Progress in Kenaf Fibre Reinforced Composites (KFRC) Research at Universiti Sains Malaysia (USM)

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PRESENTATION OUTLINE

I. Introduction to **kenaf fibre**

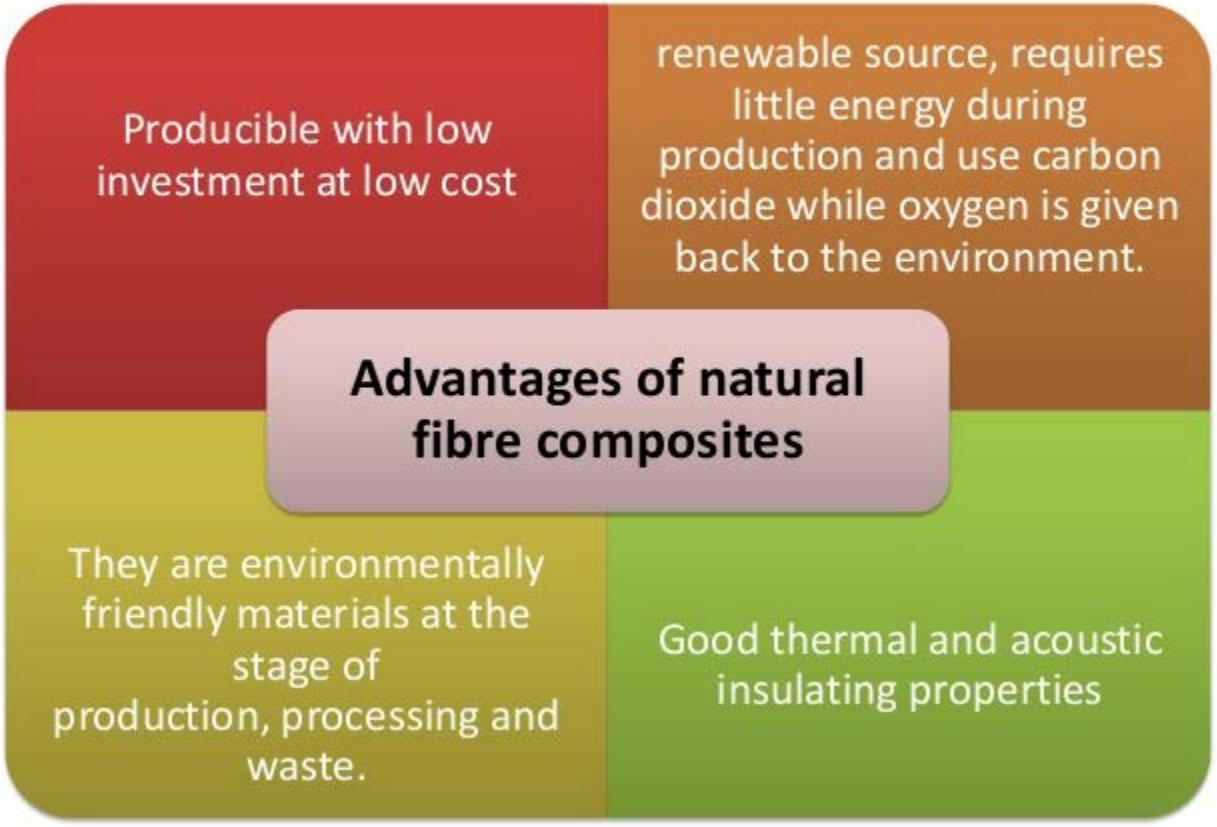
II. Recent progress in Kenaf fibre **surface treatments**

III. Recent progress in **Non-woven kenaf fibre reinforced composites**: Improving the Flammability behaviour

IV. Recent progress in **Pultruded Kenaf Fibre Reinforced Composites**: Effect of surfacing veils, Kenaf TEX and Chopped Strand Mat (CSM) on the performance of KFRC

V. Conclusions

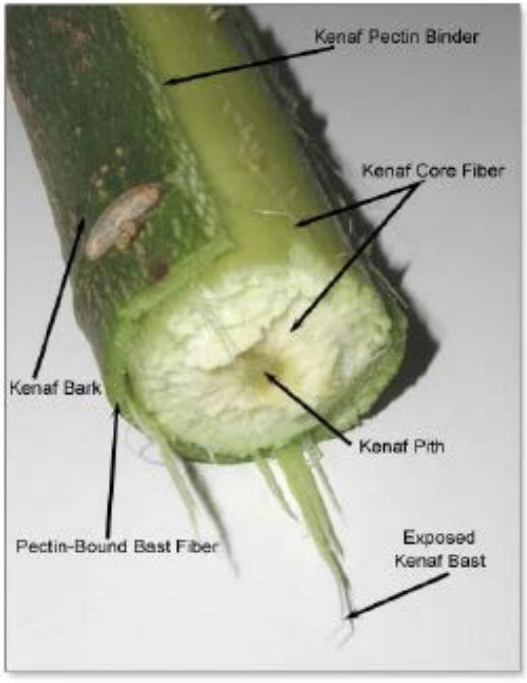
WHY KENAF FIBER?



Anatomy of Kenaf Fibre

Kenaf Plant Characteristics

- Bast
  - Tough fiber outer layer
  - 35% by weight
  - Long, strong fibers make a higher quality product
  - Better engineering qualities for plastic composites
- Core
  - Soft inner layer (including pith)
  - 65% by weight
  - Most absorbent natural material on earth (US Navy Study, 1999)



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Utilization of Kenaf Stalk



Kenaf stalk





VARIOUS FORMS OF KENAF FIBER





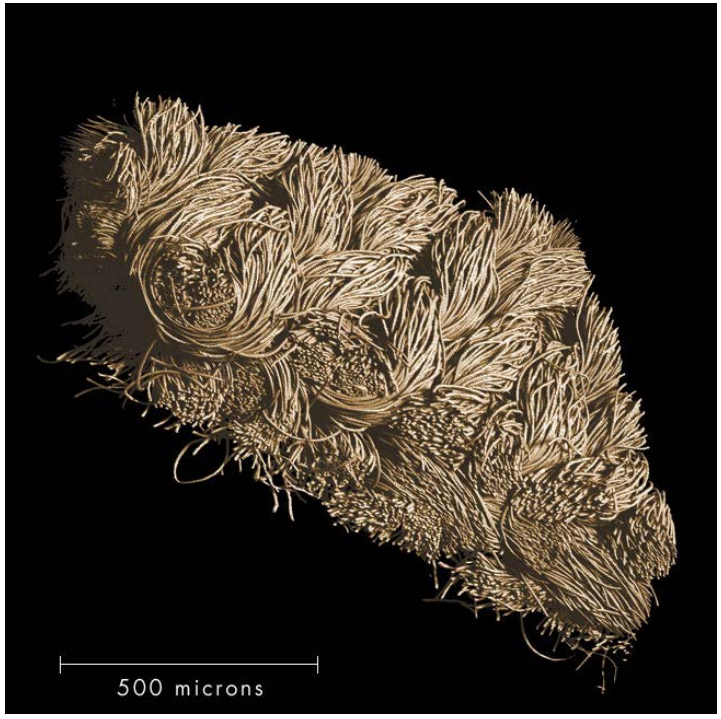




KENAF FIBER YARN





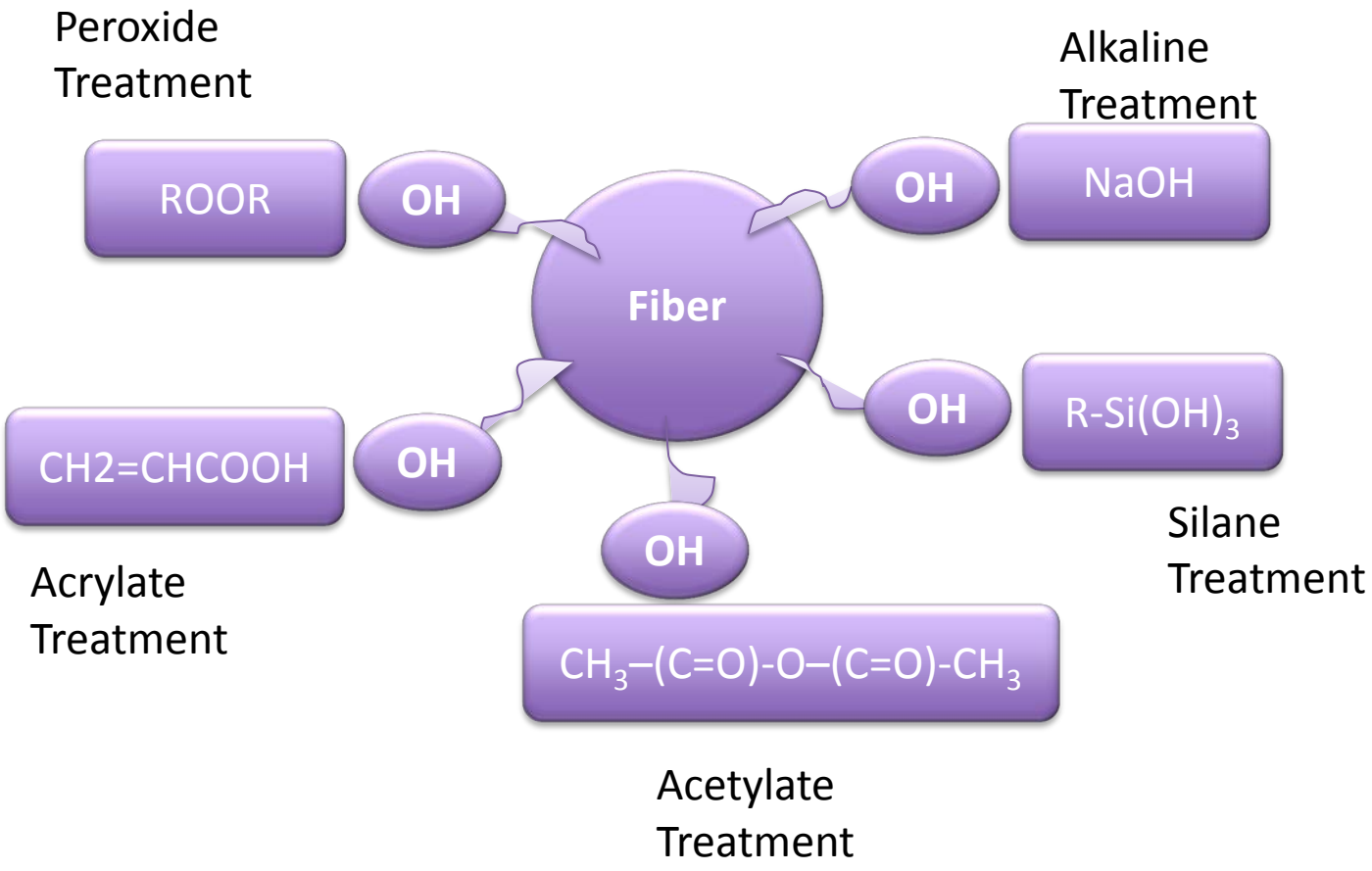




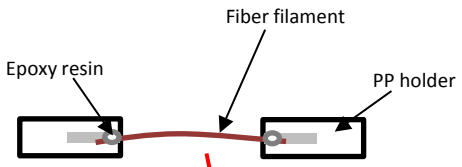
RECENT PROGRESS IN SURFACE TREATMENT OF KENAF FIBRE

EXPERIMENTAL

Surface Treatment

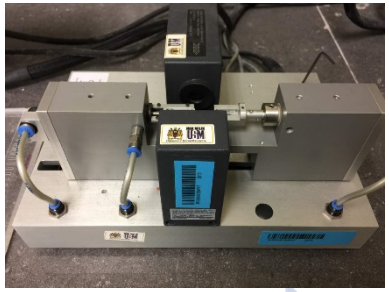


Tensile miniature machine











Fiber seperation
- Manually pick
- Choosing single fiber
- 10 strand of fibers as specimen for test for each conditions

