UNIVERSITY OF COPENHAGEN

A Brief review of Agricultural Fibers in Polypropylene

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Biofiber Thermoplastic Composites (Melt Blend Processing)

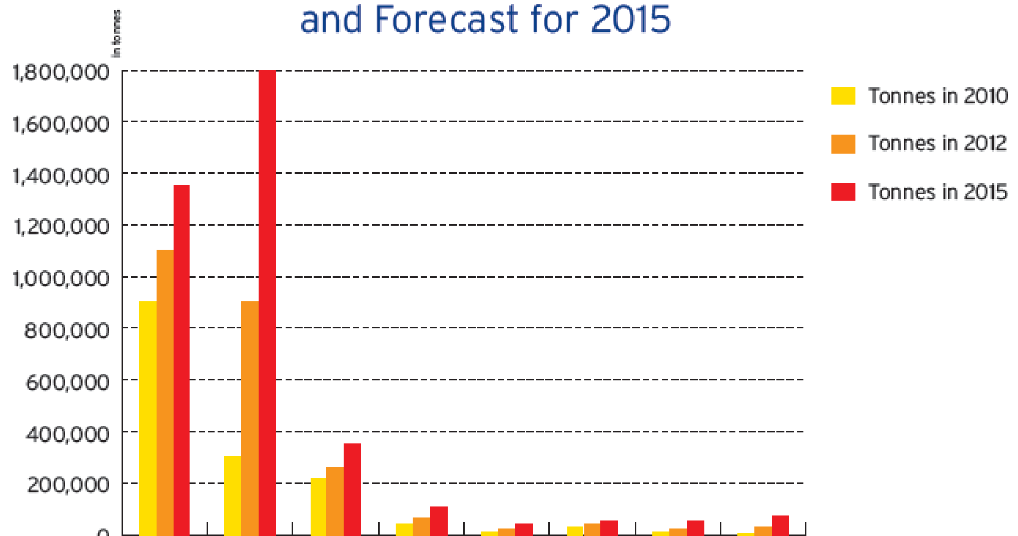
Traditional Thermoplastic Composites- fiber is surrounded by the matrix.

- Particulates like wood flour, etc. Low Performance
- Biofibers wood fiber, jute, flax, kenaf- Higher performance

Plastic Used- Limited to Biofiber Thermal Degradation ~ 190 °C for short time periods- eg. PE, PP, PVC, PS, etc

European and Global Markets 2012 and Future Trends

Global Production of WPC in 2010 and 2012, and Forecast for 2015



forecast

	North America	China	Europe	Japan	Russia	South East Asia	South America	India
2010	900,000	300,000	220,000	40,000	10,000	30,000	10,000	5,000
2012	1,100,000	900,000	260,000	65,000	20,000	40,000	20,000	25,000
2015	1,350,000	1,800,000	350,000	110,000	40,000	55,000	50,000	70,000

Authors: Michael Carus, Dr. Asta Eder, Lara Dammer, Dr. Hans Korte, Lena Scholz, Roland Essel, Elke Breitmayer

From: www.bio-based.eu/markets

Production of Biocomposites (WPC and NFC) in the European Union 2012 (in tonnes)

Wood-Plastic Composites	260,000
Decking	174,000
Automotive	60,000
Siding and Fencing	16,000
Technical Applications	5,000
Furniture	2,500
Consumer	2,500
Natural Fibre Composites	**92,000**
Automotive	90,000
Others	2,000
Total Volume Biocomposites (WPC and NFC)	**352,000**
Share	**15 %**
Composite Production in European Union, total volume (Glass, Carbon, WPC and NFC)	2.4 Million

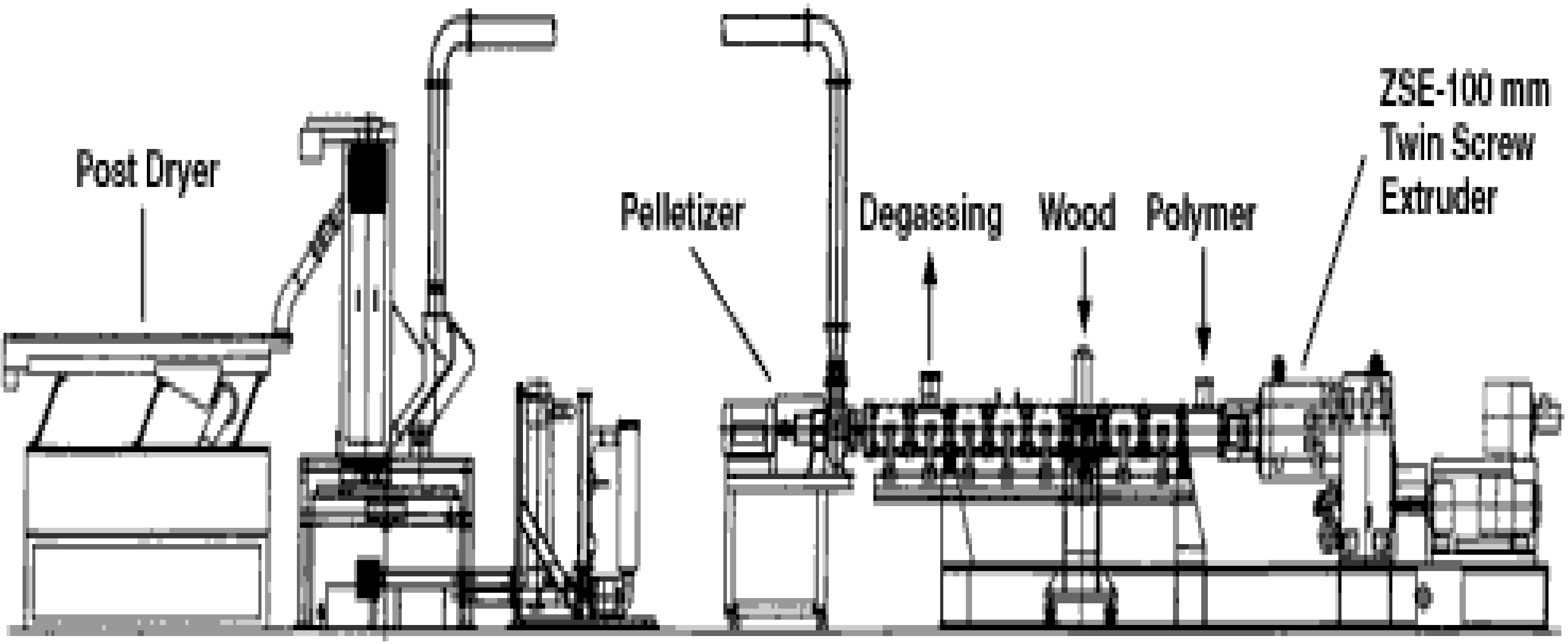
Table I: Production of biocomposites (WPC and NFC) in the European Union in 2012 (in tonnes) (nova 2014)

NFC- Almost all non-woven technology automotive

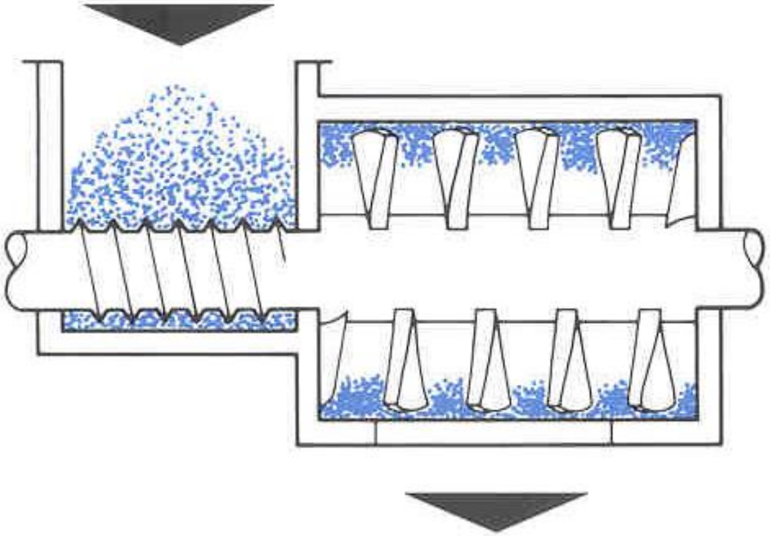
Processing Considerations (I have used)

