COST Action TU1207

Next Generation Design Guidelines for Composites in Construction

New Composites-based on natural fibers (NFRP)

Action Meeting
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Lyon, France

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DRIVING FORCE FOR A NEW GENERATION

NEW COMPOSITES / ECO-MATERIALS:

-Petroleum resources depletion rate
(100.000 times faster than nature can create it)
-Environmental awareness

New natural fiber reinforced composite materials that are compatible with the environment

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NEW COMPOSITES ?

Composites: matrices, reinforcements

Eco-friendly; eco-; green; biocomposites

- *Natural fibers - reinforcement*
- *Polymer matrix - thermoplastic recyclable, thermoset, biodegradable, bio-based*

Application in constructions:

- *upgrading existing structures and*
- *building new ones which can be applied to various types of structures as non bearing materials.*

for example: platforms, buildings, interior partition walls, ceilings, flooring, composite structural components with integral thermal and acoustic insulation for improvement of energy efficiency in eco-buildings etc.

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NATURAL FIBERS AS REINFORCEMENTS FOR COMPOSITES

- growing interest in NF reinforced composites
- high performance in terms of mechanical properties, significant processing advantages, chemical resistance, and low cost/low density ratio.
- environmental reasons - increased interest in replacing reinforcement materials (inorganic fillers and fibers) with renewable organic materials.
- brief review of the most commonly used polymers and natural fibers (NFs) in new group composite materials.

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Commonly used polymers and natural fibers

POLYMERS	NATURAL REINFORCEMENTS
Polyhydroxybutyrates (PHB)	Rice straw
Polyhydroxybutyratevalerate (PHBV)	Hemp
Poly(lactic acid) (PLA)	Jute
Polypropylene (PP)	Sisal
Polyethylenterephtalate (PET)	Cellulose (recycled paper)
	Kenaf

NFs can represent environmentally friendly alternatives to conventional reinforcing fibers (glass, carbon, kevlar)!

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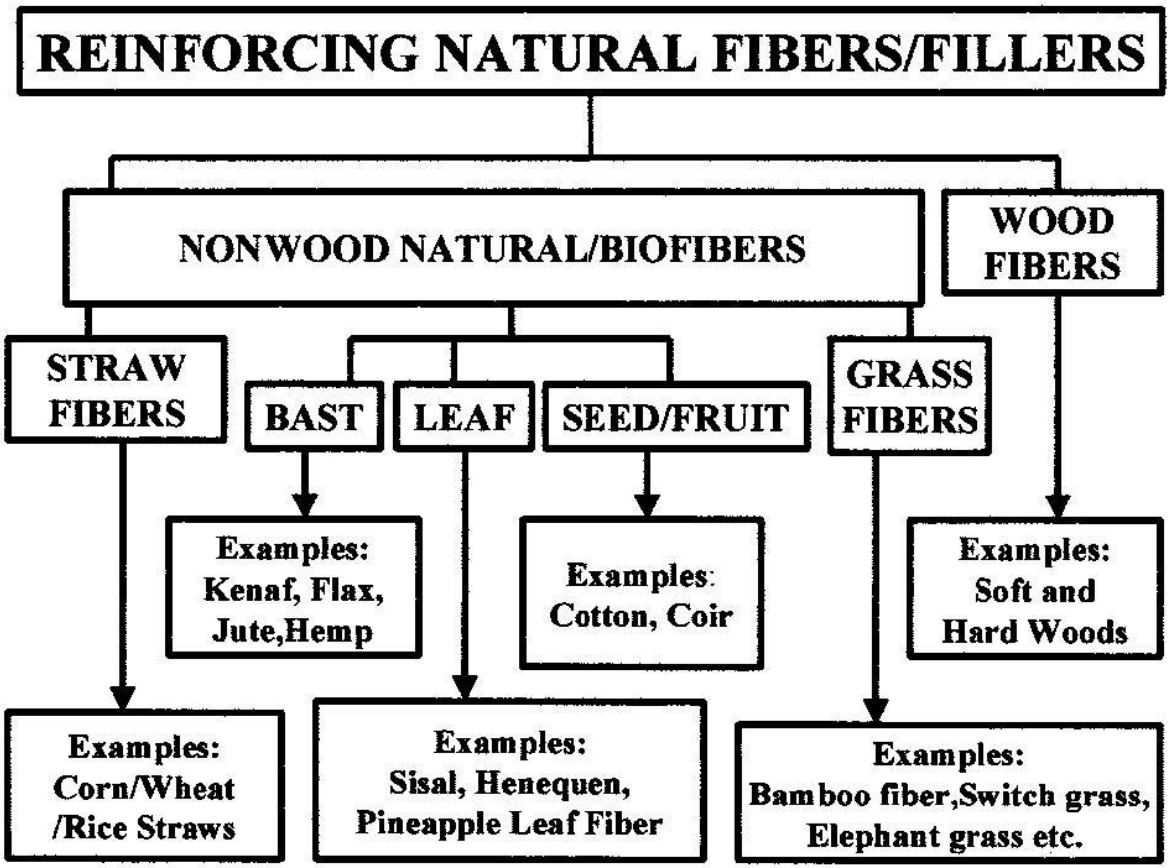
RENEWABLE RESOURCES:
NATURAL FIBERS