Fixing fiber filament with holder end-to-end
- 15mm fiber length
- Polypropylene holder, cure with epoxy resin

Fiber diameter
- Infra red scanner
- 3 times scan to get the average

Tensile test
- Fiber is placed on tensile machine and tested

Single Fiber Tensile Test

Heat Treatment:
T/Strength: ~700MPa
T/Modulus: ~4.5GPa

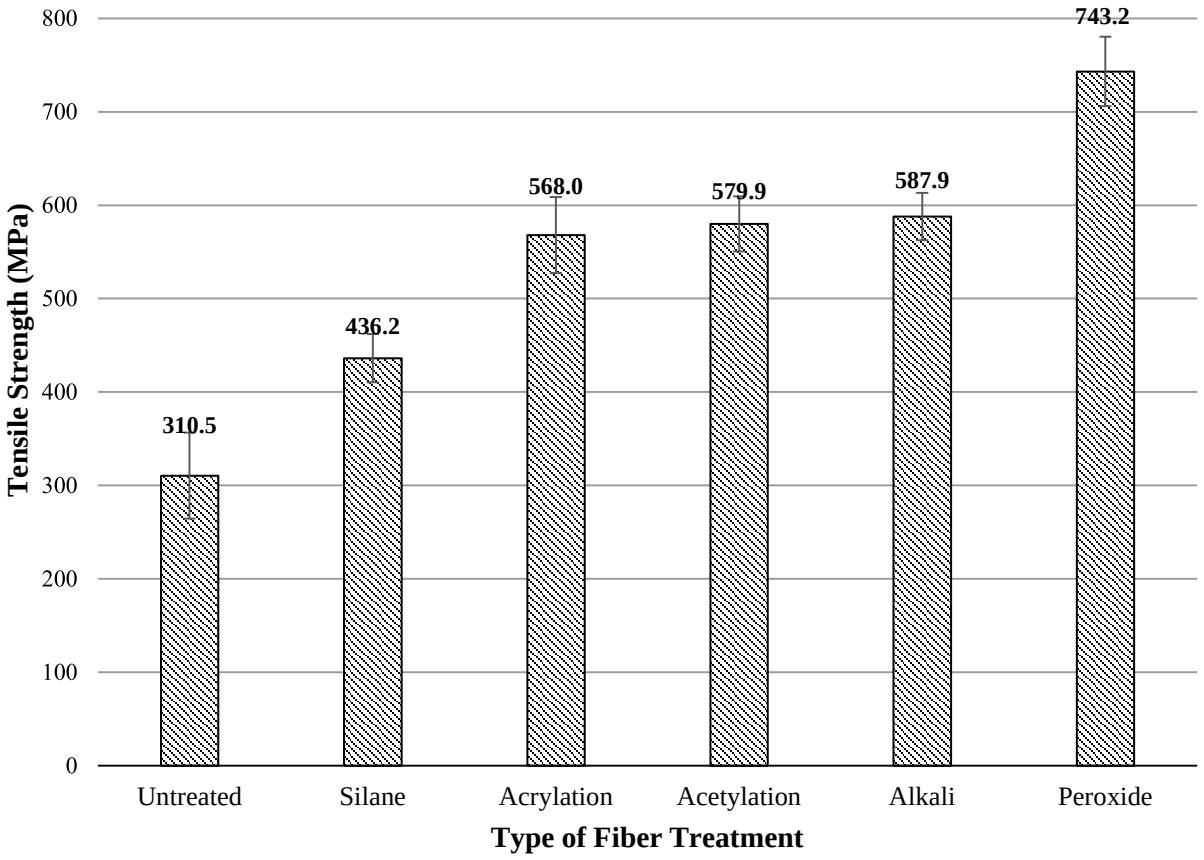


Figure: Tensile strength of kenaf fiber before and after various chemical treatment

Single Fiber Tensile Test

Heat Treatment:
T/Strength: ~700MPa
T/Modulus: ~4.5GPa

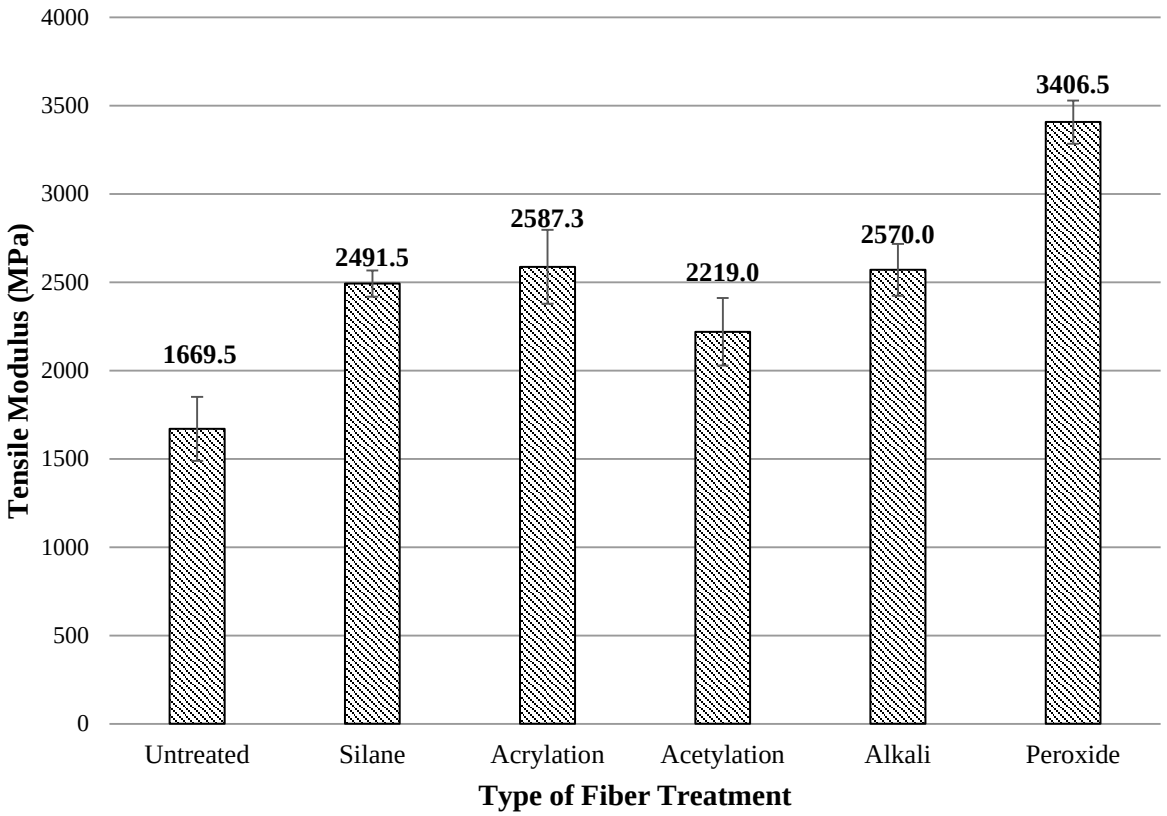
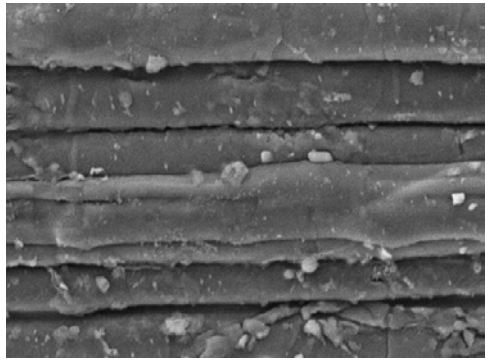
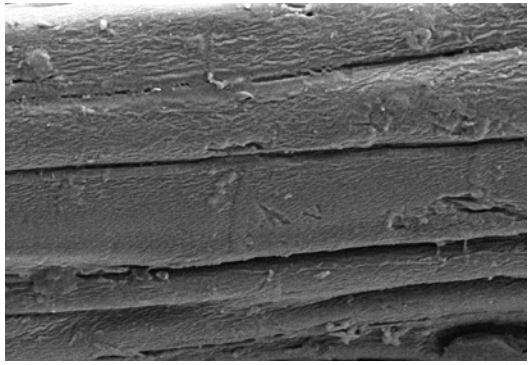


Figure: Tensile modulus of kenaf fiber before and after various chemical treatment

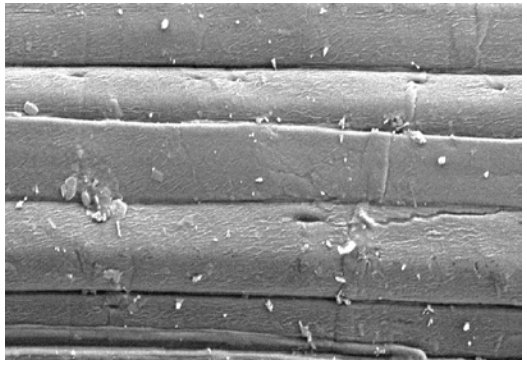
Surface Morphology



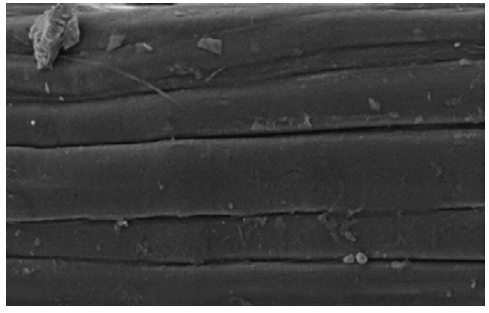
Untreated



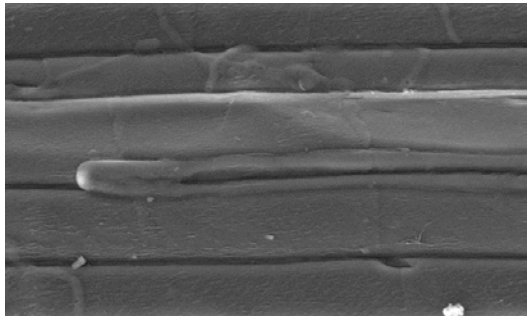
Alkalisation



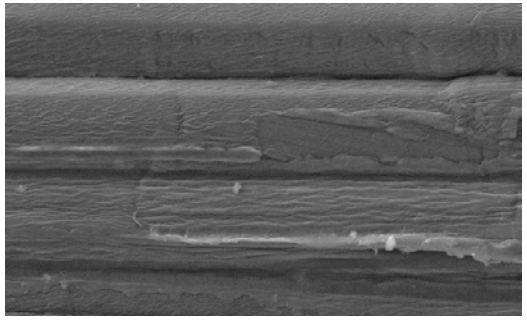
Silanisation



Acetylation



Acrylation



Peroxide

SEM images of single kenaf fiber before and after various chemical treatment.

