Kebony
Principles of the Kebony Technology

Kebony AS

2014

Wood Modification

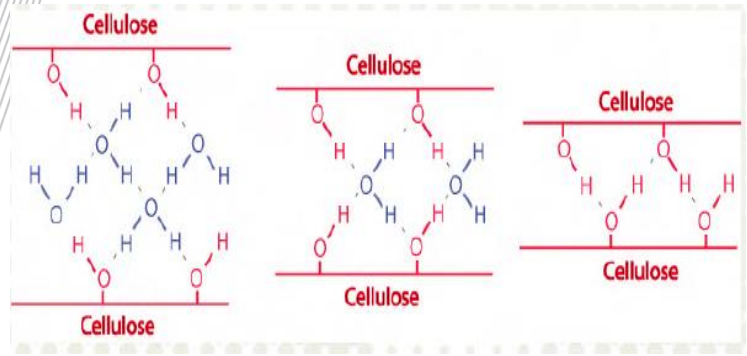
- Wood cells' composition makes the cell walls capable of absorbing high amounts of water.
- When the cell wall structure absorbs water it will swell. This is a basic feature of wood tissue.
- The water content of the wood affects its strength and durability
- A permanent change of the wood cell wall structure is termed WOOD MODIFICATION

- The wood should not exhibit toxicity in service
- The modified wood should not release toxic materials at the end of service (e.g. when incinerated)
- For biological resistance, the mode of action of the modified wood should be non-toxic (non-biocidal)

Definition by Dr. Callum Hill

Kebony Wood Fundamentals

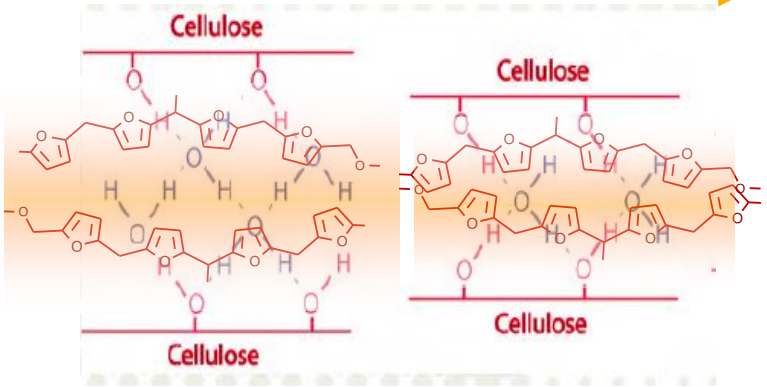
Drying & shrinking, un-treated wood



Wetting & swelling, un-treated wood

- Wood cells' composition makes the **cell walls** capable of absorbing high amounts of water.
- When the wood dries out, this leads to shrinkage

Drying & shrinking, **Kebony**



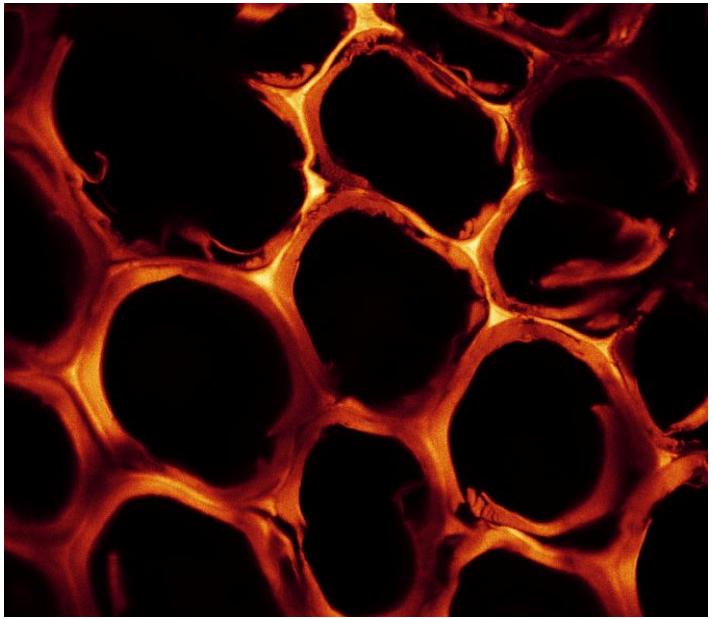
Wetting & swelling, **Kebony**

- The presence of **furan polymers** in the cell walls partly blocks the cell walls' ability to absorb water
- The blocking by the polymers also leads to **reduced shrinkage**

Technology at the wood cell level

- In the **Kebony** process the FA is *impregnated* into the wood cell wall structure, and subsequently *polymerised* to **furan polymers** that are "grafted" to the cell walls.

