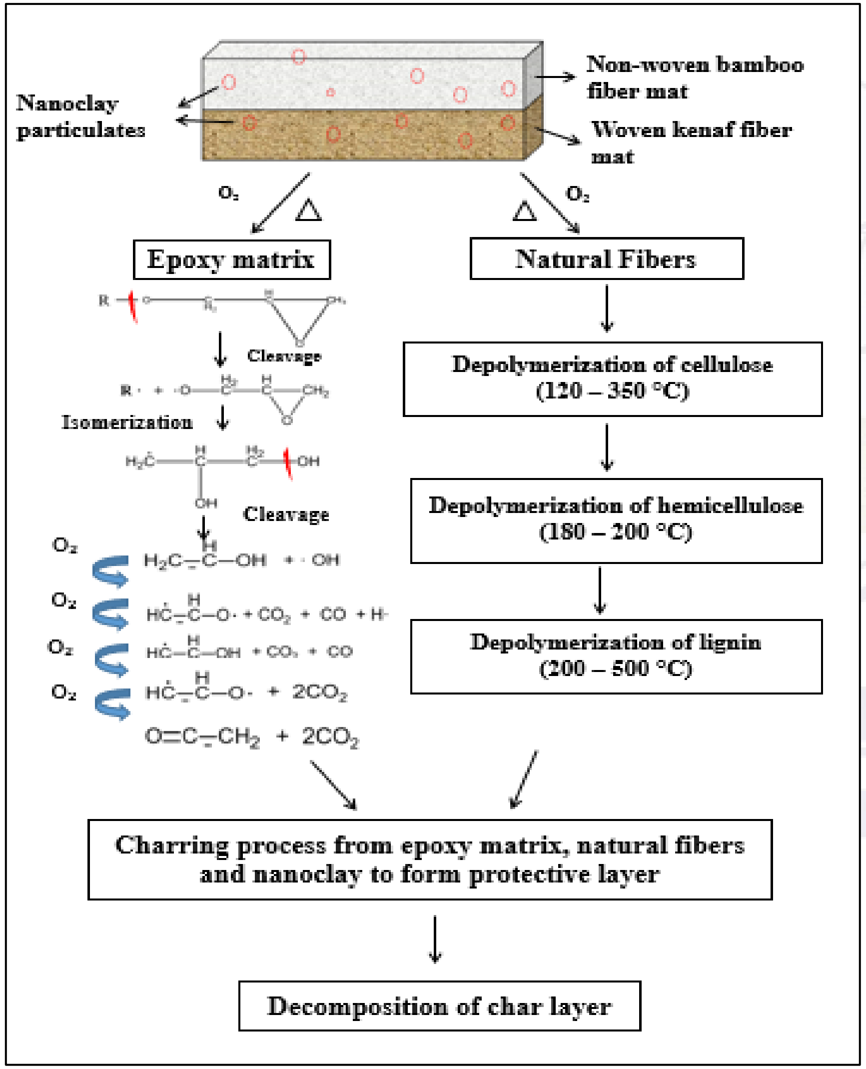
WAXS analysis on epoxy/ nanoclay



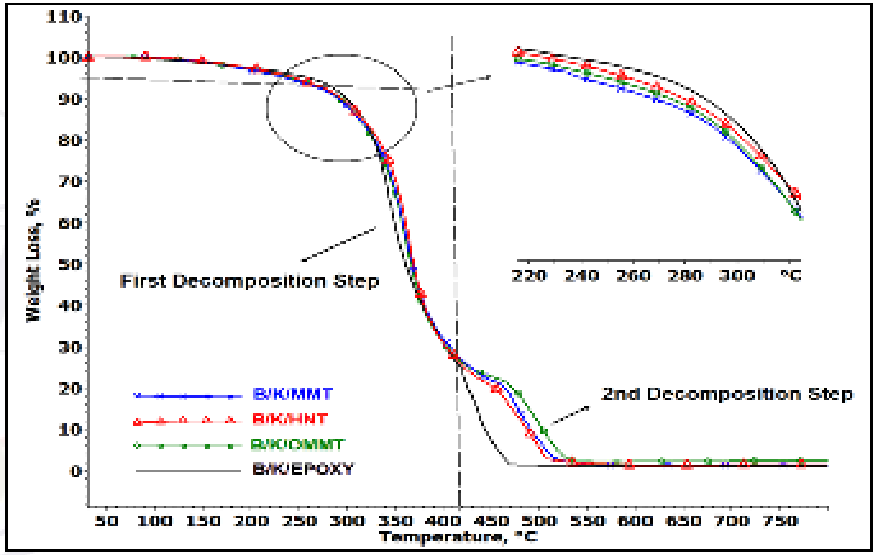
FESEM images of (a) MMT/Epoxy; (b) HNT/ ;Epoxy .OMMT/Epoxy) c(

Objective 3: Thermo-oxidative Decomposition Behavior of Bamboo/ Kenaf/Nanoclay Reinforced Epoxy Hybrid Nanocomposites

عمادة البحث العلمي



Schematic presentation on the decomposition process of bamboo/kenaf reinforced epoxy/ nanoclay hybrid nanocomposite.