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Dimensions of some natural fibers

Fiber	Average length (mm)	Width (mm)
Cotton	10–60	0.02
Flax	5–60	0.012–0.027
Hemp	5–55	0.025–0.050
Juta	1.5–5	0.02
Straw	1–3.4	0.023
Kenaf	2.6–4	0.018–0.024

- *on their origin,*
- *quality of plants location,*
- *the age of the plant, and*
- *the preconditioning.*

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Chemical composition and structural parameters of natural fibers

Fiber	Cellulose (%)	Hemi-cellulose (%)	Lignin (%)	Extractives (%)	Ash (%)	Pectin (%)	Wax (%)	Microfibril/ spiral angle (°)	Moisture content (%)
Jute	61–71	13.6–20.4	12–13	/	/	0.2	0.5	8.0	12.6
Flax	71–78	18.6–20.6	2.2	2.3	1.5	2.2	1.7	10.0	10.0
Hemp	70.2–74.4	17.9–22.4	3.7–5.7	3.6	2.6	0.9	0.8	6.2	10.8
Kenaf	53–57	15–19	5.9–9.3	3.2	4.7	/	/	/	/
Sisal	67–78	10–14.2	8–11	/	1	10	2.0	20.0	11.0
Cotton	82.7	5.7	/	/	/	/	0.6	/	/

Mechanical properties are determined mainly by the cellulose content and microfibrillar angle!