RECENT PROGRESS IN NON-WOVEN KENAF FIBRE REINFORCED COMPOSITES: IMPROVING THE FLAMMABILITY BEHAVIOUR

INTRODUCTION

- Polyester and vinyl ester have the ability to be reinforced by natural fibres. → **styrene emission** not only during processing but also from the finished products.

- **Acrodur resin by BASF** →new solution in **polymer binder** technology → **environmentally friendly** due to its **non-corrosive properties** and **does not emit styrene** during processing and in the final products.

- **Water based nature** → can extensively diluted and the ability to be miscible with other conventional polymer binders and additives → produce composites with desired properties[6].

PROBLEM STATEMENT

- One of major disadvantage NFRC → **high flammability** that limits their application in many fields.

- **Halogen, phosphorus** and **nitrogen** compounds are the common flame-retardant additives,. However, they do not meet the demands for effective flame retardancy, smoke suppression as well as a low emission of toxic gases AND **Non-environmentally friendly**

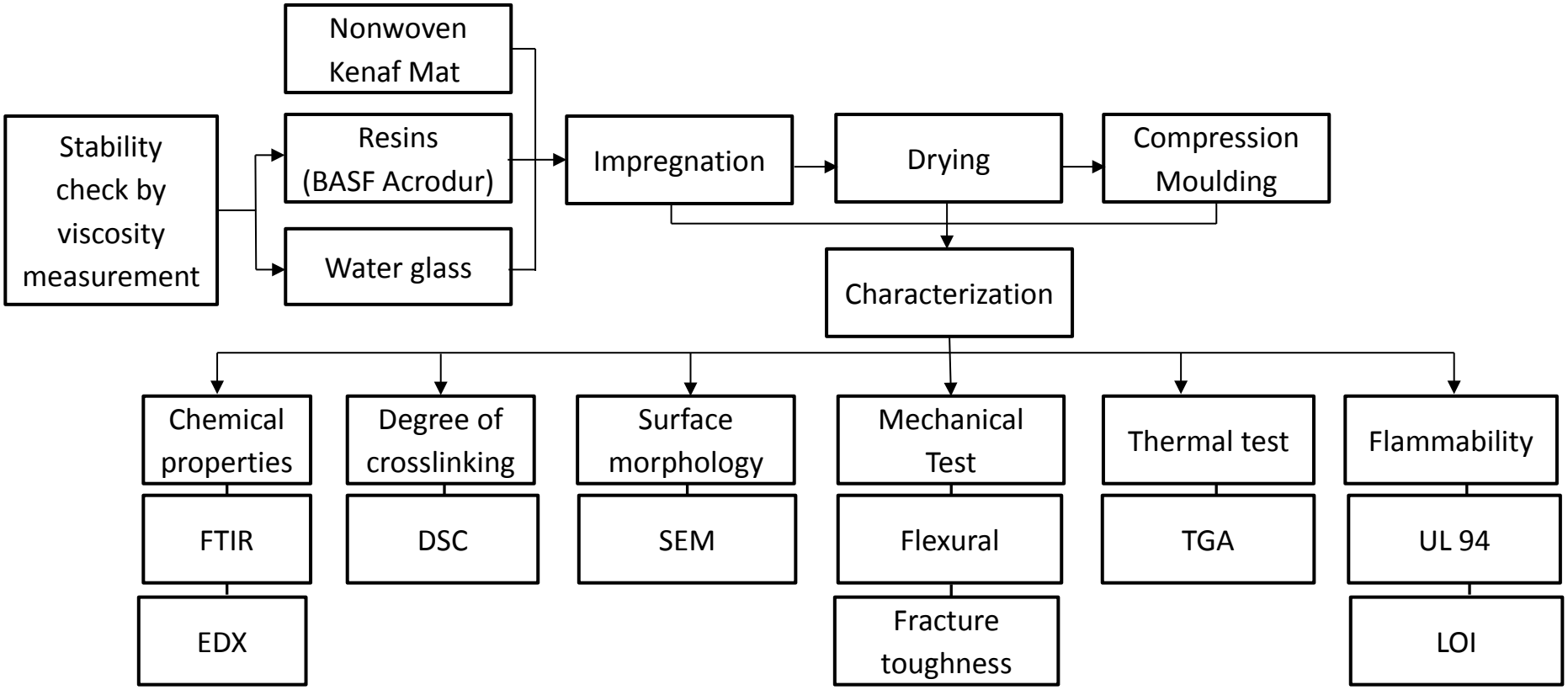
OBJECTIVES

1. To study the effect of water glass loading on the mechanical properties of non-woven kenaf fibre reinforced composites

2. To investigate the effect of water glass content to flammability properties of non-woven kenaf fibre reinforced composites

EXPERIMENTAL

Experimental Flowchart



Materials

Non-woven Kenaf fibre (KF) mat

- Needle punched nonwoven KF mat with areal density of 1350g/m^2 was obtained from Dr Rahmatullah Holdings Sdn. Bhd.

- Underwent alkali treatment at 60^{o}C for 3h based on the optimum treatment parameter reported by previous study.



Non-woven KF mat

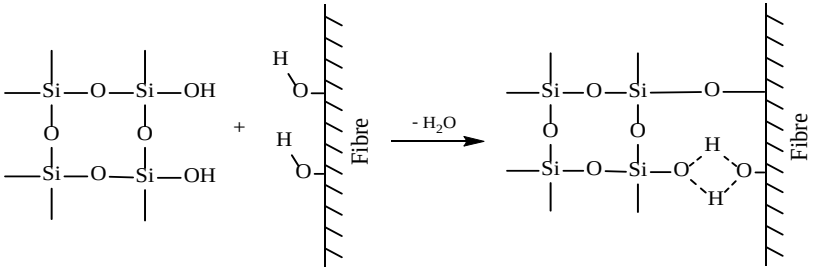
Acrodur 950L

- Acrodur 950L resin with a density, molecular weight and viscosity range of 1.20 g/cm^3, 80,000 g/mol and 900–2500 mPa.s respectively was obtained from BASF.

- The resin is an aqueous acrylic resin based on modified polycarboxylic acid, which can be thermally cured at a temperature above 130°C in the presence of a polyalcohol (crosslinking agent) creating a thermoset polyester.

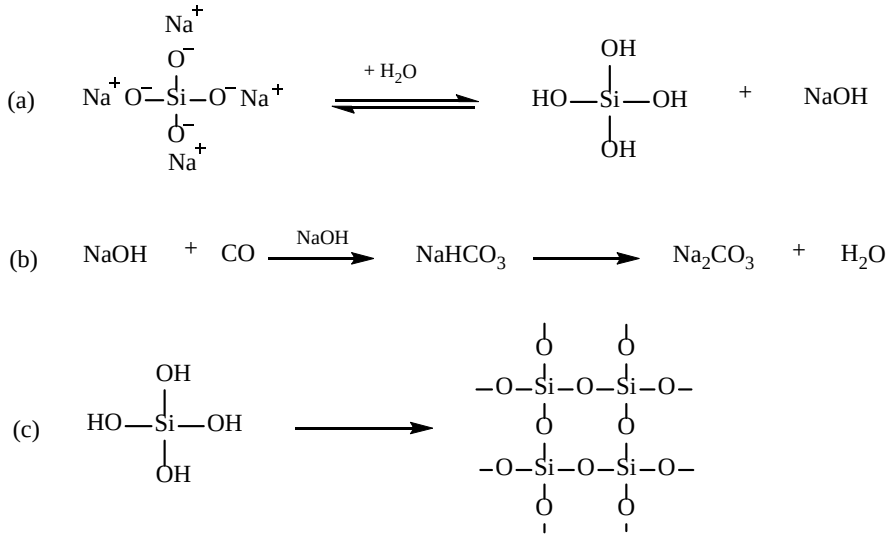
Water Glass

- Sodium silicate solution used in this study was obtained from Sigma→ containing 26 wt.% SiO_2 and 10.6 wt.% Na_2O.
- Water glass are manufactured by fusing high purity quartz sand (SiO_2) with sodium or potassium carbonate (Na_2CO_3 or K_2CO_3) in an open hearth furnace at 1100 – 1200°C
- The resulting glass is then dissolved using high pressure steam to form liquid silicate or "waterglass" which is clear and slightly viscous



Theoretical model for the surface between water glass and natural fibres

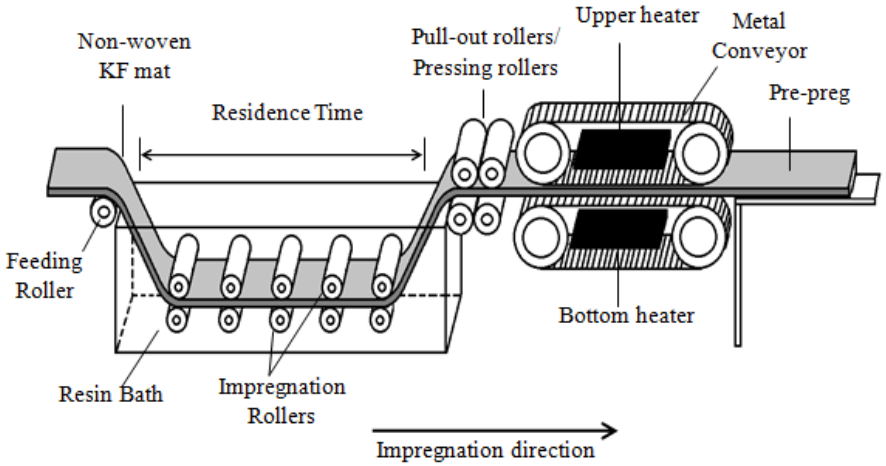
- Water glass reacts in aqueous solutions to form polysilicates as shown below



Polycondensation of water glass

- Due to the similarity between silane and polycondensated water glass, it can be assumed that the **polymerized water glass can act as a coupling agent** between the natural fibres and the matrix.