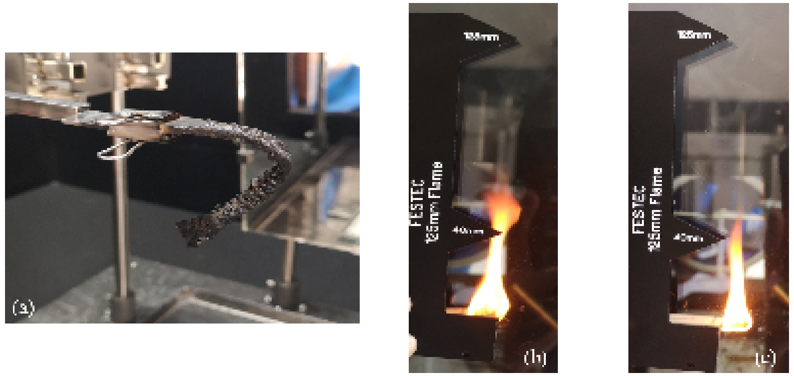
TGA curve of hybrid nanocomposites under oxygen atmosphere

Hybrid Composites	$T_{10\%}$ (°C)	T_{max1} (°C)	T_{max2} (°C)	Residue @ 800 °C (%)
B/K/MMT	289	356	485	1.54
B/K/HNT	297	365	483	1.43
B/K/OMMT	292	360	495	1.92
B/K/Epoxy	299	346	434	0.52

Objective 3: Flammability Properties of Bamboo/Kenaf/Nanoclay Reinforced Epoxy Hybrid Nanocomposites

عمادة البحث العلمي

-94 Horizontal Burning Test

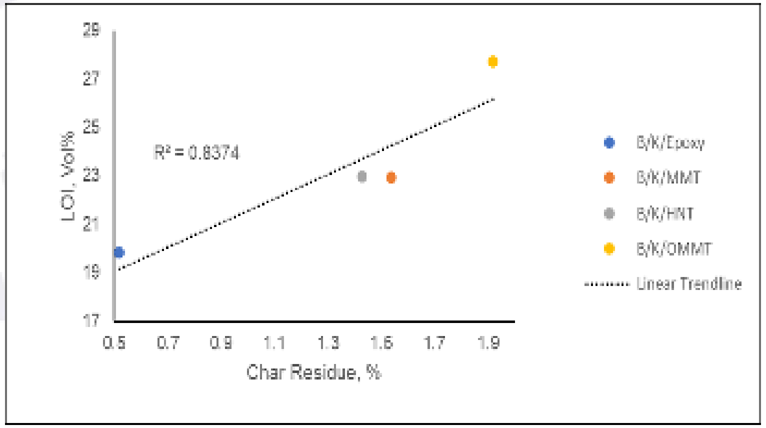


Hybrid composites after horizontal UL-94) a(
;burning test
;Estimated flame height produce by B/K/Epoxy) b(
Estimated flame height produce by B/K/OMMT) c(

Composites	Flame pass 1st gauge mark (25mm)	Flame pass 2nd gauge mark (100mm)	Dripping	Time from 1st gauge mark to 2nd gauge mark (s)	Linear burning rate (mm/min)	Rating
B/K/Epoxy	Yes	Yes	No	353.0 – 3.9	12.7	HB40
B/K/MMT	Yes	Yes	No	382.2 – 6.2	11.8	HB40
B/K/HNT	Yes	Yes	No	372.2 – 3.0	12.1	HB40
B/K/OMMT	Yes	Yes	No	455.0 – 4.2	9.89	HB40

iting Oxygen Index (LOI)

Composites	C- (°C)	k	d (°C)	OI (%)	Standard Deviation
B/K/Epoxy	19.4	2	0.2	19.80	0.24
B/K/MMT	22.8	0.61	0.2	22.02	0.42
B/K/HNT	22.8	0.68	0.2	22.94	0.12
B/K/OMMT	27.8	-0.45	0.2	27.71	0.13