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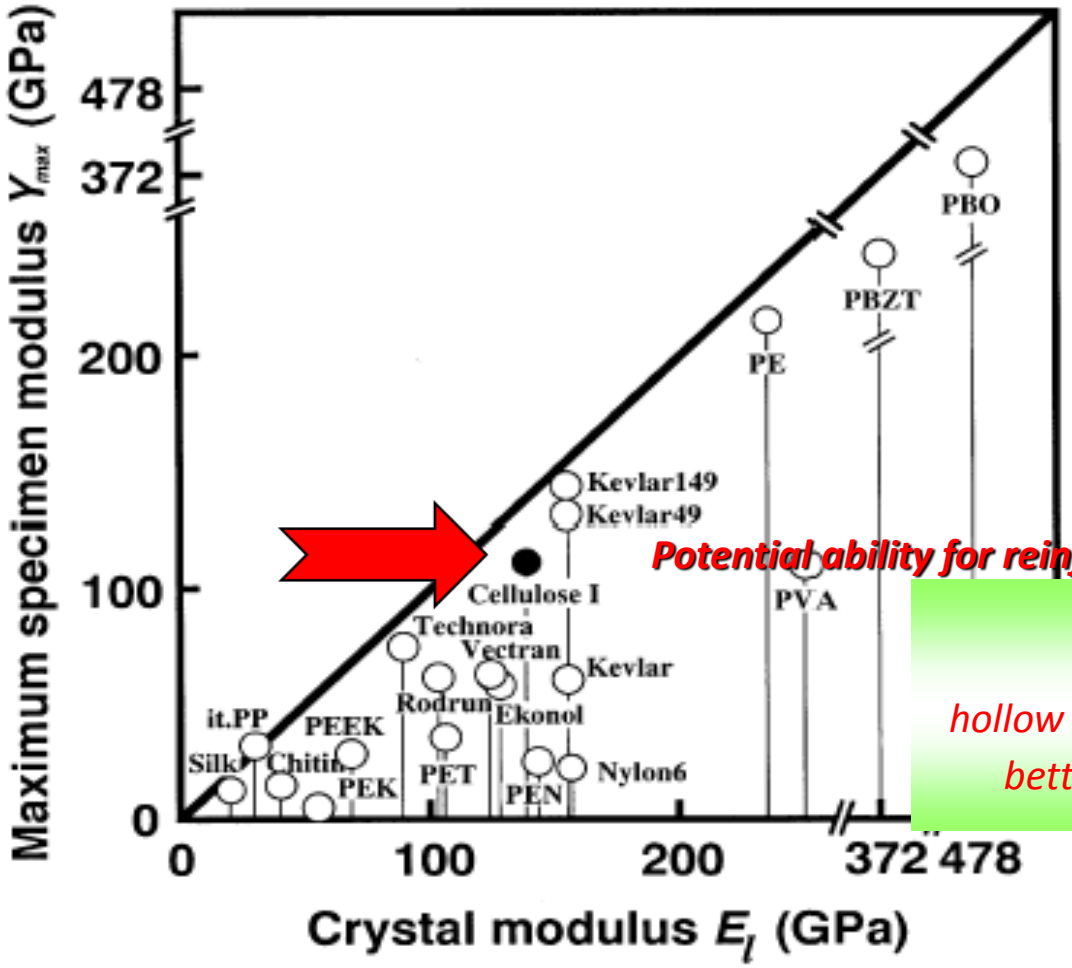
CRYSTAL MODULE OF CELLULOSE I:
E_l=138 GPa



Potential ability for reinforcing fiber

Additional value:

hollow tubular structure of cell fibers - better noise and heat insulation

Fig. 2. Relationship between the crystal modulus E_l and the maximum specimen modulus Y_{max} already reported for various polymers.

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Basic properties of some natural fibers

Fiber	Density (g/cm3)	Elongation at break (%)	Fracture stress (MPa)	Young modulus (GPa)
Cotton	1.5	7.0–8.0	287–597	5.5–12.6
Jute	1.3–1.46	1.5–1.8	393–800	10–30
Flax	1.4–1.5	2.7–3.2	345–1500	10–80
Hemp	1.48	1.6	270–900	20–70
Sisal	1.2–1.5	2.0–2.5	511–700	3.0–98
Bamboo	0.8	/	391–1000	48–89
Soft wood	1.5	/	1000,0	40.0

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REINFORCING POTENTIAL OF NATURAL FIBERS

Mechanical properties of natural fibers when compared with conventional reinforcements

Fiber	Specific gravity (g/cm3)	Tensile strength (GPa)	Tensile modulus (GPa)	Specific strength (GPa/g cm3)	Specific modulus (GPa/g cm3)
Sisal	1.20	0.08–0.5	3–98	0.07–0.42	3–82
Flax	1.20	2.00	85	1.60	71
E-Glass	2.60	3.50	72	1.35	28
Kevlar	1.44	3.90	131	2.71	91
Carbon (standard)	1.75	3.00	235	1.71	134

- excellent tensile strength and modulus, high durability, low bulk density, good moldability, and recyclability.