Composite Fabrication Process



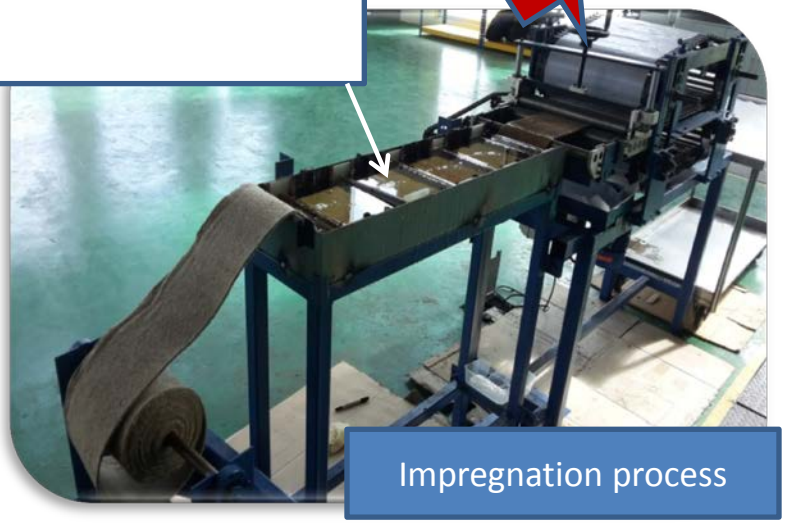
Designation of KF reinforced Acrodur composites with respect to resin and water glass content

Designation	Resin content (wt%)	Water glass content (wt%)
WG 0%	100	0
WG 10%	90	10
WG 20%	80	20
WG 30%	70	30

Resin impregnation system

1. Neat Resin
2. Resin +10%SS
3. Resin + 20%SS
4.Resin + 30%SS

Drying at 80° C until residual moisture of 15w_t%



Impregnation process



Compression moulding

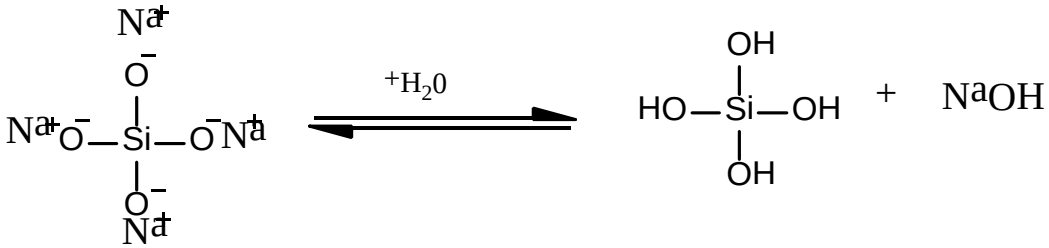


Prepared Sample

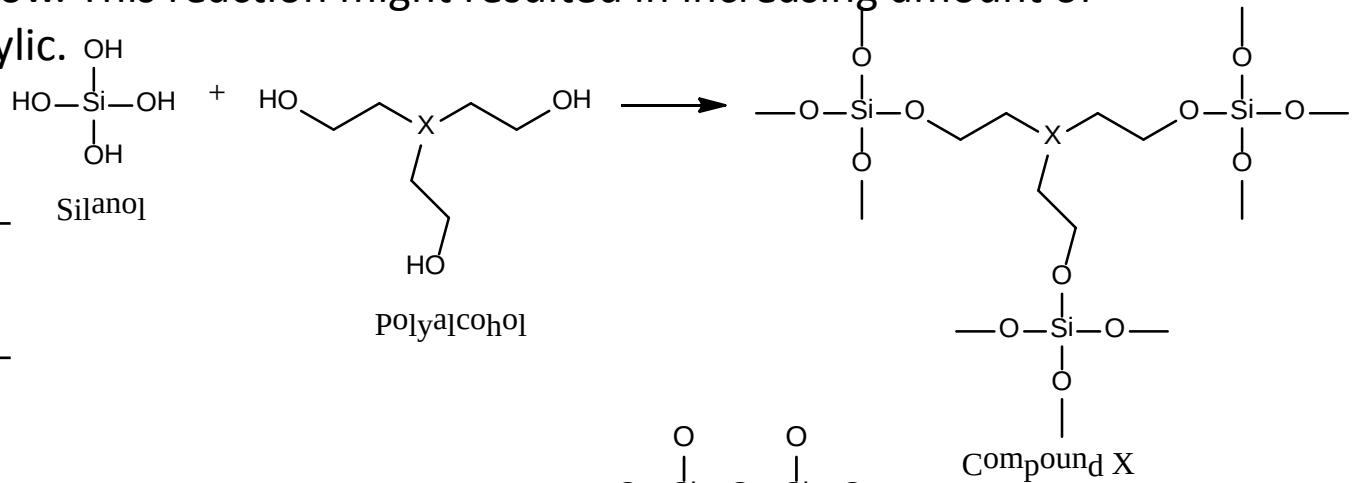
RESULTS AND DISCUSSION

Addition of water glass

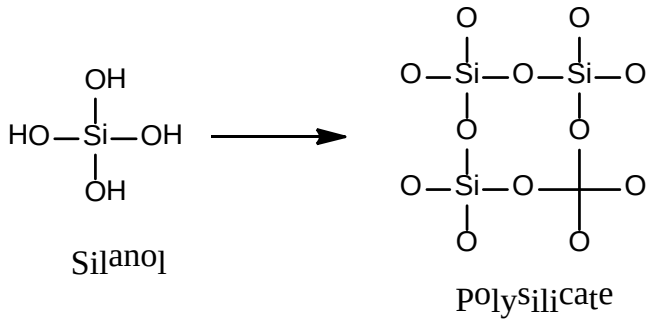
Water glass reacts in aqueous solution to form **silanol group** (**silicic acid**) as follow [7]



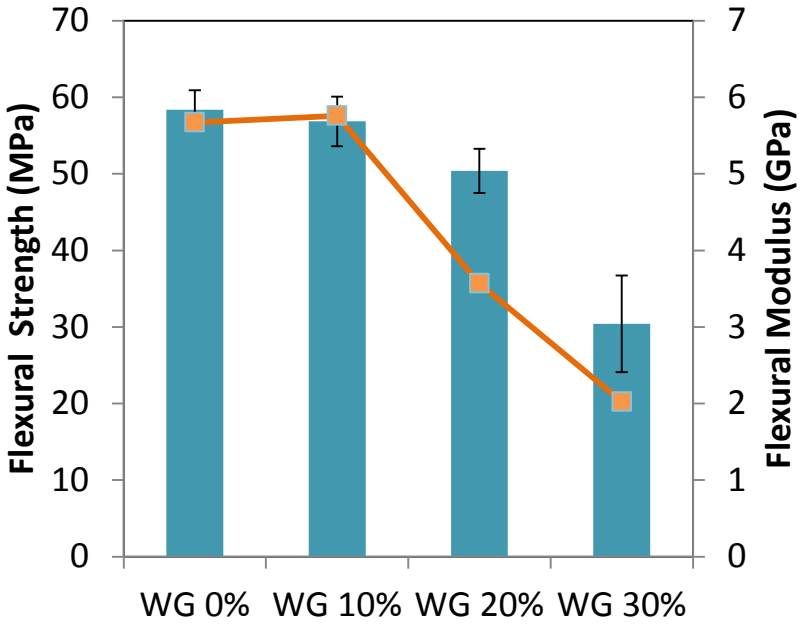
Due to the **acidic medium of Acrodur resin** even with the addition of 30% water glass, silanol group remained in the system and will not sufficiently neutralized by NaOH . The silanol potentially react either with polyalcohol or with itself as shown in the proposed reaction below. This reaction might resulted in increasing amount of unreacted polycarboxylic.



Resin mixture	pH
WG0%	3.50
WG10%	4.00
WG20%	4.18
WG30%	4.55

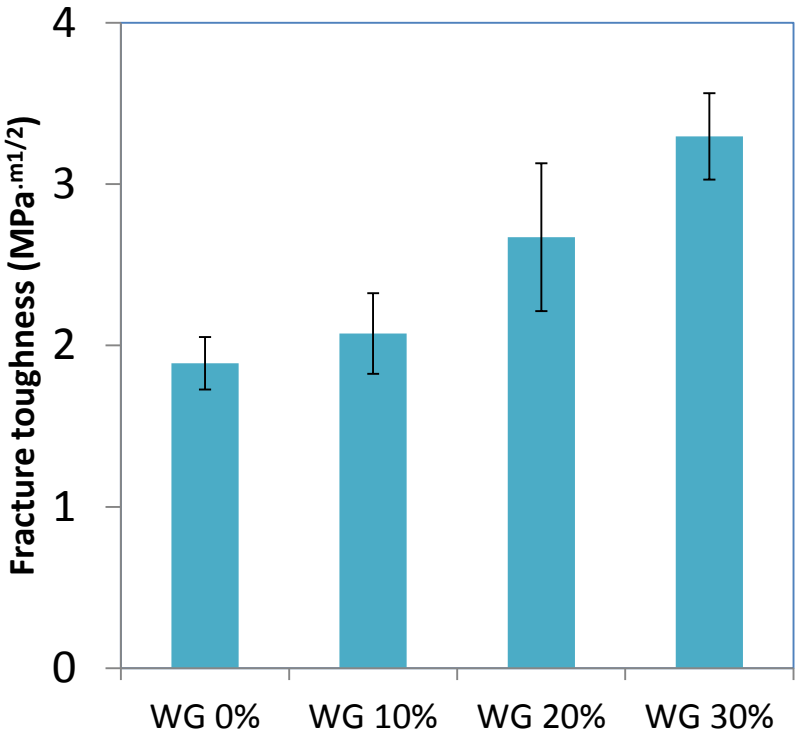


MECHANICAL PROPERTIES



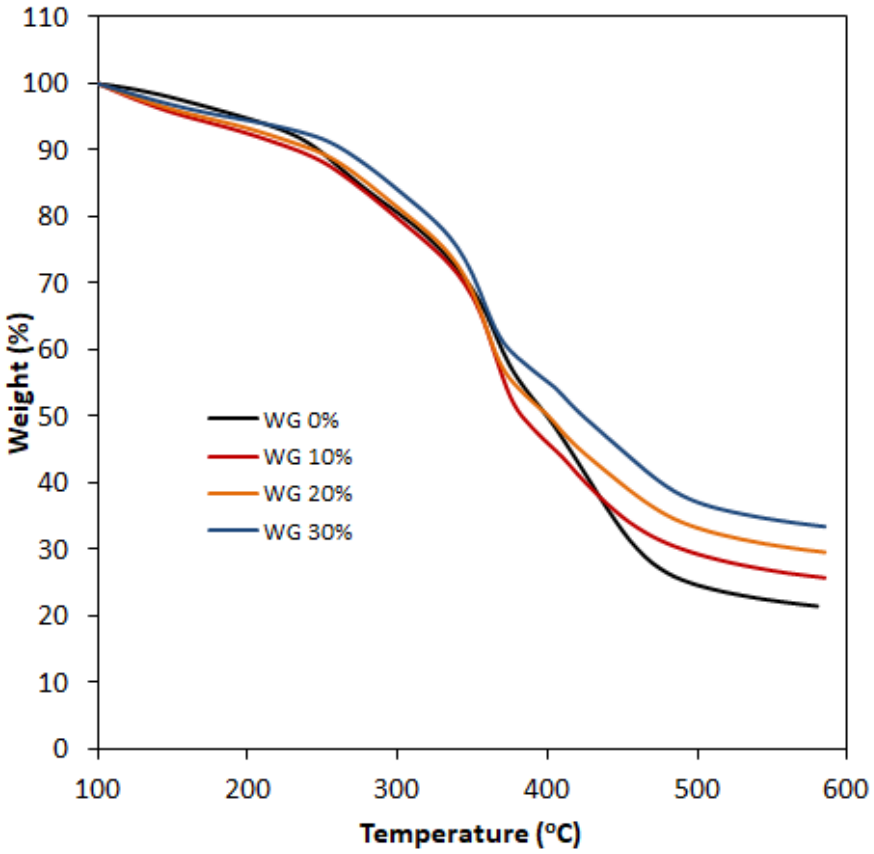
- Flexural strength
- As the water glass loading ↑ the flexural strength ↓
- Due to the interference of the curing reaction between polycarboxylic acid and the polyalcohol to form crosslinking
- Evaporation of uncured material during processing resulted in microvoid → reduce strength

- Flexural modulus-
- Incorporation of 10wt% water glass (WG10%) imparted a slight increase in flexural modulus
- This to the introduction of stiff polysilicate within the composite system as a result of polycondensation reaction between silanol group of water glass.
- However, the inhibition of crosslink by the addition of higher water glass content (above 20wt%) gives adverse effect to the flexural modulus of composites
- Uncured functional groups can act as plasticizers, reducing the flexural modulus of composites [19]



- Fracture toughness of the composites ↑ as the water glass content increases ↑
- Due the lower crosslink percentage, some flexibility properties of uncured Acrodur matrix still remained, contributed the ability of absorbing energy, and therefore increased the fracture toughness
- In addition, the formation of more flexible Si-O linkage in polysilicate and **compound X** also impart ductility to the composites.