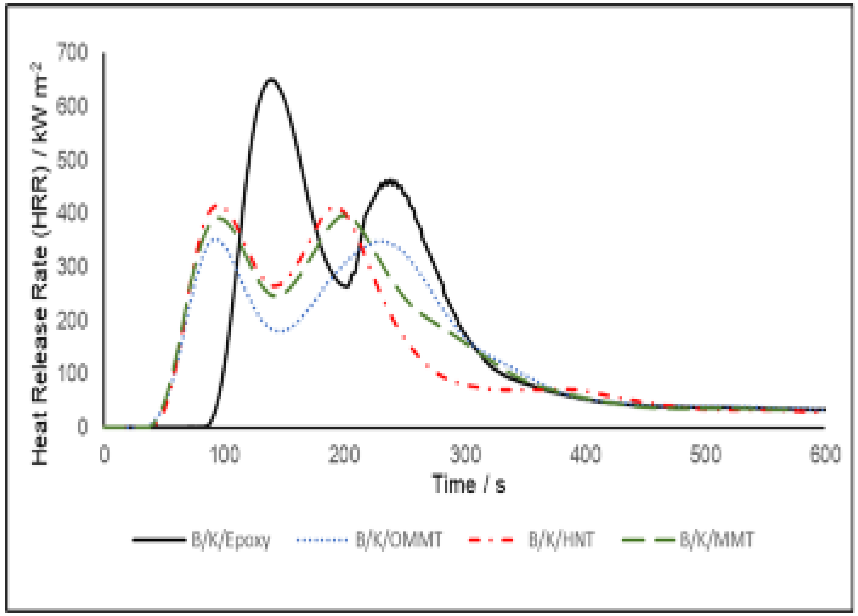
Correlation between LOI value and char residue content at 800 °C of the hybrid .nanocomposites

Van Krevelen (1975) reported on the linear correlation between char .residue and LOI

Objective 3: Flammability Properties of Bamboo/Kenaf/Nanoclay Reinfiorced Epoxy Hybrid Nanocomposites

عمادة البحث العلمي

Cone Calorimetry Test



Heat release rate curves as a function of time for filled and unfilled bamboo/kenaf reinforced epoxy hybrid composites at 35 kW/m2 heat flux.

Composites	Time to ignition (s)	pHRR (kW/m^2)	Total heat release (MJ/m^2)
B/K/Epoxy	95 (4.9)	680 (40)	103 (4)
B/K/MMT	38 (2.2)	414 (21)	92 (5)
B/K/HNT	46 (4.0)	432 (20)	101 (6)
B/K/OMMT	45 (1.7)	388 (35)	83 (7)

- TTI: Time required for ignition
- TTI of all nanoclay filled hybrid nanocomposites are shorter compare to control sample.
- HRR: Quantity of heat release per unit area of a material.
- pHRR: Highest amount of heat emitted during combustion.
- Reduction of total heat release and pHRR between 36-43% on nanoclay filled hybrid nanocomposites.

ـ جامعة الملك سعود
King Saud University
عمادة البحث العلمي

Objective 3: Flammability Properties of Bamboo/Kenaf/Nanoclay Reinfiorced Epoxy Hybrid Nanocomposites

Smoke Density

Composite	Cone Calorimeter			Smoke Density
	Total smoke production/ TSP (m^2)	SMOGRA)m^2/s^2(	Average Specific Extinction Area/ SEA_{AVG} (m^2/kg)	VOF4
B/K/Epoxy	)284 (2827	)1.46 (10.5	)41 (305	573
B/K/MMT	)102 (2289	)0.05 (9.17	)42 (168	180
B/K/HNT	)137 (2620	)0.19 (9.64	)13 (280	256
B/K/OMMT	)156 (1833	)0.05 (8.91	)6 (86	35.6

Total smoke production (TSP), smoke growth rate index (SMOGRA) and average .specific extinction area (SEA_{AVG}) were obtained from cone calorimetry analysis

SEA_{AVG} refer to the light absorption by the surface of smoke particles under a dynamic .gas flow

Smoke density tester provides information on the change of optical density of smoke .accumulation under a closed chamber

Nanocaly filled hybrid nanocomposites all show better smoke properties compare to .unfilled hybrid composites

.Excel smoke properties observed on B/K/OMMT hybrid nancomposites

Conclusions

Objective 1: *To explore the effect of hybridizing bamboo and kenaf fibers on the thermal properties of bamboo/ kenaf fibers reinforced epoxy hybrid composites*

→ B/K:70/30 hybrid composites shows the best thermal and thermo-oxidative stability. B/K:50/50 hybrid composites exhibit the best thermal .expansion property and viscoelastic behaviour

Objective 2: *To evaluate the morphology, thermal stability, viscous elastic behavior and tensile properties of nanoclay modified epoxy nanocomposites*

→ Addition of nanoclay improve the thermal stability, viscoelastic .behaviour and tensile properties of nanoclay/epoxy nanocomposites

nanoclay loading display the best performance due to the better 1% dispersion of the nanoclay which induce strong interfacial adhesion .strength between the difference phases