- Twin Screw Extruder
- Thermo-Kinetic Mixer

Twin Screw Compounding



Thermokinetic Mixer



Feed Screw Model
(Semi-Continuous)

Effect of Fiber Type

- Cellulose Crystallinity (%)
- Cellulose Degree of Polymerization
- Micro-fibril Angle
- Lignin and Other extractives Could Influence Flow Characteristics
- Extracting fibers from plants

Fiber Properties

Fiber	Young's Modulus (GPa)	Tensile Strength (MPa)	Failure Strain (%)
Flax	50-80	800-1500	1.3-3.3
Hemp	30-70	550-900	2-4
Jute	20-55	400-800	2-3
Sisal, abaca, hennequin and like	9-38	600-840	3-14
Glass	70	2,400	3

Theoretical Modulus of Cellulose Crystallites ~ 130 GPa

NF- 1.45 g/cc Glass fibers- 2.5 g/cc

Table 4.7 Mechanical and Physical Properties of Bast and Core Fibers from Dicotyledons[1]

Property	Flax	Hemp	Jute	Kenaf	Ramie
Density (g/cm^3)	1.5	1.48	1.5	1.47	1.51
Moisture Regain (%)	12	12	13.7		6
Stiffness (10^6 psi)	4.13	4.29	3.8		3.28
Strength (10^3 psi)	51	119	84	232[2]	121
Elongation (%)	2.5	3.5	1.5	2.7	4

[1] Joseph, 1986.
[2] Mukherjee et al., 1992.

Composite Properties Depend On:

- Good dispersion can´t be compromized
- Good stress transfer (adhesion between fiber and matrix)
- Fiber alignment
- Ultimate fiber length after processing

Importance of the Interface

- The interface is where the stress is transferred to the fiber from the matrix by shear and affects most/all properties.

1cc of composite at 50 V_f and fiber diameter of 20 μm has a fiber-matrix surface area of about 1000 cm^2.

Grafts other molecules- (eg, styrene, methacrylate)
Traditional Coupling Agents (silanes, titanates, zirconates, isocyanates)
Polymeric Compatibilizers (MAPP/MAPE, MA-SEBS, MA-EPDM)

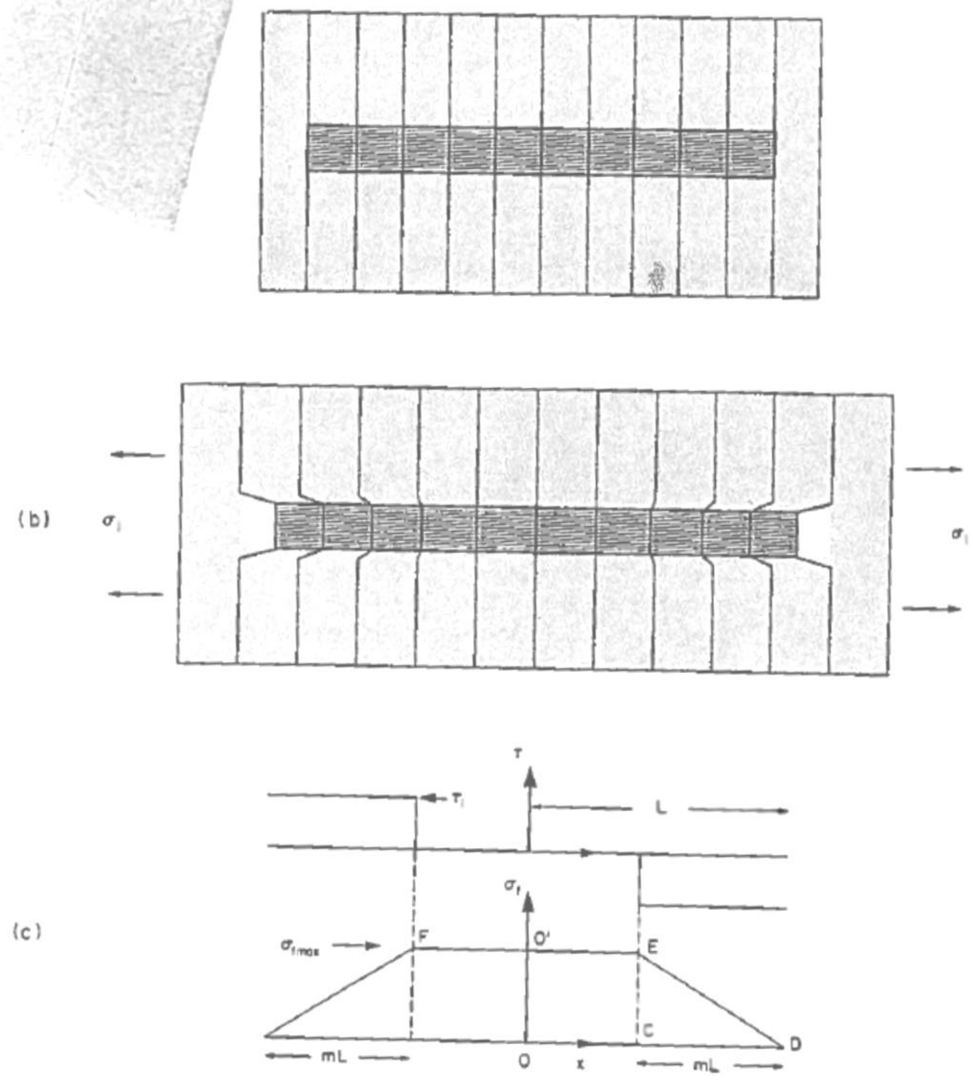
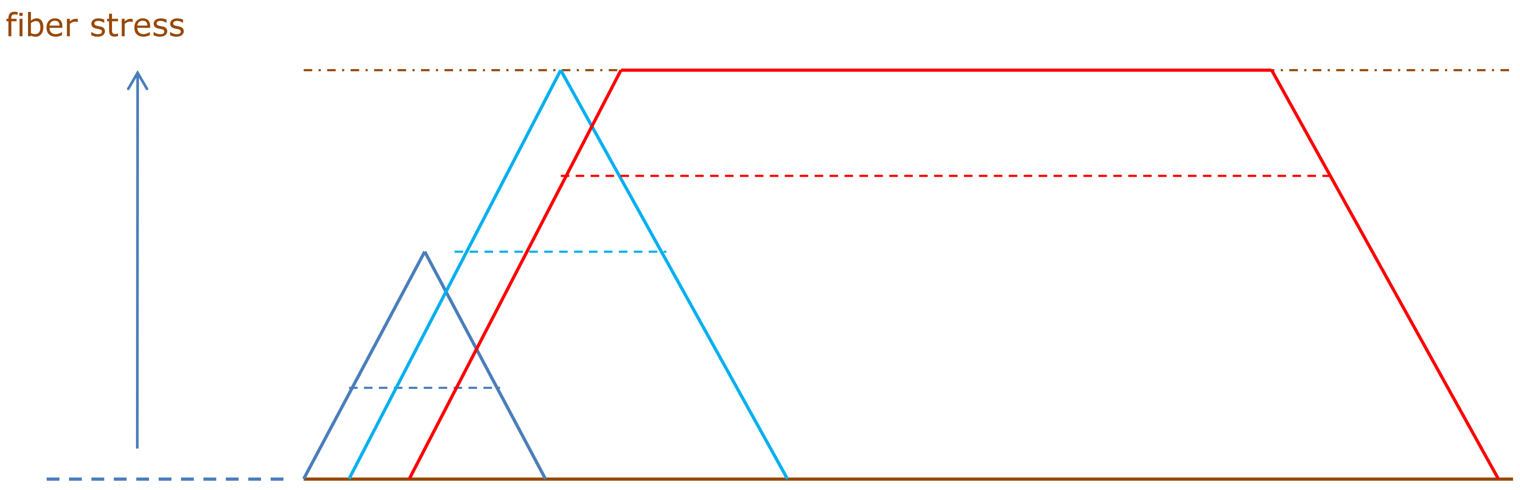


FIG. 4.1. Single fibre composite element: (a) unstressed and (b) stressed. (c) shows the fibre–matrix interfacial stress and the fibre internal stress for stress transfer by slip.