TGA ANALYSIS



Thermal properties of the composites

Composites	$T_{10\%}$ (°C)	Char yield (%)
WG0%	240	23.60
WG10%	165	27.02
WG20%	190	31.08
WG30%	225	36.0

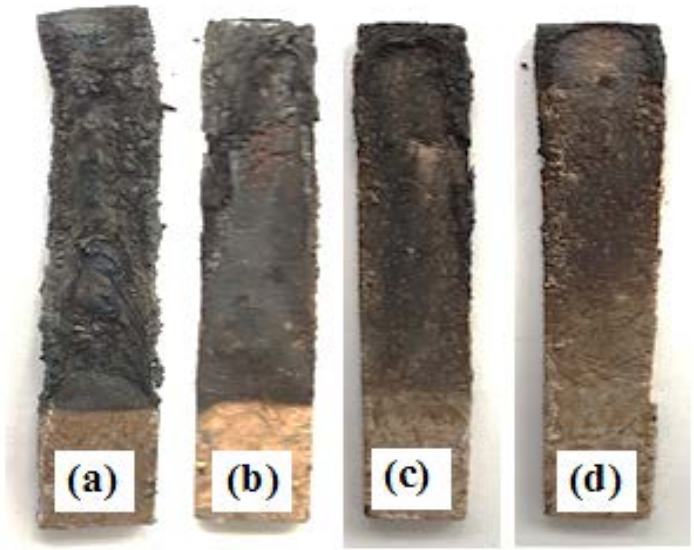
FLAMMABILITY PROPERTIES

Flammability rating of UL94-V

	V-0	V-1	V-2
Burning time after flame application (s)	≤ 10	≤ 30	≤ 30
Total burning time (s) for 10 flame applications	≤ 50	≤ 250	≤ 250
Burning and afterglow times of samples after second flame applications	≤ 30	≤ 60	≤ 60
Dripping of burning specimens	no	no	yes
Specimen completely burn	no	no	no

UL94 classification and LOI index of composite with different amount of water glass content

Composites	UL94 Classification	LOI
WG 0%	V-1	24
WG 10%	V-1	34
WG 20%	V-0	39
WG 30%	V-0	47



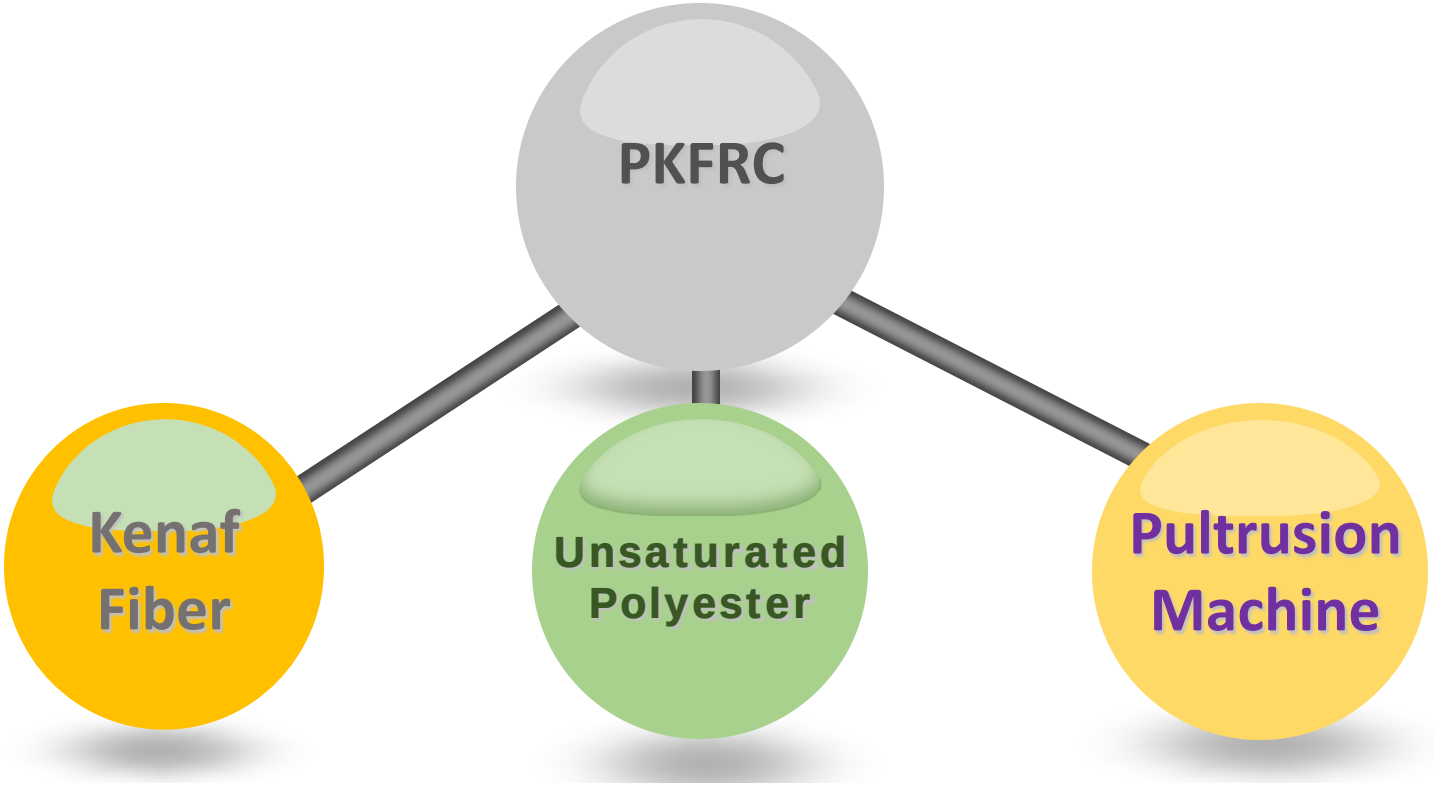
- The non-flammable, fire resistant layer of silicates on the material's surface help to provide an insulating barrier between the product and the flame, and will thus slow down the spread of fire.
- In addition, adsorption of heat energy by polysilicates cools down the fire
- The non-flammable composition of polysilicate exhibited by the char residue in the TGA results

UL 94 tested sample (a) WG 0%, (b) WG 10%, (c) WG 20% and (d) WG 30%

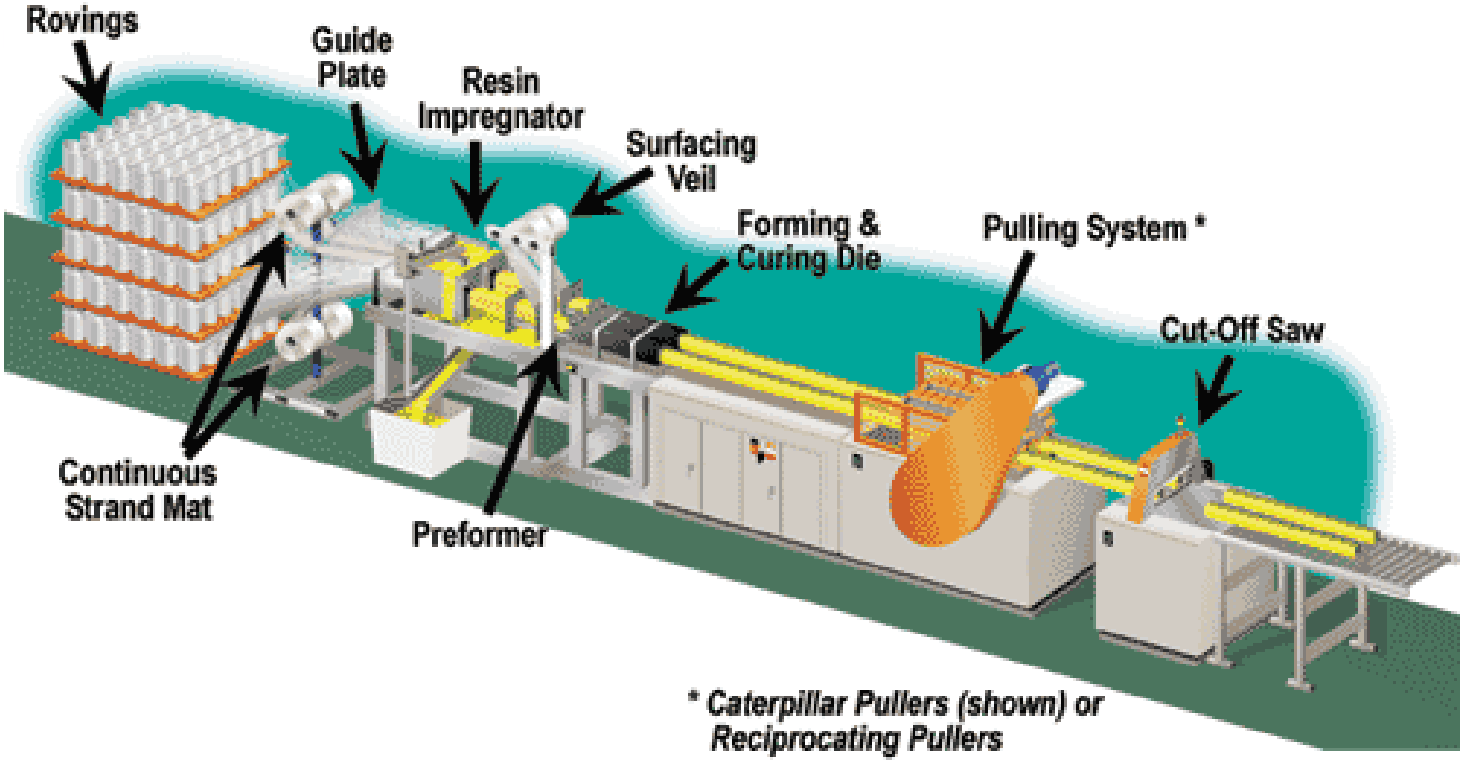
Recent progress in Pultruded Kenaf Fibre Reinforced Composites: Effect of Kenaf TEX, surfacing veils and Chopped Strand Mat (CSM) on the properties of KFRC