- advantage over conventional reinforcement fibers in that they are less expensive, available from renewable resources, and have a high specific strength.

- application of long NFs instead of short wood-fibers, such as flax, kenaf, and sisal, is reasonable in architectural and civil works because of the specific modulus, close to that of glass-reinforced composites.

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Advantages and disadvantages of reinforcing NF

- low cost,
- high toughness,
- low density,
- good specific strength properties,
- reduced tool wear (nonabrasive to processing equipment),
- enhanced energy recovery,
- CO_2 neutral when burned,
- biodegradability,
- hollow and cellular nature,
- acoustic and thermal insulators,
- exhibit reduced bulk density.

Lack of good *interfacial adhesion (cell + lignin + pectin…)*

Relatively *low processing temperature (below 200°C)*

High sensitivity to *humidity*

Low dimensional stability *(swelling, shrinkage)*

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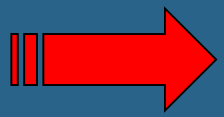
TREATMENTS/MODIFICATIONS OF NATURAL FIBERS

Research on "a cost-effective" modification of NFs is necessary!

- **Dewaxing (delignification, defatting)**
- Bleaching
- Esterification and etherification
- **Steam explosion**
- Graft polymerization
- Mercerization (alkali treatment)
- Liquid ammonia treatment
- **Compatibilizers based on novel silane chemistry**
- Isocyanates
- Permanganate treatment
- …



These treatments should not decrease the thermal stability of fiber!

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Eco-Houses Based on Eco-Friendly Polymer Composite Construction Materials

Project tasks:

- **Production of eco-friendly polymer composites construction materials** - main task

- Development of natural fiber composites suitable for structural applications.
- Application of various forms of plant fibers: short, long, continuous, woven fabrics and non-woven mats and investigation of their influence on 3P (properties/performance/price) ratio.
- Tailoring of the fiber/matrix interactions and interface characterization.
- Mechanical characterization of the produced composites.
- Development of panelized components with integral thermal and acoustic insulation for improvement of energy efficiency in eco-buildings.
- . . . .

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Several kinds of materials were used:

1. SMC

- Kenaf/PP
- Kenaf/biocom
- Kenaf/polyester
- Kenaf/PLA

2. Pellets

- Kenaf/PLA
- Rice straw/PLA

Different ratio of the main components + coupling agent

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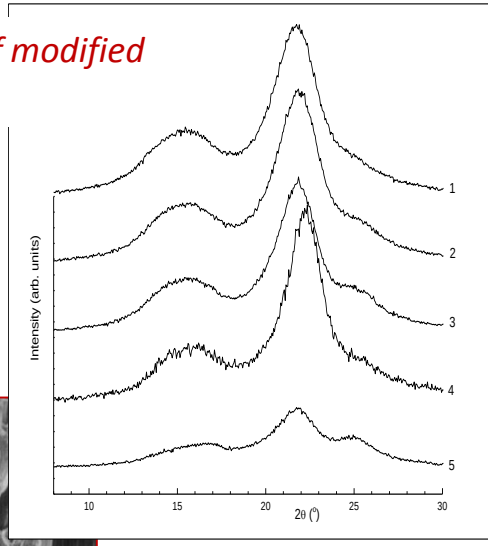
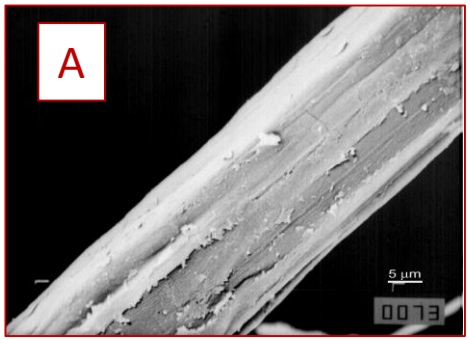
FP6 Project ECO-PCCM:

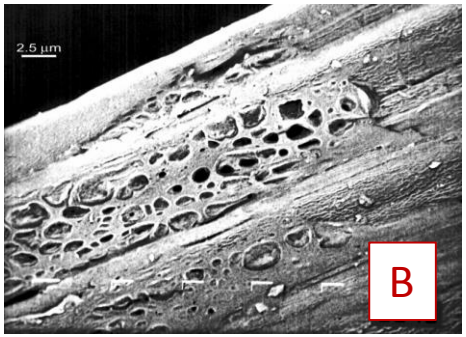
WAXS analysis, FTIR, SEM of modified kenaf fibers

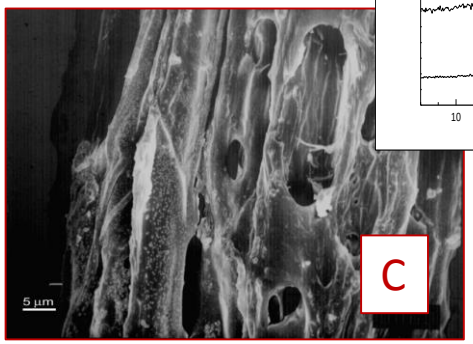
WAXS patterns of modified kenaf fibers

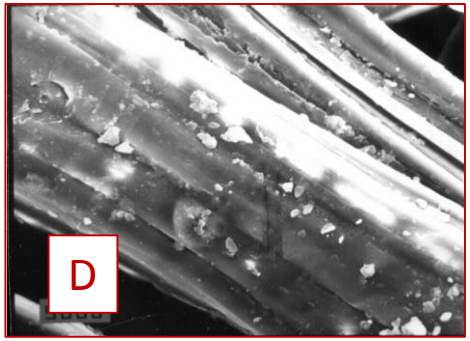


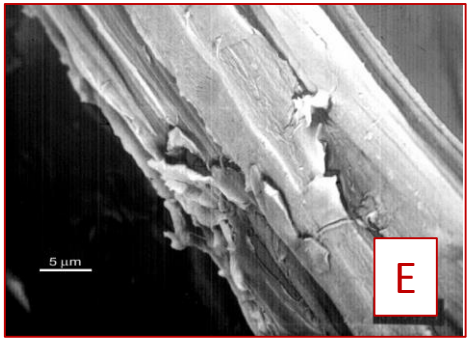
SEM images of kenaf samples



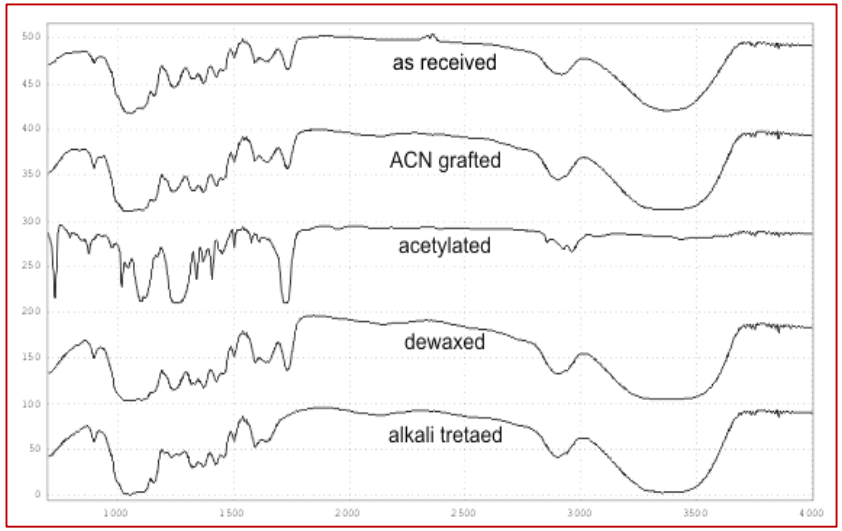








FTIR spectra of treated kenaf fibres



A – As received fiber
B – ACN grafted fiber
C – Acetylated fiber
D – Dewaxed fiber
E –Alkali treated fiber