Load Bearing Fiber Composites- M. R. Piggot 1980

Effect of Fiber Length



length/diameter=aspect ratio

$$L_c = \sigma_f d / 2\tau_i$$

Modified Rule of Mixtures- Simple Theory

- C= composite f=fiber, m=matrix, E=Youngs Modulus, σ=strength
- $E_c = E_f V_f + E_m V_m$ (aligned fibers-high aspect ratio ∞- s>1000)
- (shorter fibers)
- $E_c = X_1 E_f V_f + E_m V_m$
- (X_1- orientation effect)
- $\sigma_c = \sigma_f Y_1 Y_2 V_f + \sigma_m V_m$
- (Y_1=orientation effect: Y_2=stress transfer efficiency effects)

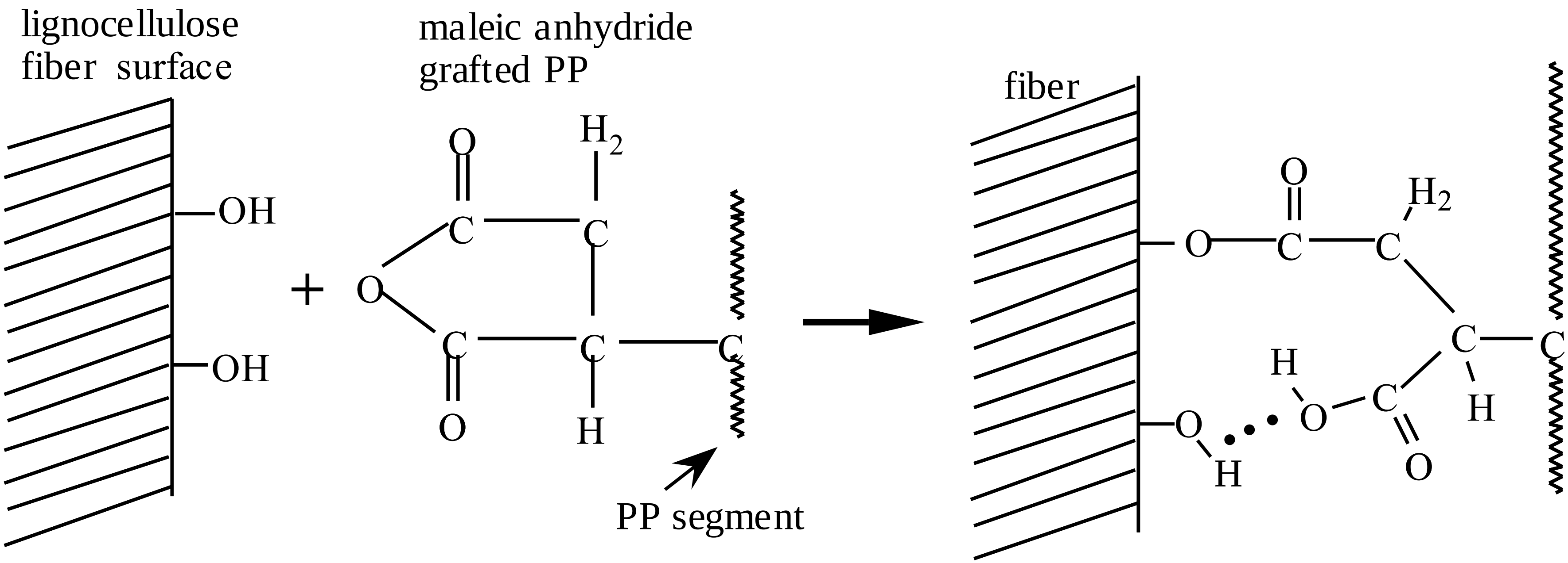
TABLE III

Some Typical Representative Commercial Coupling Agents[115]

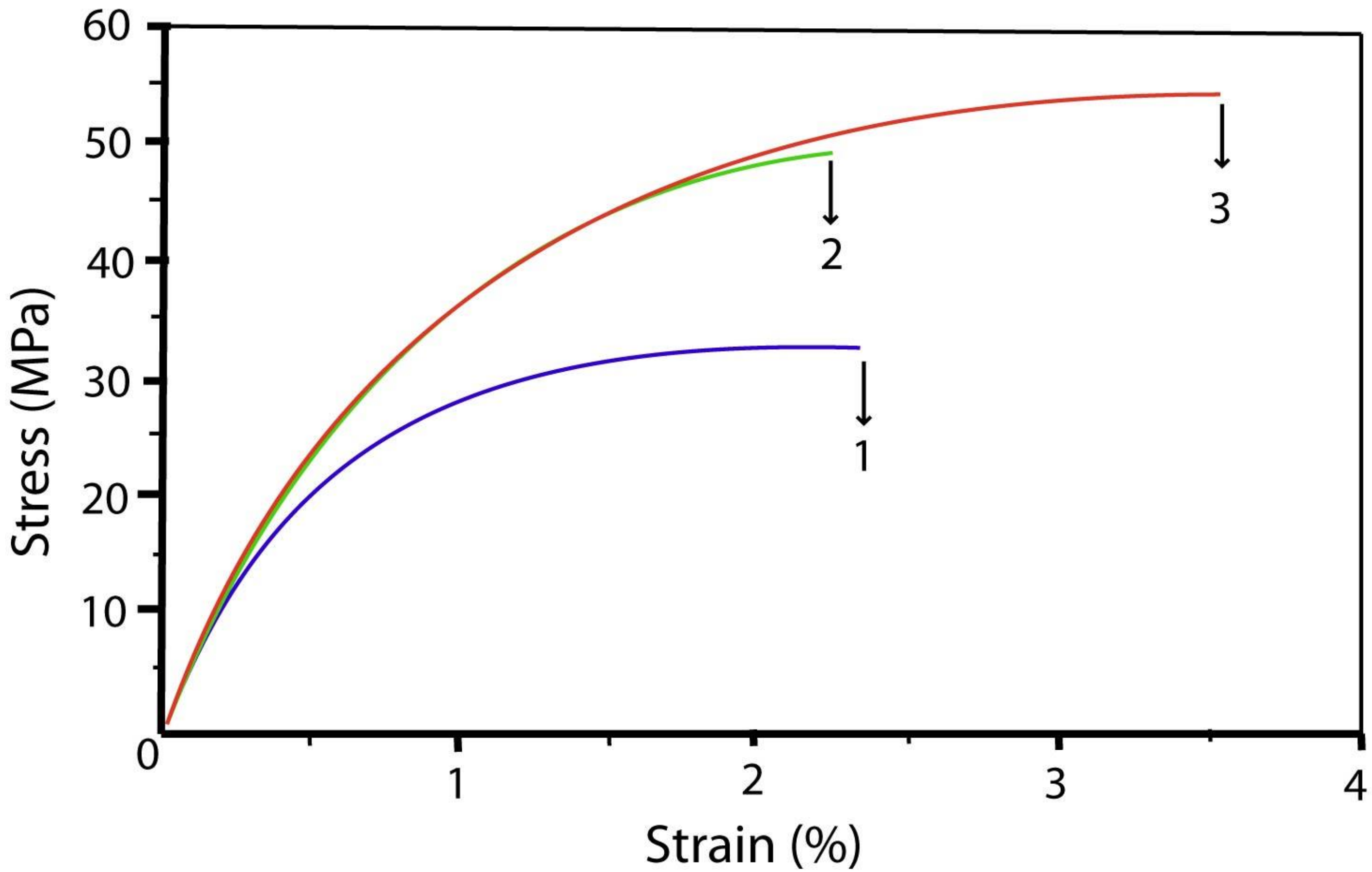
Sl. No.	Functional Group	Chemical Structure	Applicable Polymer[a]
1	Vinyl	$CH_2{=}CHSiCl_3$ $CH_2{=}CHSi(OC_2H_5)_3$	Elastomers, polyethylene, silicone elastomers, UP, PE, PP, EPDM, EPR
2	Chloropropyl	$ClCH_2CH_2CH_2Si(OCH_3)_3$	EP
3	Epoxy	epoxy-$CH_2CHCH_2O(CH_2)_3Si(OCH_3)_3$	Elastomers, especially butyl elastomers, epoxy, phenolic and melamine, PC, PVC, UR
4	Methacryl	$CH_2{=}C(CH_3){-}COO(CH_2)_3Si(OCH_3)_3$	Unsaturated polyesters, PE, PP, EPDA, EPM
5	Amine	$H_2N(CH_2)_3Si(OC_2H_5)_3$ $HN(CH_2)_2NH(CH_2)_3Si(OCH_3)_3$	Unsaturated polyesters, PA, PC, PUR, MF, PF, PI, MPF
6	Cationic styryl	$CH_2CHC_6H_4CH_2H^{+}H_2(CH_2)_3Si(OCH_3)_3Cl^{-}$	All polymers
7	Phenyl	$C_6H_5Si(OCH_3)_3$	PS, addition to amine silane
8	Mercapto	$HS(CH_2)_3Si(OCH_3)_3$ $HS(CH_2)_2Si(OC_2H_5)_3$	EP, PUR, SBR, EPDM
9	Phosphate (titanate)	$C_3H_7OTi[O{-}P(O)(OH){-}O{-}P(O)(OC_8H_{17})_2]_3$	Polyolefins, ABS, phenolics, polyesters, PVC, polyurethane, styrenics
10	Neoalkoxy (zirconate)	neoalkoxy-$Ti[O{-}P(O)(OH){-}O{-}P(O)(OC_8H_{17})_2]_3$	Polyolefins, ABS, phenolics, polyesters, PVC, polyurethane, styrenics