(1) Effect of Kenaf TEX on the properties of KFRC

COMPOSITE PREPARATION



PULTRUSION TECHNIQUE

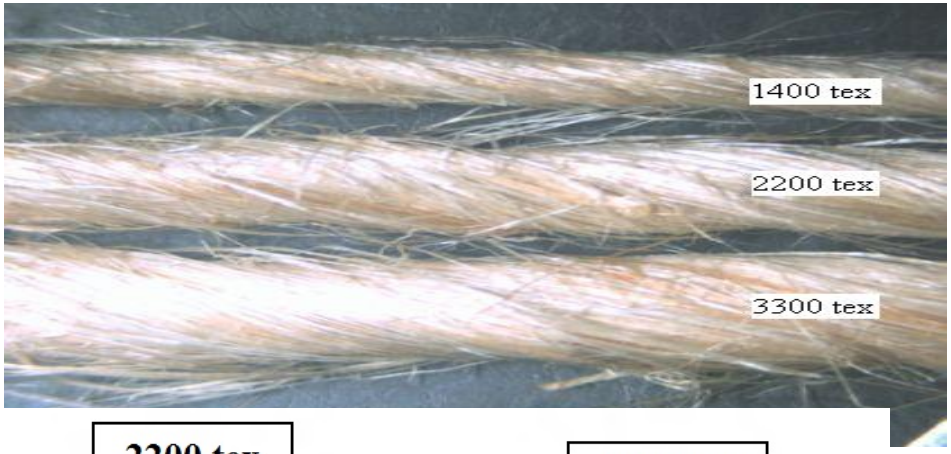


Schematic diagram of standard pultrusion machine

KENAF FIBRE TEX

Changes on tex numbers will significantly change the properties of PKFRC

Kenaf fibers with different tex



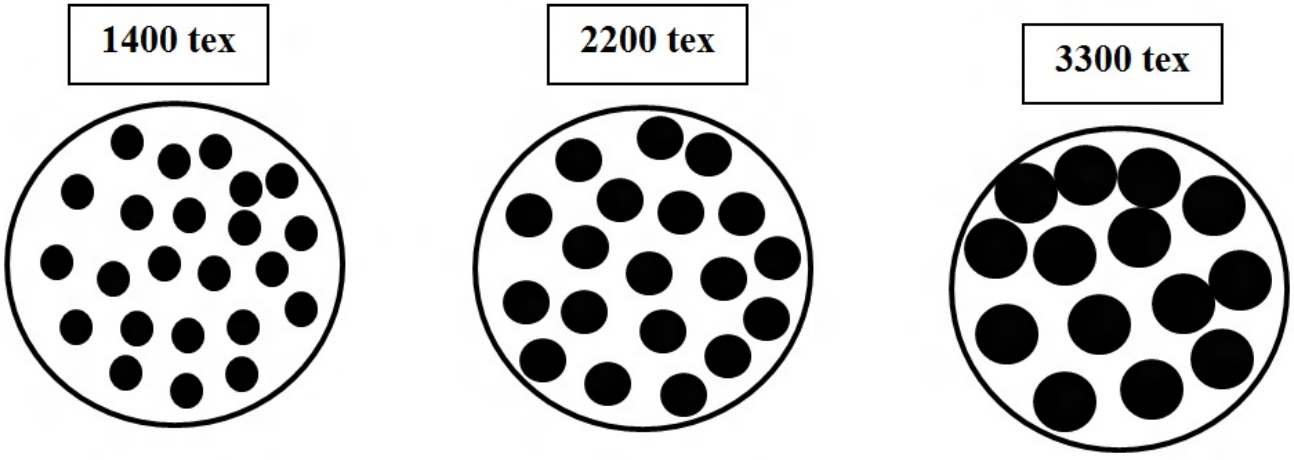


Illustration of different kenaf tex in pultruded composites

EXPOSURE

NATURAL WEATHERING EXPOSURE

CONDITION
Exposed to 100% outdoor natural environment

DURATION
Exposed to natural ageing for 200 days (4800 hours)



FLEXURAL PROPERTIES (Different Tex)

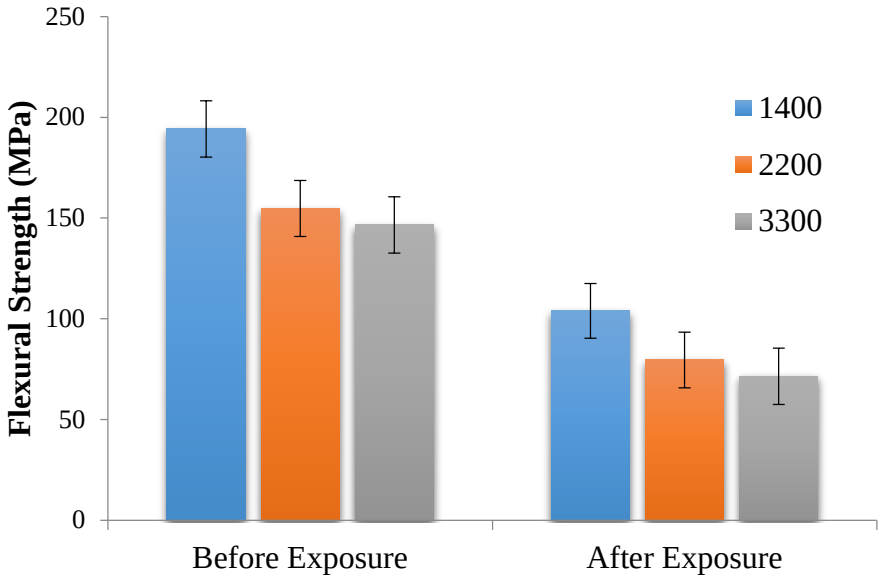


Figure : Flexural strength of PKFRC specimen before and after exposure

FLEXURAL PROPERTIES (Different Tex)

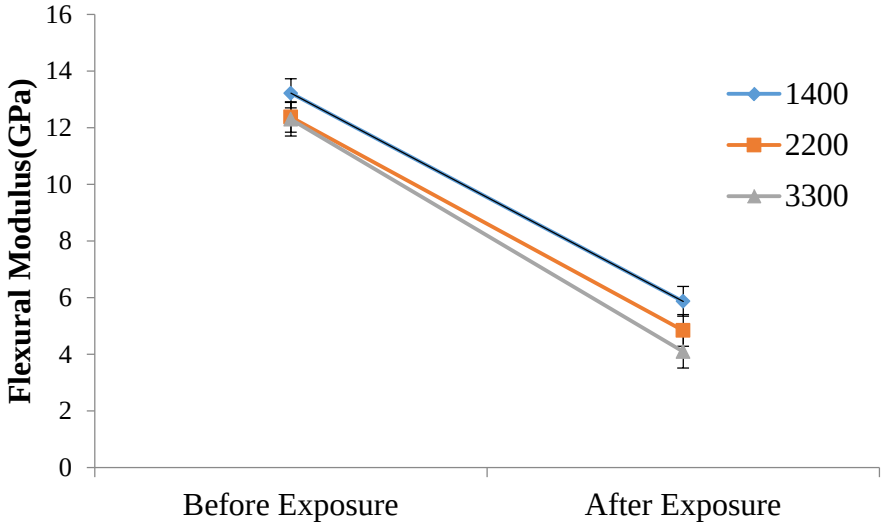


Figure : Flexural modulus of PKFRC specimen before and after exposure

COMPRESSION PROPERTIES (Different Tex)

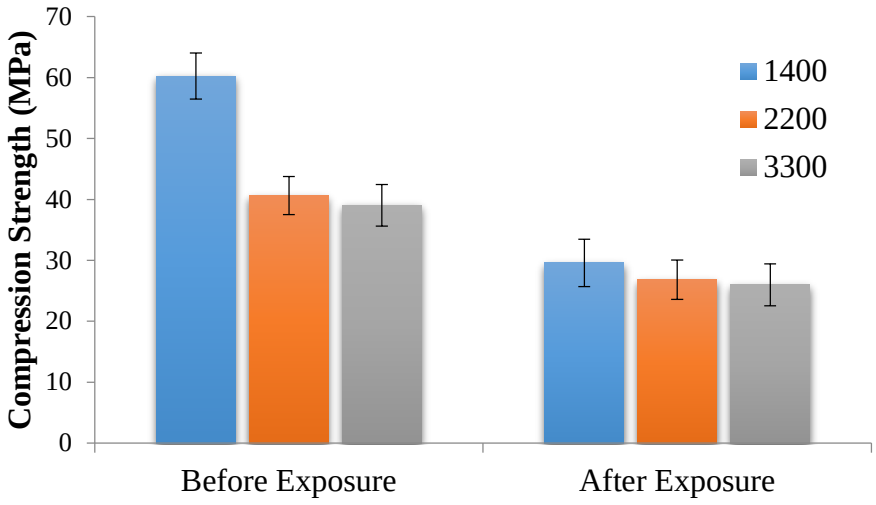


Figure : Compression strength of PKFRC specimen before and after exposure

COMPRESSION PROPERTIES (Different Tex)