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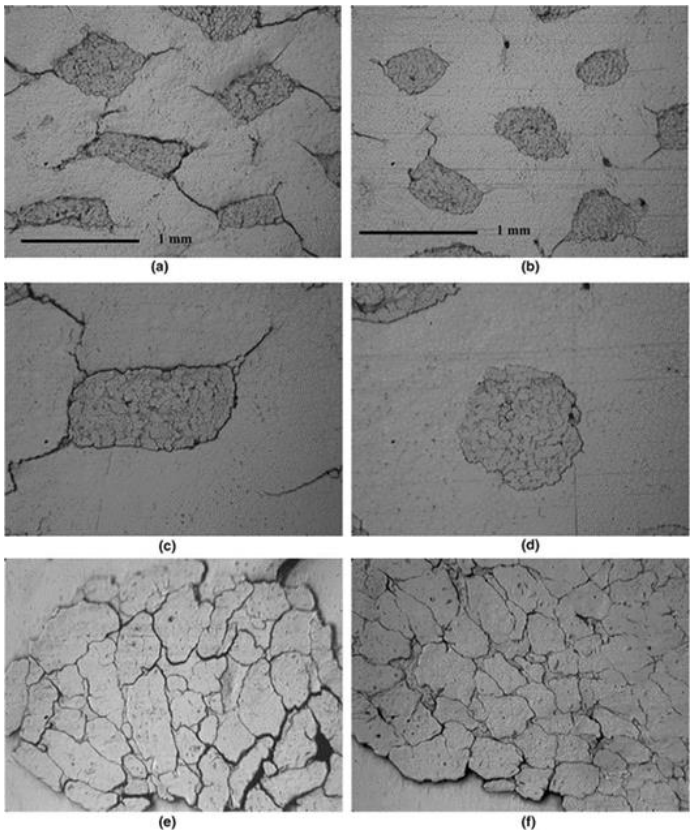
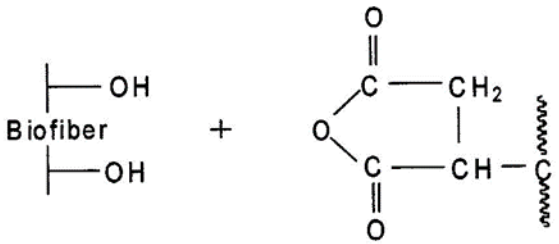
INTERFACIAL ADHESION:
natural fibers embedded in polymer matrix

- *polymer matrix modification (by using compatibilizing agent (CA)*
- *fiber (surface) modification*
- *polymer and fiber modification*
- *processing conditions/new technologies*

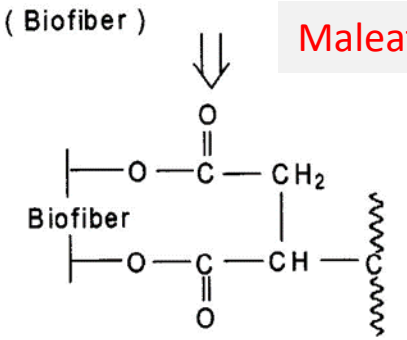
Fiber/matrix interface region-
key factor determining the load transfer



FP6 Project ECO-PCCM approach:
PP, PHB, PHBV, PLA modification with MAH-modified polymers



Maleated Polymer



Polymer matrix modification: creation of chemical bonds

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FP6 Project ECO-PCCM:

Two forms of materials were used:

- **SMC (Sheet Molding Compounds)**
- **Pellets/granules**

SMC	Pellets
• Appropriate for big size panels • No molding tool is required • Multiple panels can be produced in one molding cycle • Cheaper manufacturing process • Better mechanical properties since longer fibers can be applied • Inappropriate for 3D moldings with complicated shape	• Inappropriate for big size panels • Molding tool is required • One panel only per cycle • Expensive manufacturing process • Only very short fibers can be used making panels with limited mechanical properties • Better control of fiber/resin ratio • Appropriate for 3D shapes with complicated shapes