From N. Saheb and J. P. Jog, Advances in Polymer Technology, Vol 18, p 351, 1999

MAPP-Fiber Interactions



40 % Recycled Newspaper- 60 % PP/MAPP



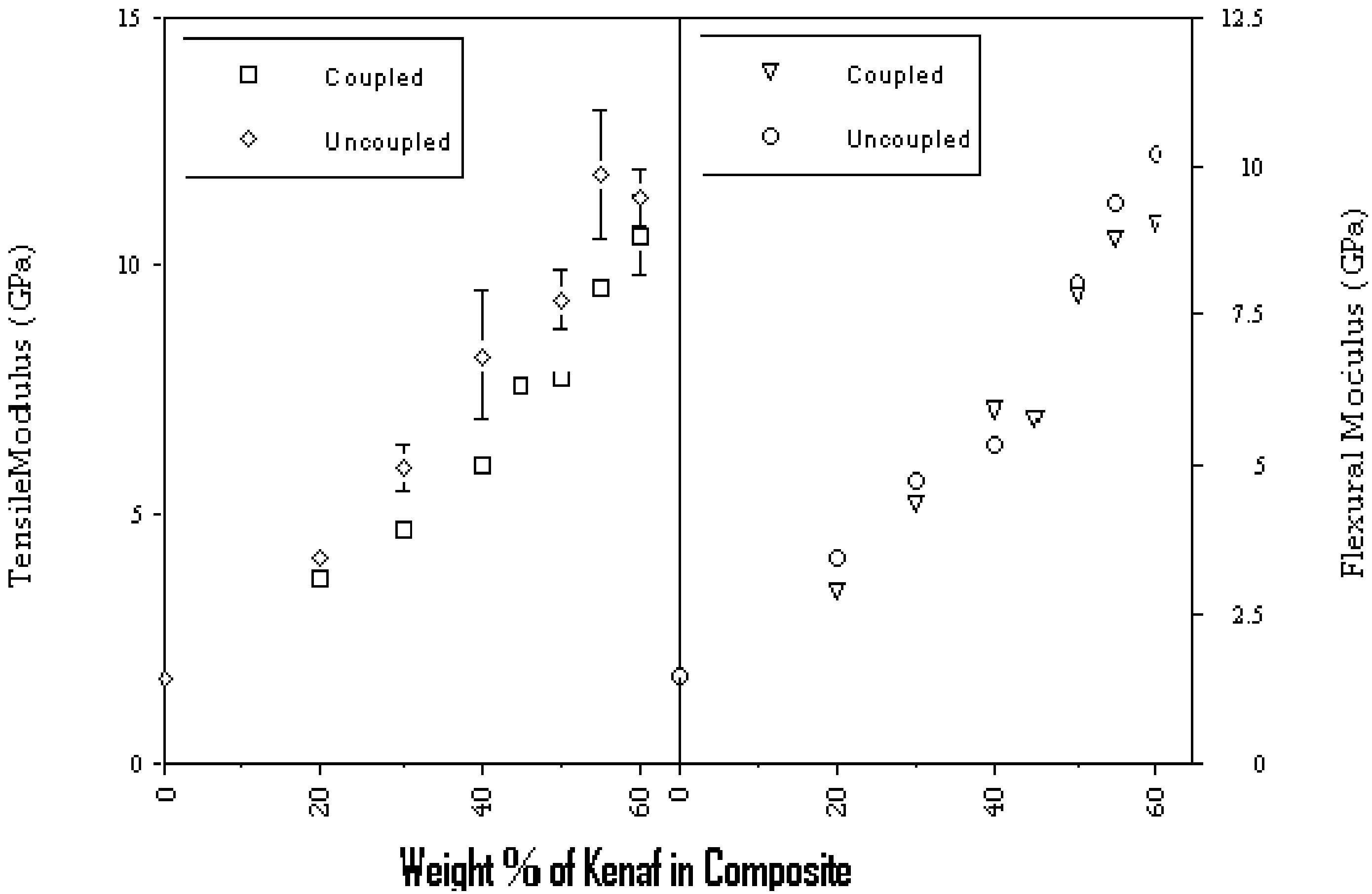
#1→ No MAPP → Uncoupled

#2→ 2% MAPP → 1% MA; MW_{wt} 10,000; $MW_{\#}$ 4,200

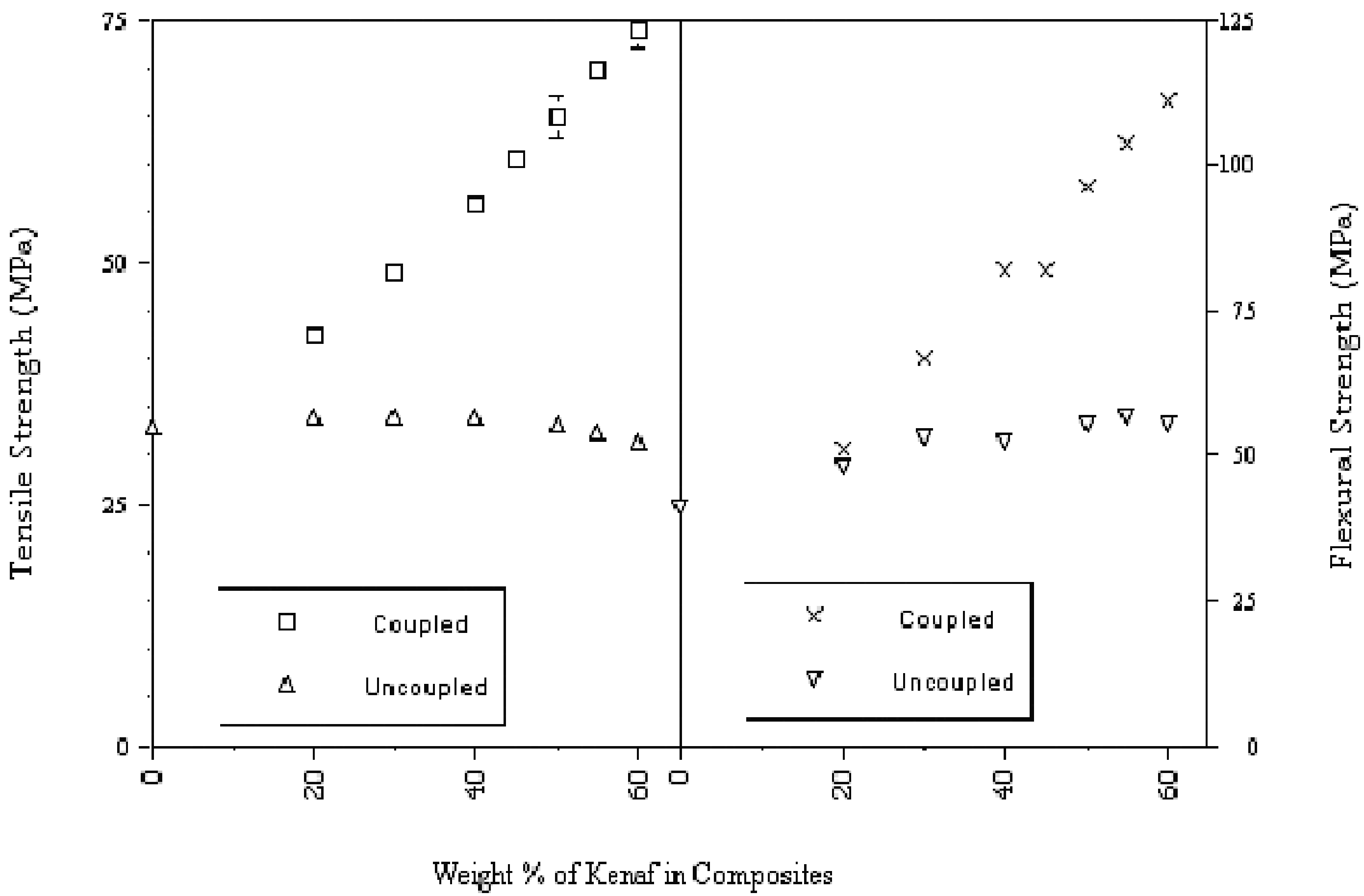
#3→ 2% MAPP → 1% MA; MW_{wt} 40,000; $MW_{\#}$ 11,000