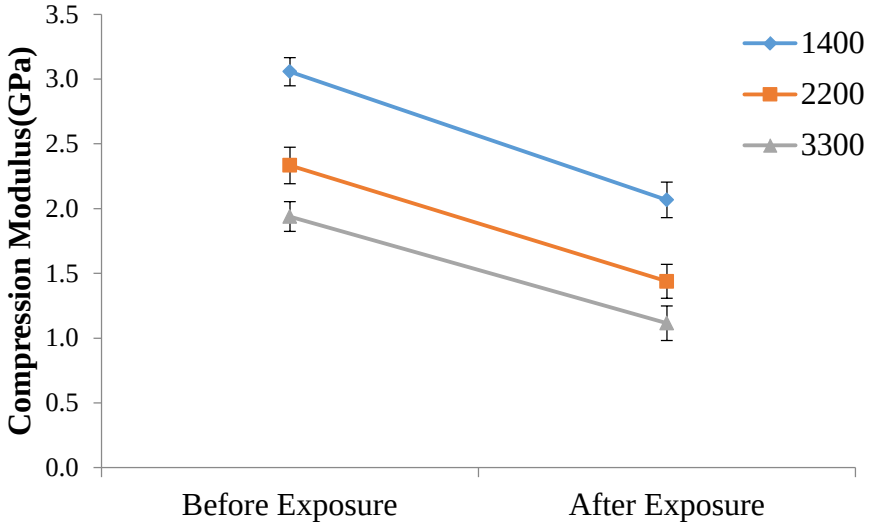


Figure : Compression modulus of PKFRC specimen before and after exposure

(2) Effect of hybrid architecture on the properties of KFRC

HYBRID COMPOSITE PREPARATION

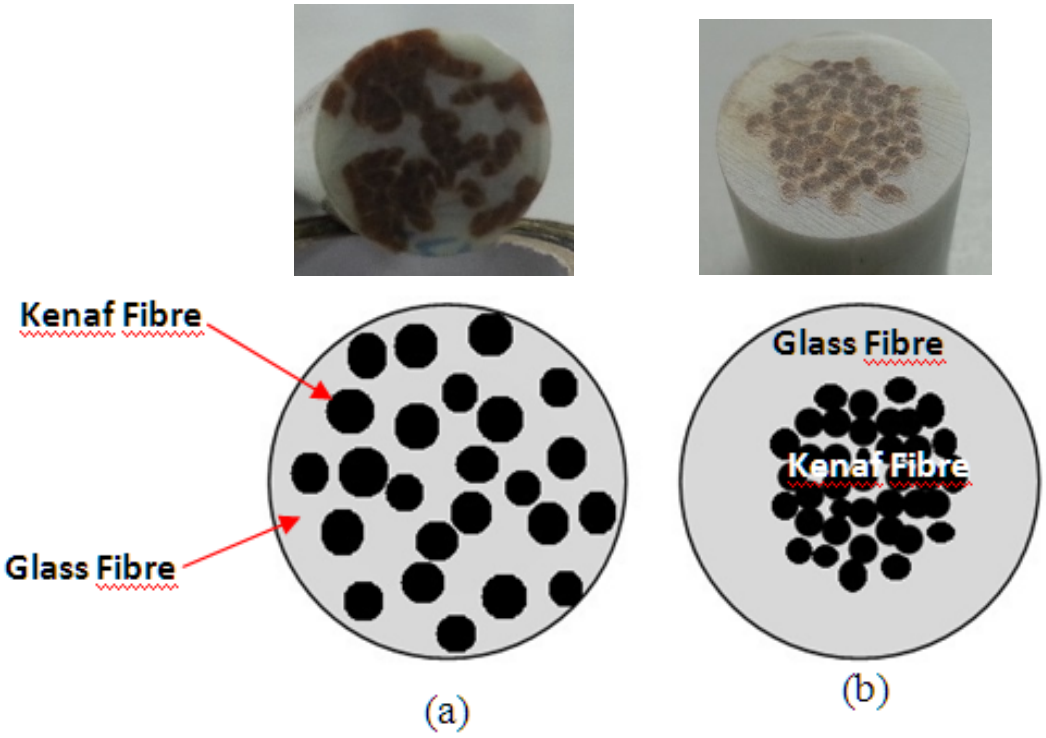
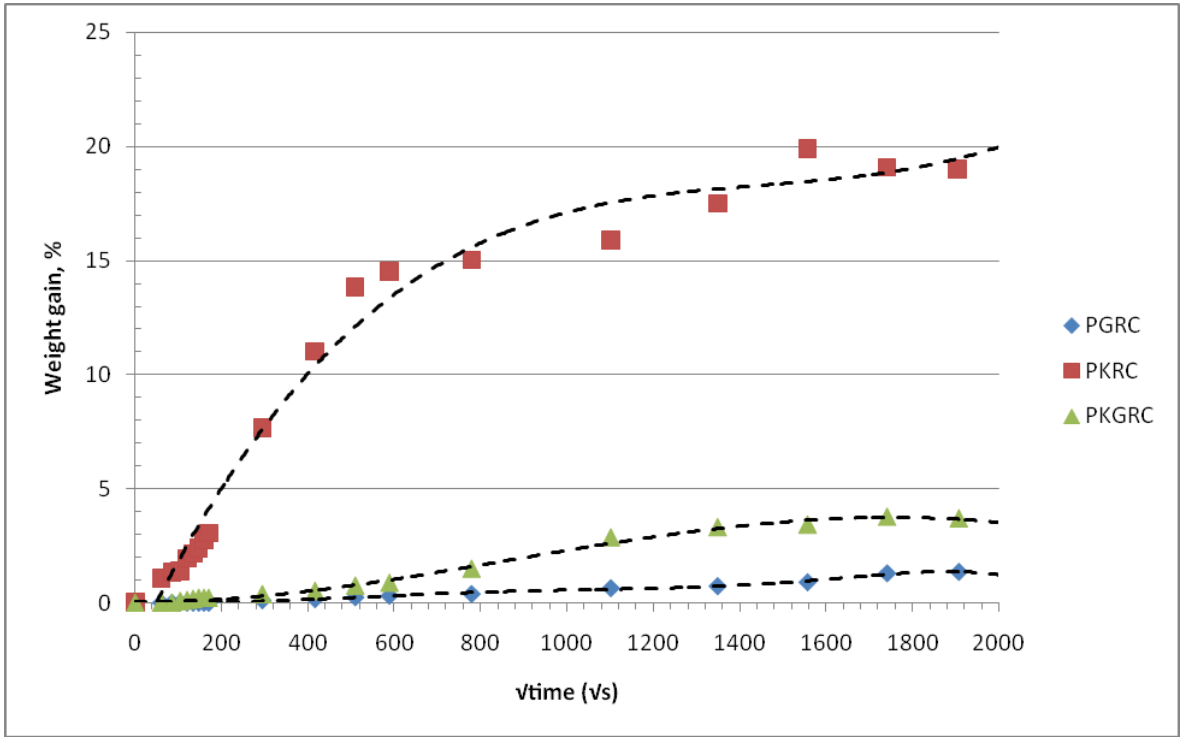


Illustration of cross-section view of pultruded kenaf/glass hybrid reinforced unsaturated polyester composite,
(a) random fiber distribution (b) allocated fiber arrangement.

MOISTURE ABSORPTION (Hybrid Composites)

Moisture Absorption Behavior for Hygrothermal Ageing



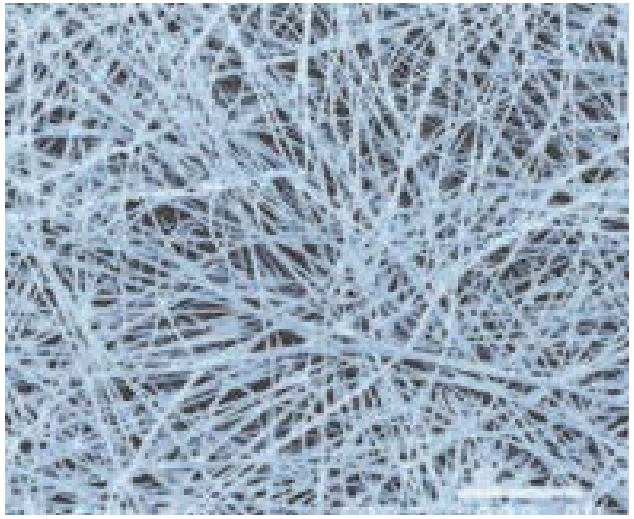
- PGRC – Pultruded Glass Fibre Reinforced Composite
- PKRC – Pultruded Kenaf Fibre Reinforced Composite
- PKGRC – Pultruded Kenaf/Glass Fibre Reinforced Composite (Hybrid)

(3) Effect of Surfacing veil on the properties of KFRC

COMPOSITE PREPARATION (Surfacing Veil)



The variety of polyester surfacing veils



The randomly oriented fiber of the surfacing veils

COMPOSITE PREPARATION (Surfacing Veil)



Application of surfacing veil to PKFRC during pultrusion manufacturing

MOISTURE ABSORPTION (Surfacing Veil)

Moisture Absorption Behavior for Hygrothermal Ageing

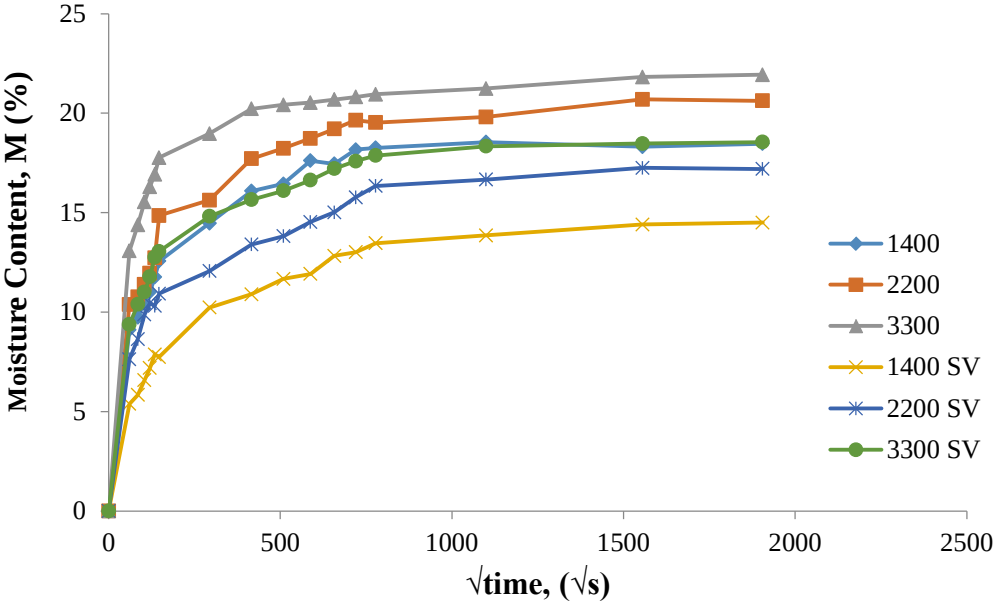


Figure 4.10 Moisture content for PKRC specimens with and without SV for hygrothermal ageing in distilled water.

- Same trend in sea water and acidic solution

(4) Effect of CSM on the properties of KFRC

Materials and Methodology



Kenaf fiber rovings 1300 tex



Glass fiber chopped strand mat 400gsm

Kenaf Fiber yarns
+
Glass fiber chopped strand mat (CSM)
Hybrid fiber reinforced polymer (HFRP)



Hybrid components. Kenaf fibers and fiber glass CSM 400gsm.