- These polymers are very stable, and will not degrade or leach out of the wood.



- *Cross section of Radiata pine; cell walls containing furan polymer, image through fluorescence microscopy (L. Garbrecht Thygesen, RVAU, Copenhagen, 2006).*

- Fluorescence caused by furan polymer
- Cell walls are invisible in this system without the fluorescence from the polymer

The Production Concept

Input Materials

READILY AVAILABLE WOOD

- **Sustainably managed**
- **Environmentally sound**

RENEWABLE CHEMICALS

- **Produced from plant waste**
- **Sugar cane bagasse**
- **Corn cobs**
- **Wood**

Technology

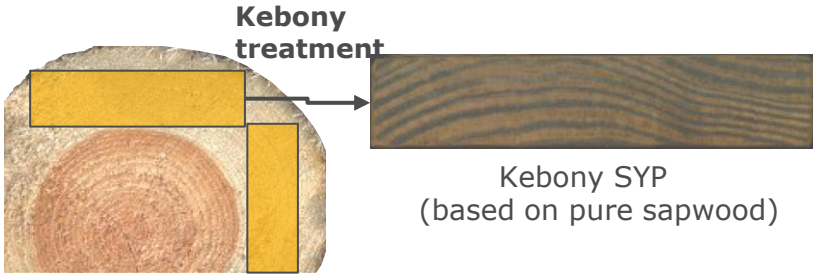
Kebony Products

THE NEW WOOD

- **Extended lifetime**
- **Enhanced physical properties**
- **Consistent quality & supply**
- **Environmentally friendly**

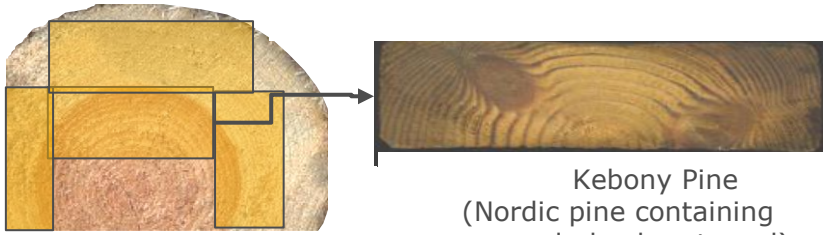
Sapwood treatment gives a homogeneous material

In softwoods, only the sapwood can be impregnated with liquids
=>
For homogeneously treated materials clear sapwood boards are used



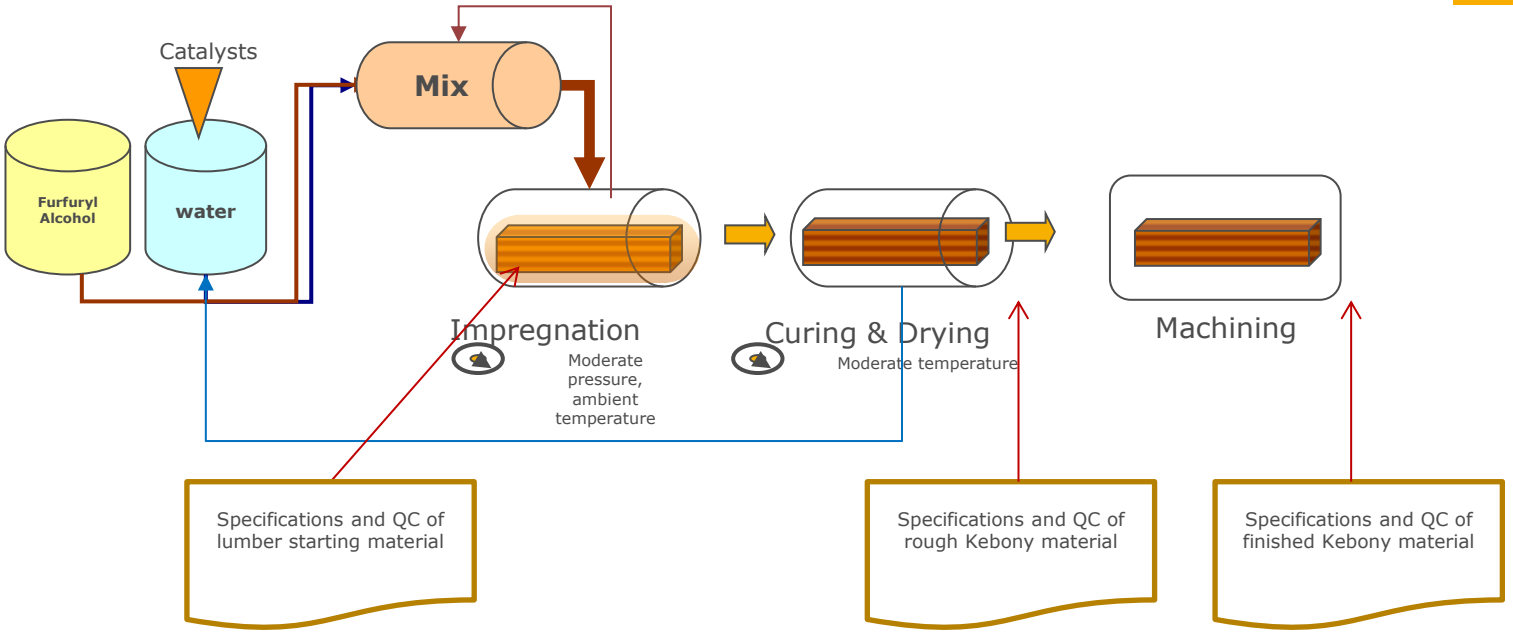
Kebony SYP
(based on pure sapwood)