Sanadi, Clemons, Young and Rowell, J. Reinf. Plast. & Comp., Jan 1994

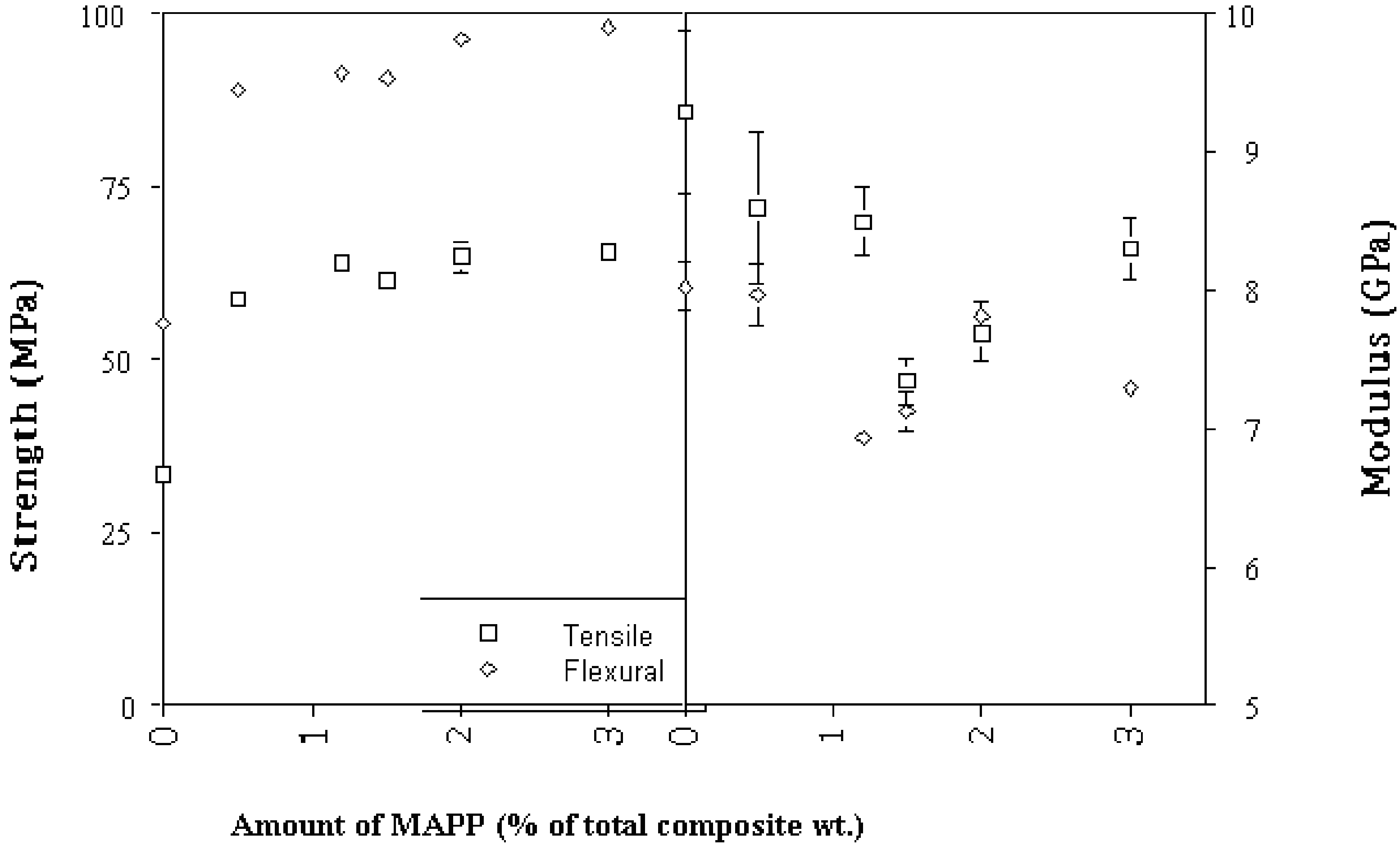
Effect of W_f on Modulus



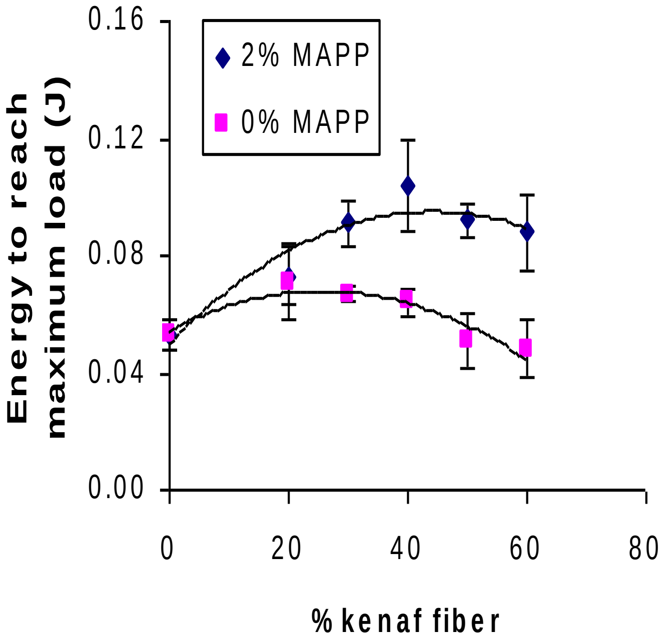
Effect of W_f on Strength



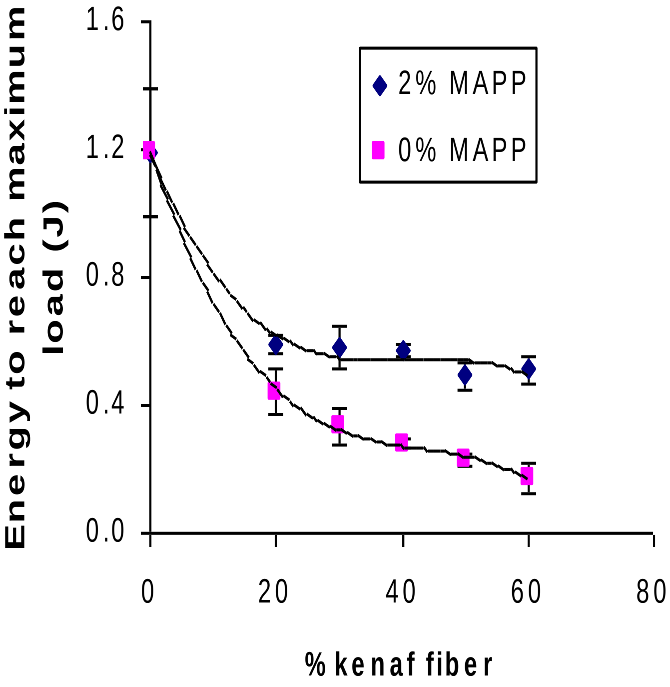
Effect of MAPP on Strength and Modulus- 50 % fiber