SAMPLES

- Rectangular profile 24mm x 5mm

	Kenaf	Hybrid
Matrix	Unsaturated polyester resin	Unsaturated polyester resin
Fiber reinforcement	Kenaf	Kenaf + Glass (CSM)
Fiber volume ratio	0.5	0.39 + 0.11 =0.5
Density (g/cm^3)	1.12	1.21
Hardness (Shore A)	76	81



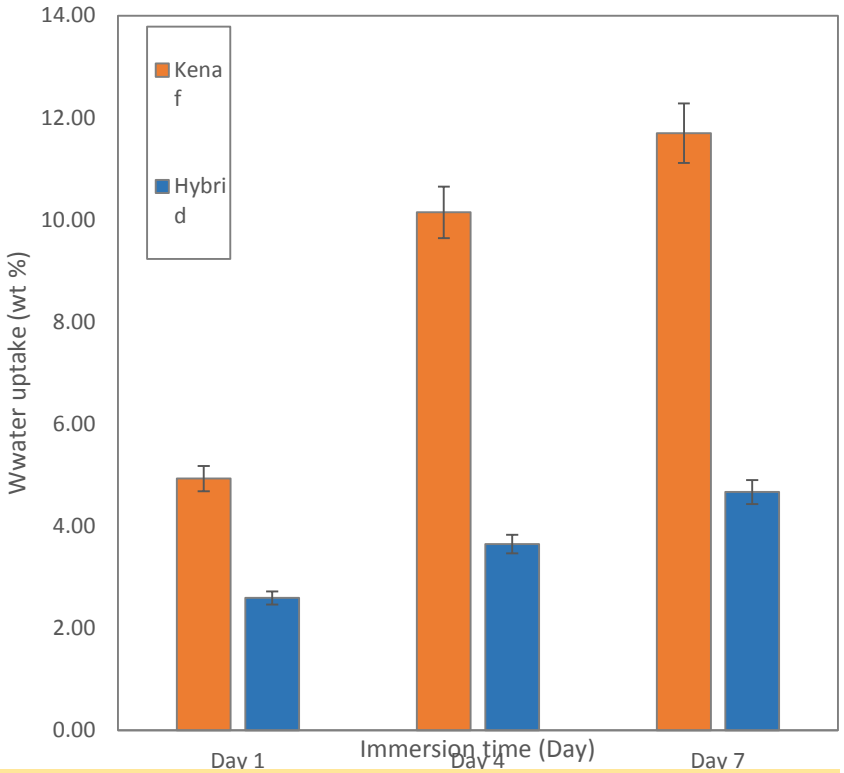
(a) Kenaf FRP



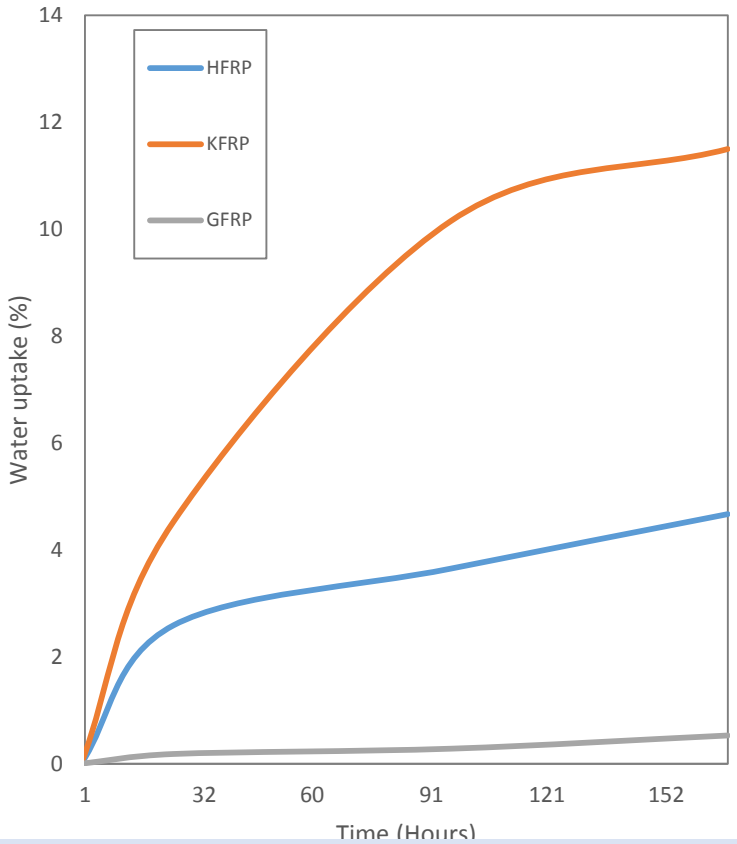
(b) Hybrid FRP

CSM: Chopped Strand Mat

- Moisture absorption

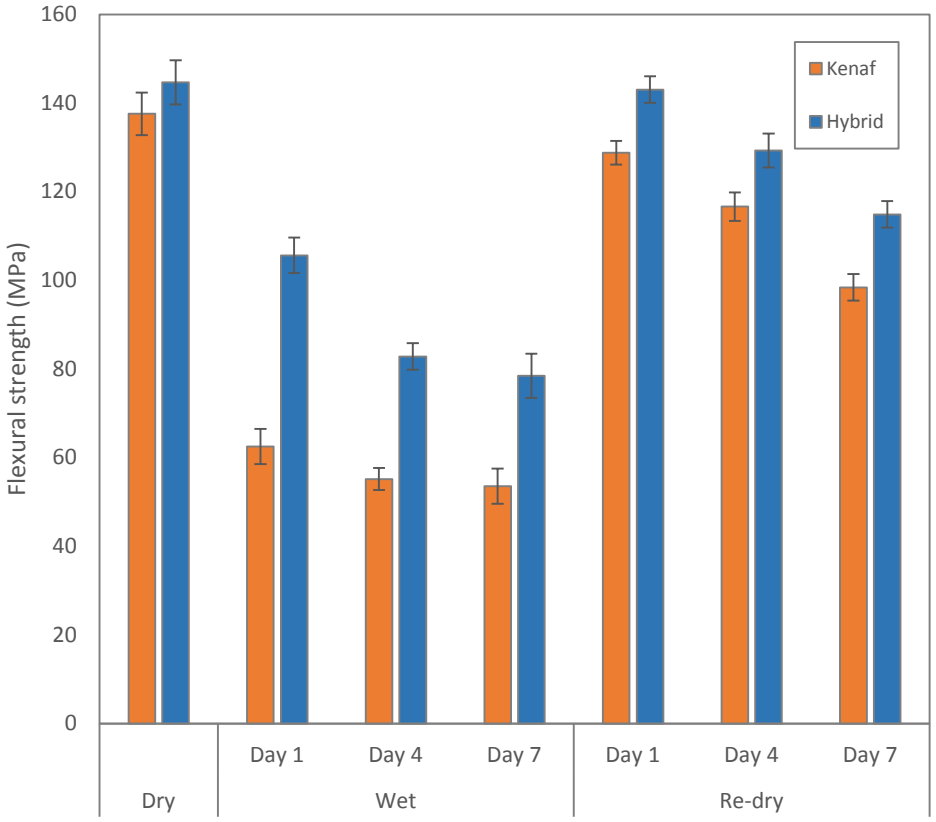


KFRP absorbed water more than HFRP proving that presence of CSM helps to reduce the water uptake of kenaf pultruded composites by more than 50%.



Comparison of moisture uptake between KFRP, HFRP and GFRP. KFRP have the highest water uptake (wt %) followed by KFRP and GFRP.

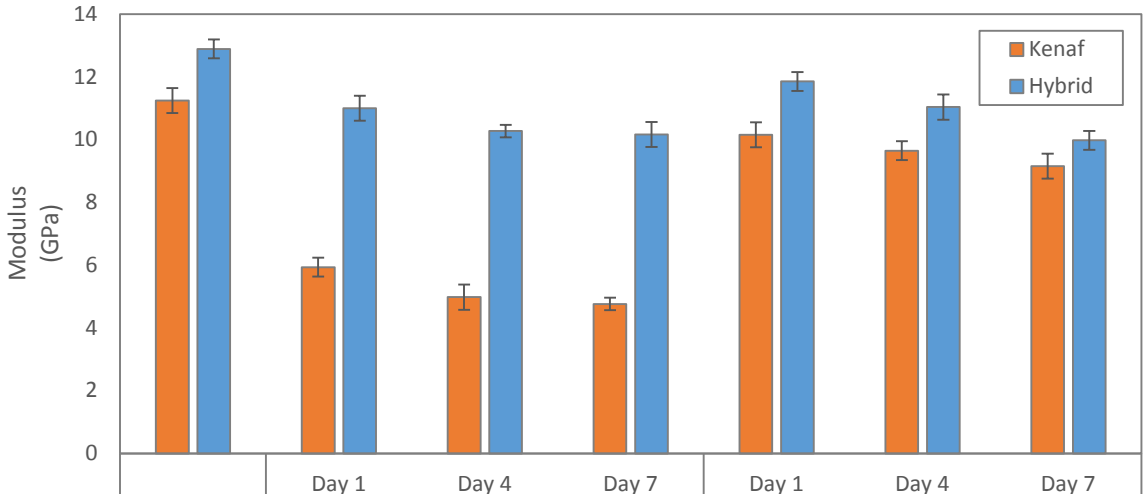
- Effect of water absorption on flexural strength

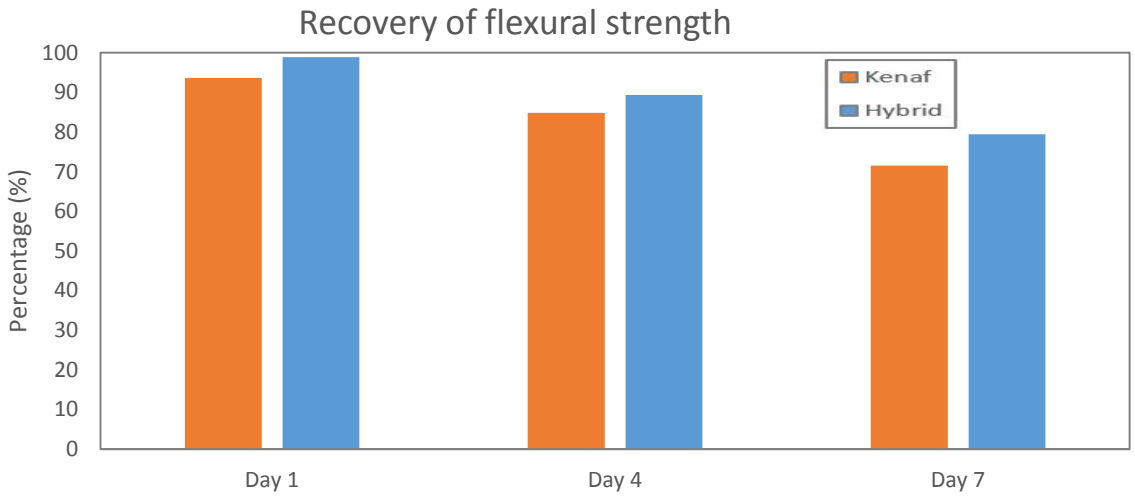


There were three conditions in conducting mechanical performance of pultruded composites for a week.

Conditions	Description
Dry	Samples were dry at 80°C in oven for 24 hours. Then, cooled down inside desiccator for 1 hour before tested.
Wet	Samples were test with wet conditions after immersed in distilled water for 1, 4 and 7 days.
Re-dry	Samples were firstly immersed before re-dry at 80°C for 24 hours.

Wet sample shows deterioration in flexural properties where the strength of KFRP were decreased from 137 MPa to 62 MPa (50% drop in performance) while HFRP strength decreased from 145 MPa to 105 MPa equivalent to 37% reduction of flexural strength.





Modulus of KFRP and HFRP showing the same trend with flexural strength. Presence of moisture resulted a serious deterioration in the modulus of the composites

The properties of both composites show a good recovery upon redrying.
Better recovery could be observed for HFRP as compared to KFRP indicating that the natural fibres are more adversely affected by the water uptake.

CONCLUSION

- The best surface treatment so far is peroxide treatment followed by alkaline treatment
- Water glass successfully enhanced flame retardancy and act as a coupling agent in the composites.
- The fracture toughness somehow increased as the water glass content increases.
- Self-extinguishing properties is successfully introduced to the composites during the fire testing for the sample containing as low as 20% water glass content giving an excellent UL94 classification of V-0 high LOI of 39.
- Lower tex gives better properties of pultruded kenaf fibre reinforced composites
- Surfacing veils and chopped strand mat are capable of enhancing the properties of KFRC

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