Nordic pine (P. Sylvestris) is a pine where the heartwood has a degree of natural durability.



Kebony Pine
(Nordic pine containing sapwood plus heartwood)

The process steps and QC

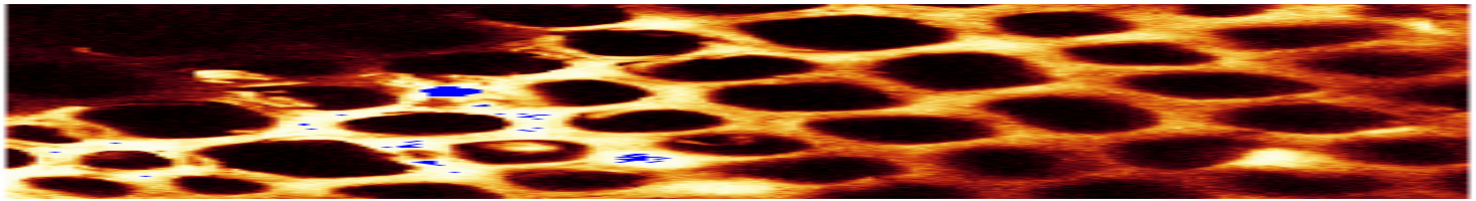


- Kebony is produced in standardised production procedures
- Each batch is controlled from receipt of raw materials to the final product
- The QC procedures and specifications are adapted to each product.
- QC is documented with procedures, instructions, internal and external specifications

Fundamental Product Factors Affected by the Kebony Process

Decay resistance	→	Resistance to rot (fungi), insects and larvae
Dimensional Stability	→	Stability against swelling and shrinkage caused by moisture variations
Hardness	→	Important for resistance to wear
Bending Strength	→	Improved stiffness against elastic bending and against breakage between two points
Increased density	→	Increased weight per volume unit
Altered colour	→	The formed furan polymer is dark brown

The size of all these effects is influenced by the *treatment level*, the concentration of furan polymer formed in the wood



Kebony product testing & documentation

- Durability against fungi and insects
  SP (Sweden); SHR (Netherlands); BRE (UK); Forest & Landscape Inst. (Norway); University of Gent (Belgium); Christian August Universität (Germany); Louisiana State University (USA); Danish Technological Institute, AIDIMA

- Weathering, coating and gluing
  SP (Sweden); SHR (Netherlands); Dynea (Norway); Norwegian Inst. Of Wood Technology; Jotun AS (Norway), AIDIMA, TEI

- Environmental Impact
  - Smoke gas testing, fire testing, leaching, eco-tox, emissions:
  SP (Sweden); SHR (Netherlands); AnalyCen (Norway), Forest & Landscape Inst. (Norway); Toxicon (Sweden); Danish Technological Institute.

- Physical / Mechanical properties
  SP (Sweden); SHR (Netherlands); Virginia Tech (USA); Norwegian Inst. Of Wood Technology

- Human health – chemical risk assessment
  IVAM (Netherlands)

Equilibrium moisture content (EMC)

Kebony EMC of 7 % corresponds to 12 % for untreated wood and a Kebony EMC of 10 % corresponds to an EMC of 18% for untreated pine.
Adsorption and desorption curves for Kebony SYP are shown in the figure below
(tests performed by the department of wood biology at Georg-August Universität, Göttingen, Germany).

Adsorption and desorption cycle for furfurylated and untreated SYP are shown in figure
Single values are displayed in the annex.