Objective 3: *To investigate the effect of nanoclay on the morphological, thermo-oxidative stability and flammability properties of the bamboo/kenaf fibers reinforced epoxy hybrid composites*

→ Nanoclay filled bamboo/kenaf fibers reinforced epoxy hybrid nanocomposites exhibits improved thermo-oxidative and flammability .properties compare to unfilled hybrid composites

Hybrid composites filled with organo modified nanoclay exhibit better performance compare to unmodified nanoclay due to the better interaction between nanoclay and polymer matrix and achieved a .better dispersion level with less agglomeration

عمادة البحث العلمي

List of publications

:Journal Article

S. S. Chee, M. Jawaid, and M. T. H. Sultan. Thermal stability and dynamic mechanical properties of kenaf/ bamboo fiber reinforced epoxy composites. **BioResources. 2017; 12(4):7118–7132. (Q2) (IF:1.396)**

S. S. Chee, **M. Jawaid**, M. T. H. Sultan, **O. Y. Alothman**, and L. C. Abdullah. Thermomechanical and dynamic mechanical properties of bamboo/woven kenaf mat reinforced epoxy hybrid composites. **Composites Part B-Engineering. 2018; 163:165–174. (Q1) (IF: 6.864)**

S. S. Chee, **M. Jawaid**, M. T. H. Sultan, **O. Y. Alothman**, and L. C. Abdullah. Evaluation of the hybridization effect on the thermal and thermo-oxidative stability of bamboo/kenaf/epoxy hybrid composites**. Journal of Thermal Analysis and Calorimetry. 2019; 137(1): 55-63. (Q2) (IF: 2.471)**

S. S. Chee, **M. Jawaid**, M. T. H. Sultan, **O. Y. Alothman**, and L. C. Abdullah. Accelerated weathering and soil burial effects on colour, biodegradability and thermal properties of bamboo/kenaf/epoxy hybrid composites. **Polymer Testing. 2019; 79:106054. (Q1) (IF: 2.943)**

S.S. Chee, & Jawaid, M. The Effect of bi-functionalized MMT on morphology, thermal stability, dynamic mechanical, and tensile properties of epoxy/organoclay nanocomposites. **Polymers. 2019; 11(12):2012. (Q1) (IF: 3.164)**

List of Publications

جامعة الملك سعود
King Saud University
عمادة البحث العلمي

S. S. Chee, **M. Jawaid**, M. T. H. Sultan, **O. Y. Alothman**, and L. C. Abdullah. Effects of nanoclay on physical and dimensional stability of bamboo/ kenaf/ nanoclay reinforced epoxy hybrid nanocomposites, **Journal of Materials Research and Technology(Online Available). (Q2) (IF: 3.327)**

S. S. Chee, M. Jawaid, **O. Y. Alothman**, Ridwan Yahya. Thermo-oxidative stability and flammability properties of bamboo/kenaf/nanoclay reinforced epoxy hybrid nanocomposites, **RSC Advances, 2020, 10(37), 21686-21697(Q2) (IF: 3.049)**

S. S. Chee, M. Jawaid, **O. Y. Alothman,** Effect of Nanoclay on mechanical and dynamic mechanical properties of bamboo/kenaf reinforced epoxy hybrid nanocomposites. **Polymers, 13(3), 1-17, 395 (IF:4.324)(Q1)**

Proceedings/ Conference

S.S. Chee, N. Saba, M. Jawaid, M.T.H. Sultan. A review on thermal properties of roselle fiber reinforced polymer composites, Malaysia Polymer International Conference 2017, Pusat PERMATApintar Negara, Universiti Kebangsaan Malaysia. 19-20th July 2017

Acknowledgements

:Supervisory Members
Dr. Muhammad Jawaid (Chairman)
Prof. Ir. Ts. Dr. Mohamed Thariq Bin Hameed Sultan (Member)
Professor Dr. Luqman Chuah Abdullah (Member)
Prof. Dr. Othman Y. Alothman (Member)

:Hybrid Composites Research Group
Dr. Naheed Saba
Dr. Mohamad Asim
Dr. Ramengmawii Siakeng
Dr. J. Naveen
Dr. Lau Kia Kian
Muhammad Safwan
Azlina Ramlee

:INTROP's Staff
Pn. Khaizatul Mazni Binti Khaidir
En. Mohd Lufti Mohd Tawil
Pn. Ana Salleza Md Salleh
En. Mohd Shazwan Jamhari
Pn. Eli Rashidah Ashari
En. Hafizie Manap

:Others
Dr. Ridwan Yahya (STRIDE)
Mr. PS Ng (GT Instrument)
Mr. JT Tan (Mettler Toledo)
Mr. Urs Joeriman (Mettler Toledo)
Friends and family members

شكراً لحضوركم

عمادة البحث العلمي

Thank You

jawaid@upm.edu.my