Coupling Agent- Effect on Izod Impact

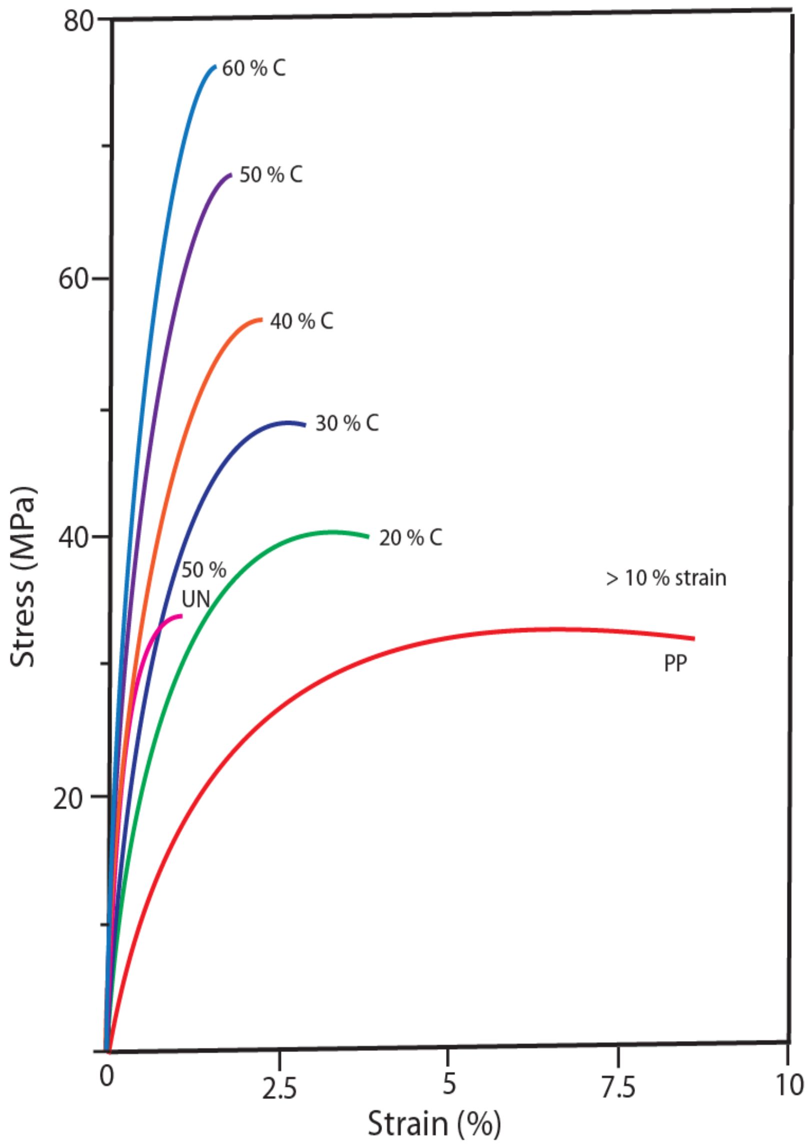


notched



Un-notched

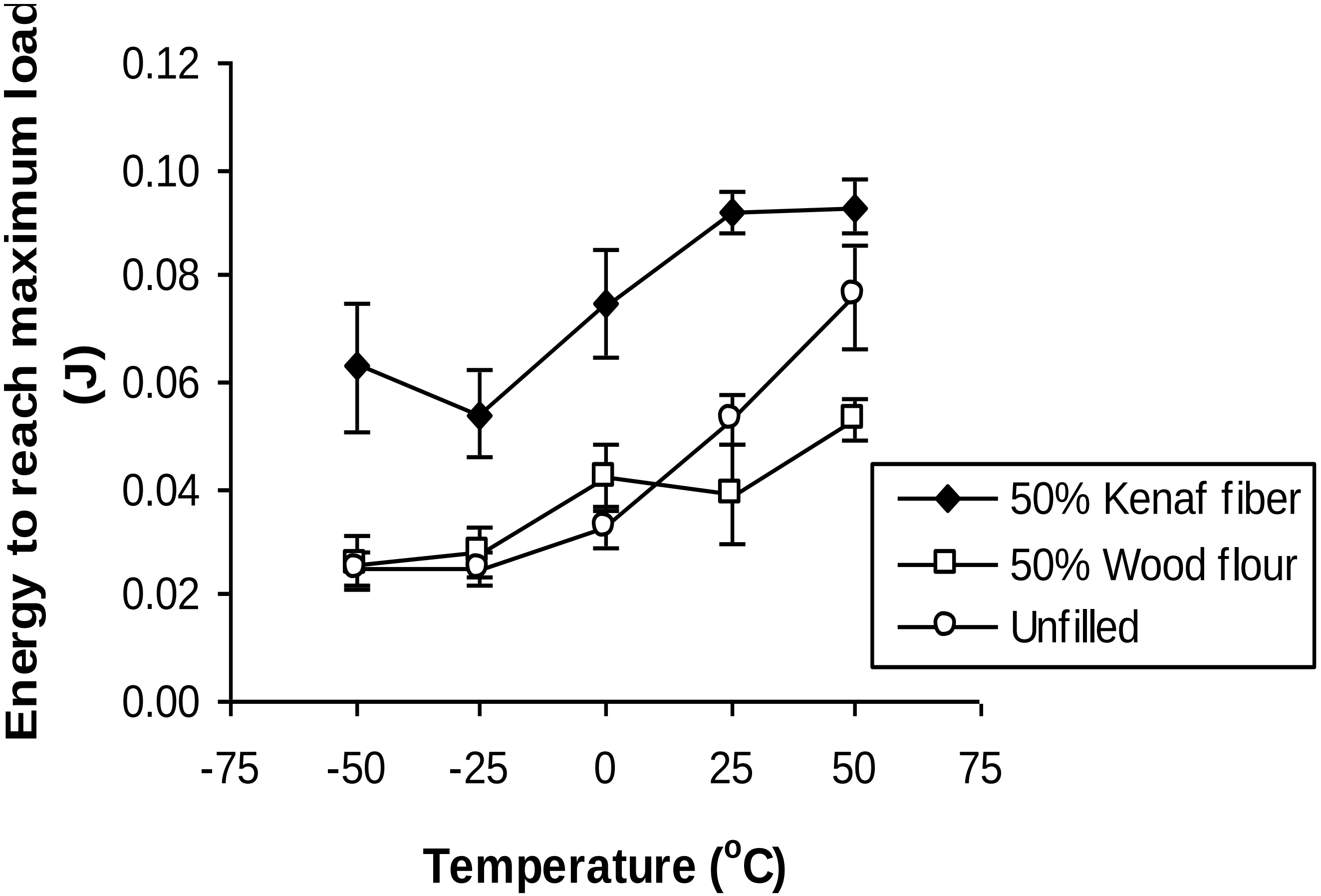
Stress-Strain Curves



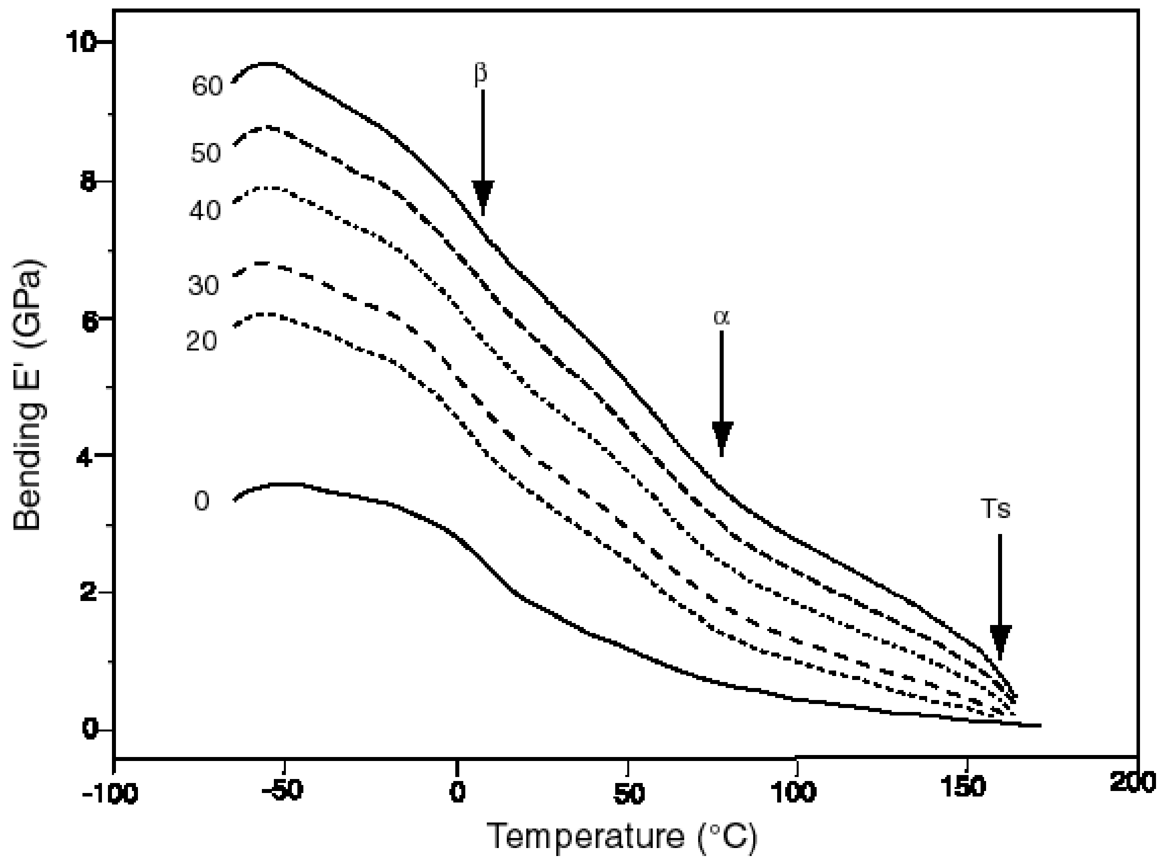
1995. A. R. Sanadi, D. F. Caulfield, et. al, “Mechanical