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Applied processing techniques

Open mold compression molding

Closed mold compression molding

In both techniques main process parameters are:

- **Temperature** – high enough to let the polymer melt

- **Time** - long enough to let the polymer flow

- **Holding pressure** – high enough to make the composite stiff, compact, void free

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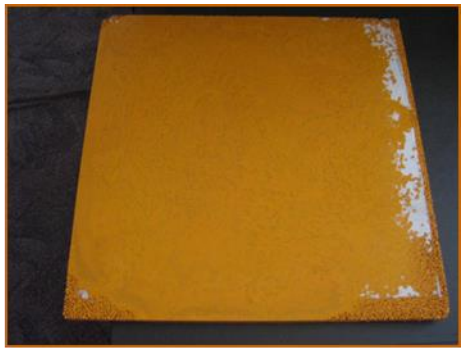
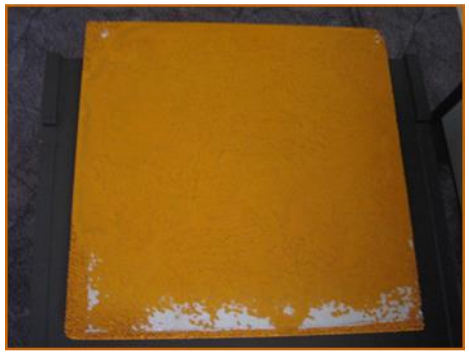
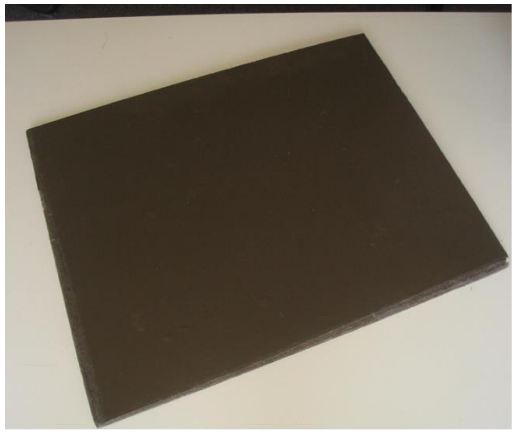
FINAL PANELS







Property	Test Method	Composite based on kenaf fiber
Specific weight, g/cm ^{3}	JUS G.S2.51	0,93
Water absorption, %	ISO/DP 9674	30,5
Fire resistance	UL 94	burns
Flexural strength, MPa	DIN 53457	30,1
Flexural modulus, GPa	DIN 53457	9,0
Impact strength, kJ/m ^{2}	DIN 53453	65,5
Compression strength, MPa	DIN 53454	17,4

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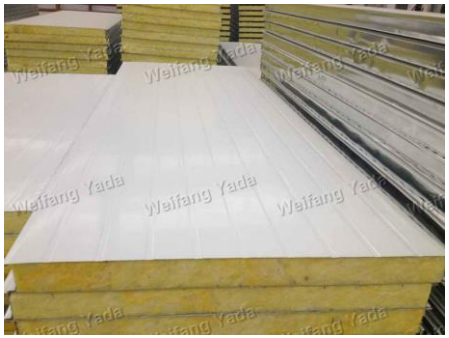
APPLICATION

- *Acoustic ceiling tiles*
- *Z-truss structures for load floors*
- *Partition panels and movable walls*
- *Furniture*
- *Automobile door panels, dashboards*
- *etc.*