Properties of Kenaf Fiber-Polypropylene Composites,” *Industr. Eng. Chem. Res.*, 34, p1891.

Kenaf-PP/MAPP

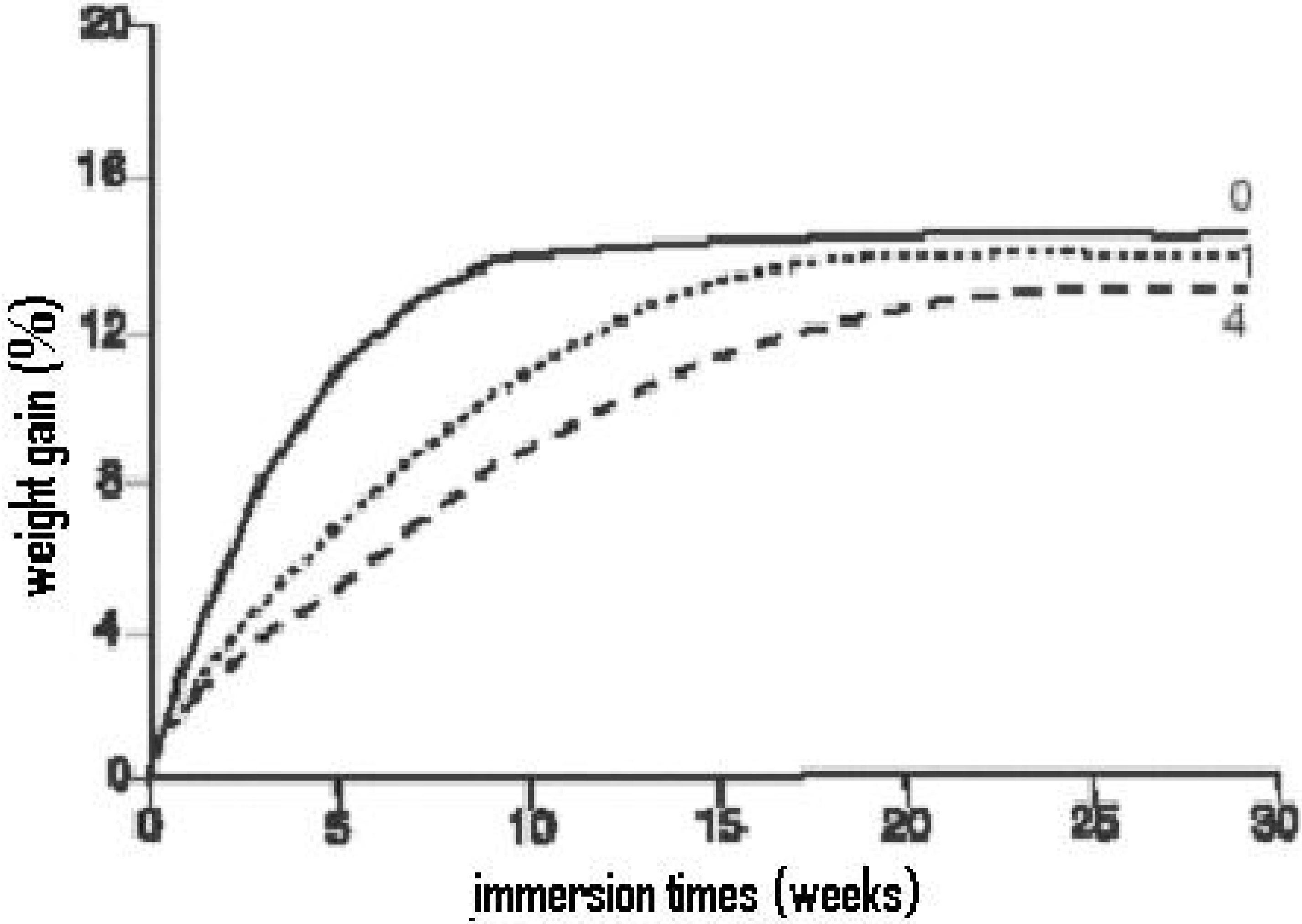
Notched Impact Energies



Bending Storage Modulus- kenaf-PP (coupled 3% MAPP)



Water Absorption of 50% Sisal-PP



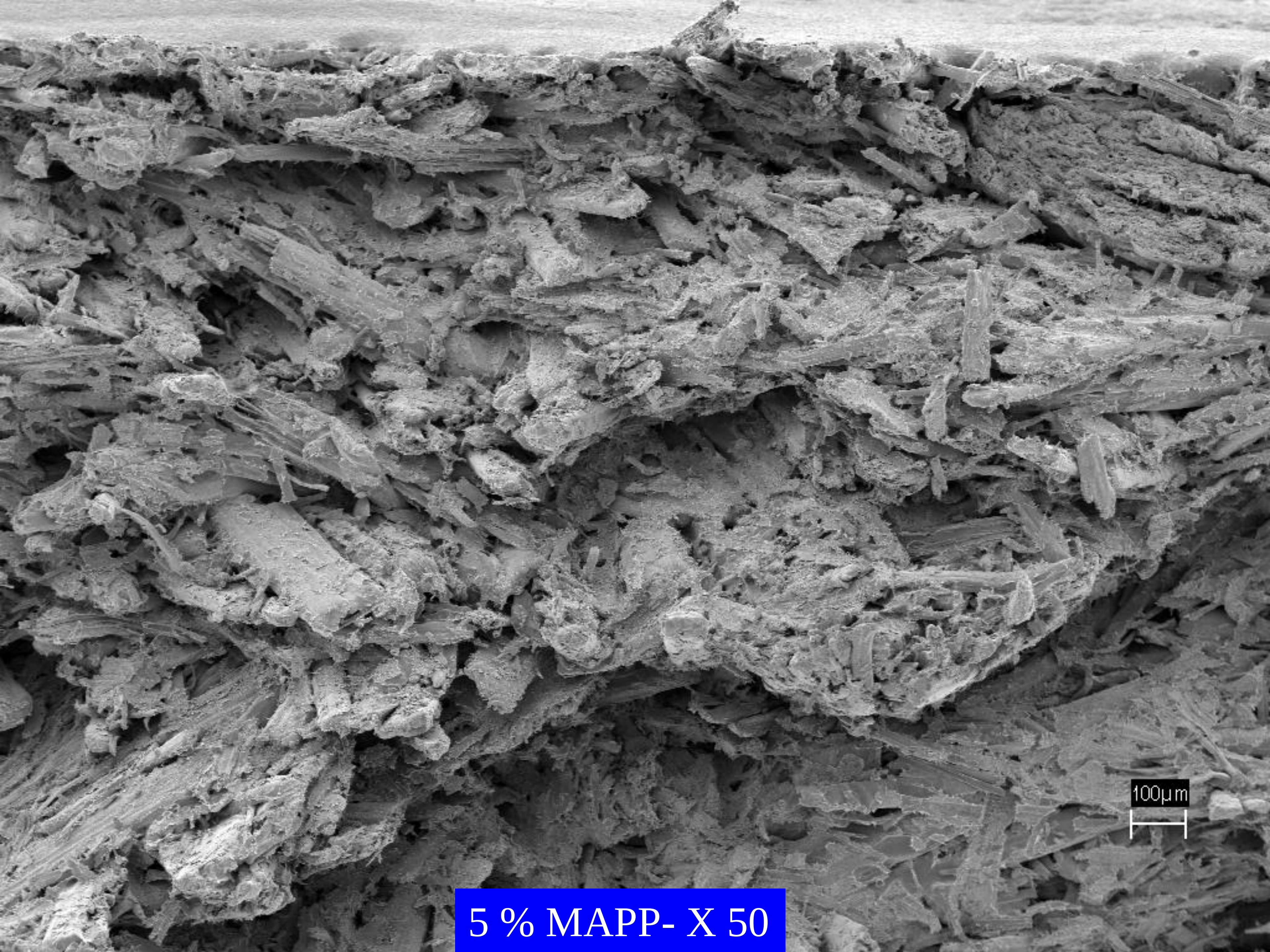
Effect of Water on Mechanical Properties: Sisal 50 %-PP

Properties	Coupling agent (%)	Control	2 hr boil
Tensile modulus (GPa)	0	5.5	4.6
	1	5.9	5.1
	2	6	5.1
	4	5.9	5.8
Tensile Strength (MPa)	0	37	35
	1	65	61
	2	66	61
	4	67	64

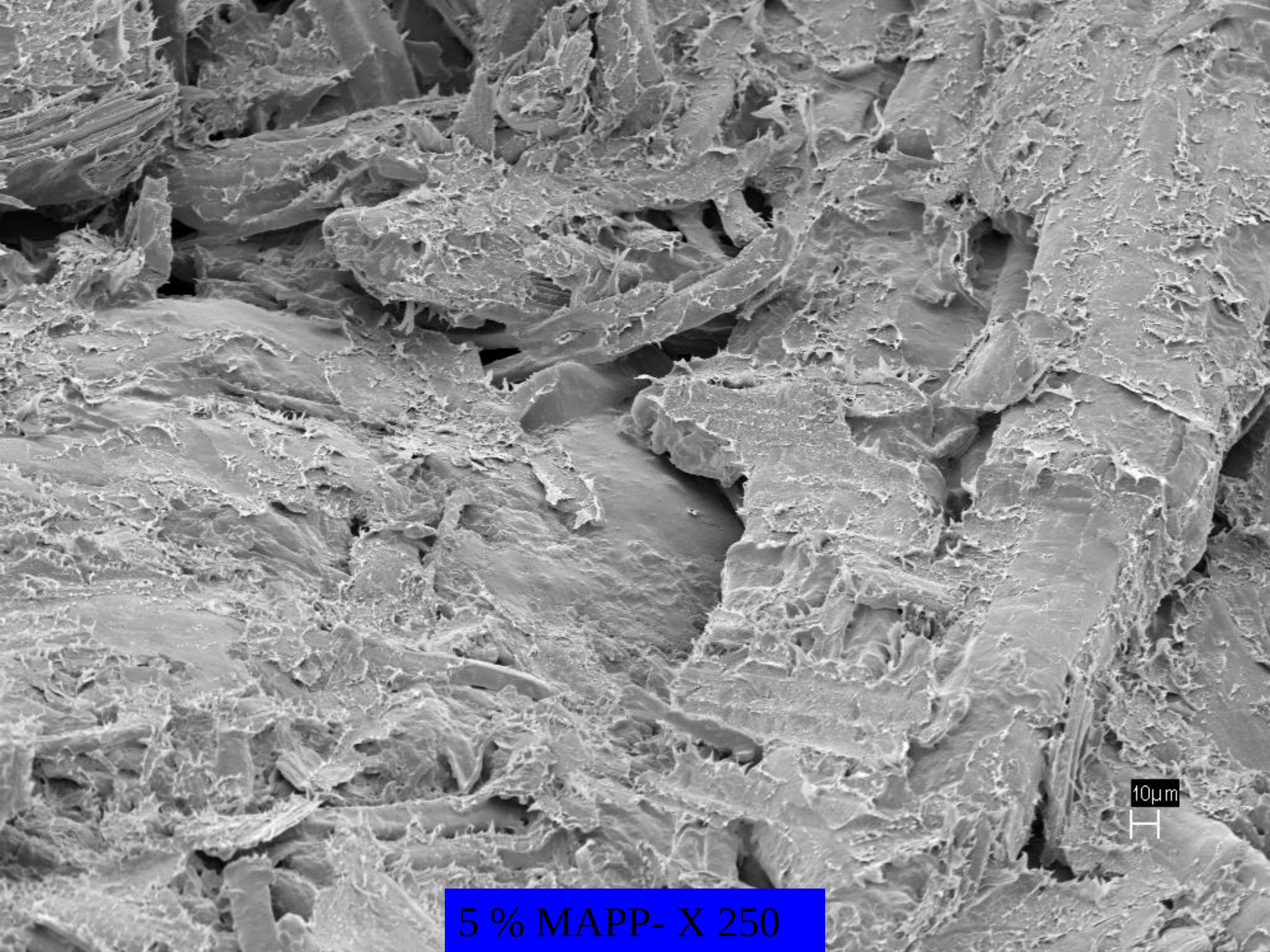
Effect of Various Fibers:
40 % fiber weight- 3 % coupling agent- PP

Fiber Type	Tensile strength (MPa)	Tensile modulus (MPa)	Notched Izod (J/m)	Un-Notched (J/m)
Kenaf	56	6.4	28	157
Coir	46	3.5	18	100
Henequen	55.4	5.1	50	156
Pineapple	63	5.6	42	170
Jute	64	6.2	36	189
Sisal (50%)	65	5.9	64	----
Kenaf (50%)	62	7.2	32	----

0 % MAPP- X 50


100µm
5 % MAPP- X 50


10µm
0 % MAPP- X 250


10µm
5 % MAPP- X 250

	Kenaf-PP	Kenaf-PP	Glass-PP
% weight (volume-estimated) of fiber	40 (30)	50 (39)	40 (19)
Volume of Plastic	70	61	81
Tensile E (GPa)	6	8.3	9
Tensile σ (MPa)	56	66	110
Notched Izod J/m	28	32	107
Water Absorption (%)- 24 hr	-	1.05	0.06

Data on Glass-PP from Modern Plastics Encyclopedia

WPC Composites - Extrusion Decking

Furniture (prototype) NFC

Shipping pallet

Single Panel Shake

Panel Shake Installation

Tiles

Southwestern or French Style Natural Fiber/Thermoplastic Composite Roof Tiles

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