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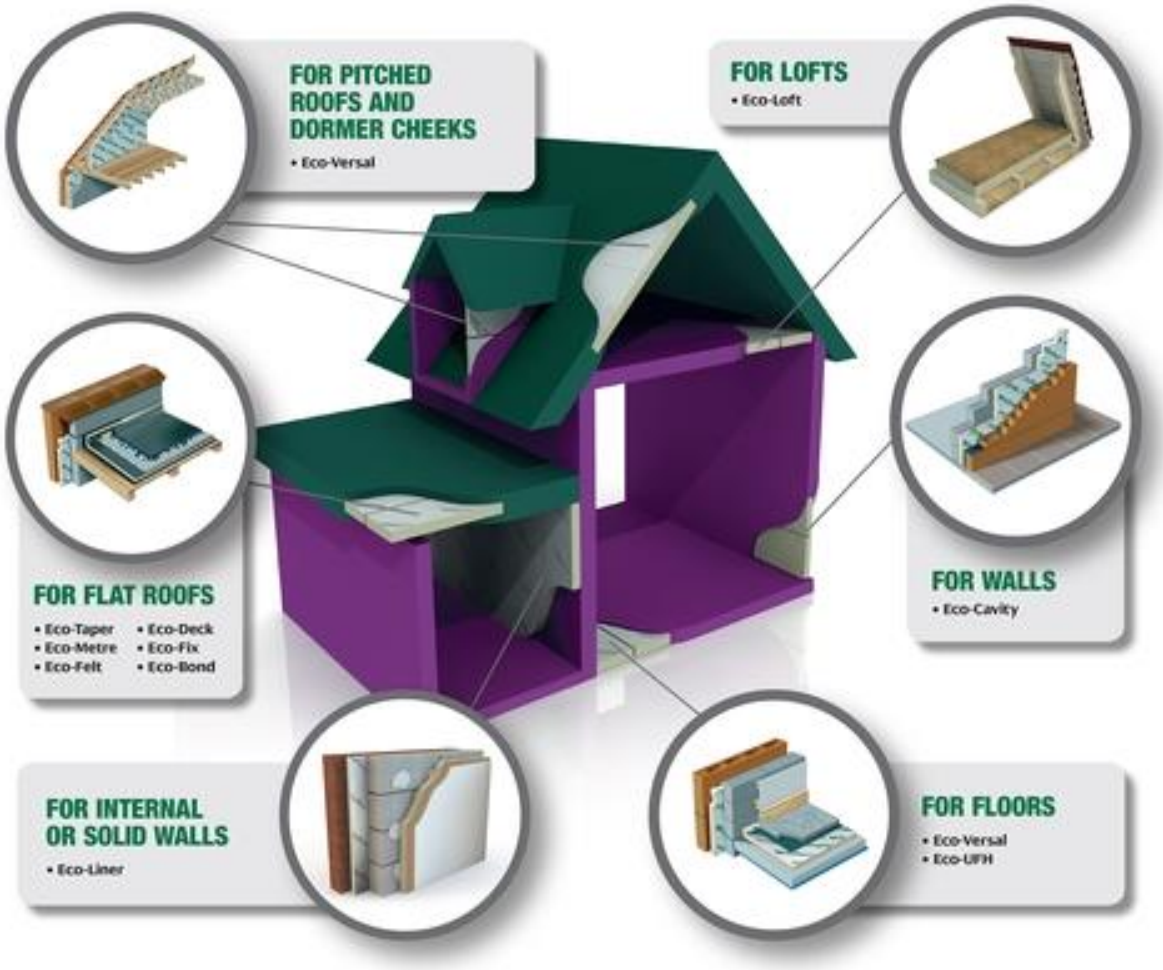
- *as non bearing material*
- *as interior partition walls, ceilings, flooring*
- *as thermal and acoustic insulation for improvement of energy efficiency in eco-buildings etc.*



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COMMERCIAL PRODUCTS

FlexForm – interior products (partition panels, movable wall systems, and ceiling tiles) from various blends of natural fiber, recycled polymers and fire retardant additives

Kenex Hemp Ltd.: mat-making line for hemp or NF blends with PE and PP

SIPs are composite building panels, environmentally friendly

Tipco Industries - commercial production of TIPWOOD®50EX eco-friendly building material, applicable for door panels, interior partition walls, ceilings, flooring.

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Thank you

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