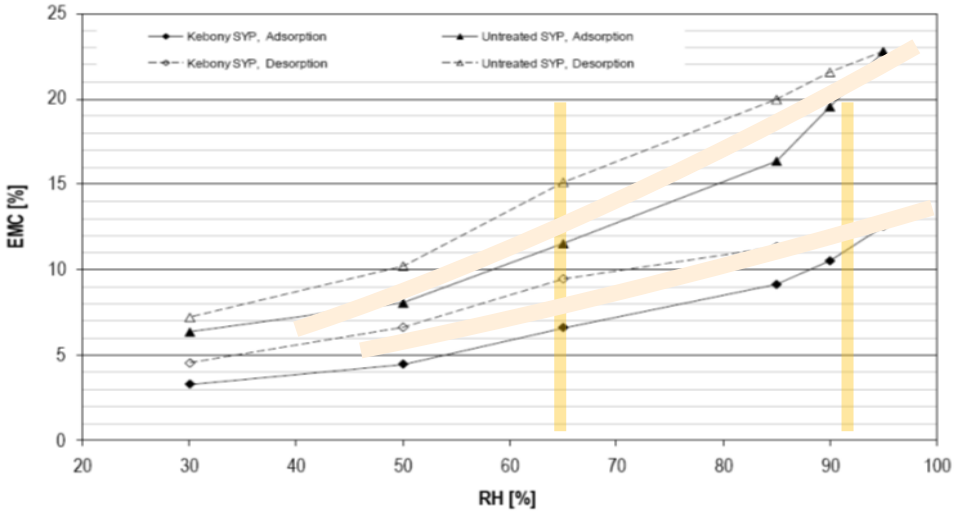


Figure 1: EMC [%] related on RH [%] of Kebony SYP and untreated SYP during adsoption and desoption cycle

Product performance

Decay resistance - Resistance to rot (fungi) :

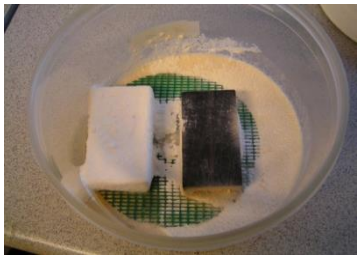
Kebony durability is tested both in lab and field

Field tests:

- Stakes in ground (EN 252)
- Close-to-ground
- Marine (EN 275)

Common lab tests:

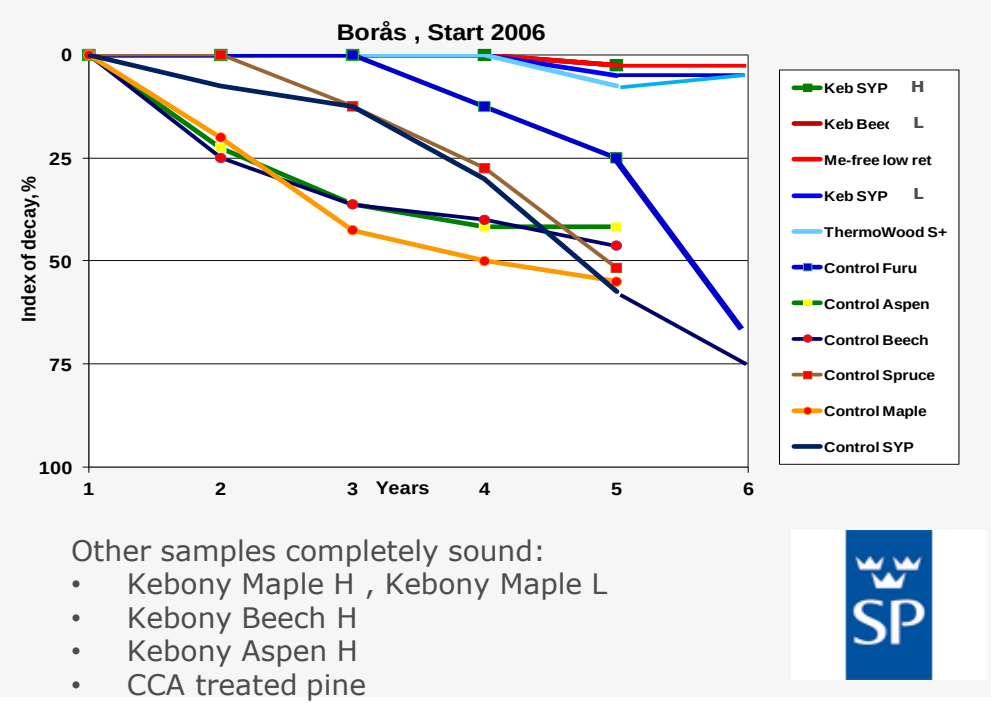
EN 113
(agar-block test)



AWPA E10
(soil-block test)

Product performance – decay resistance

Double Layer Deck Borås, Sweden



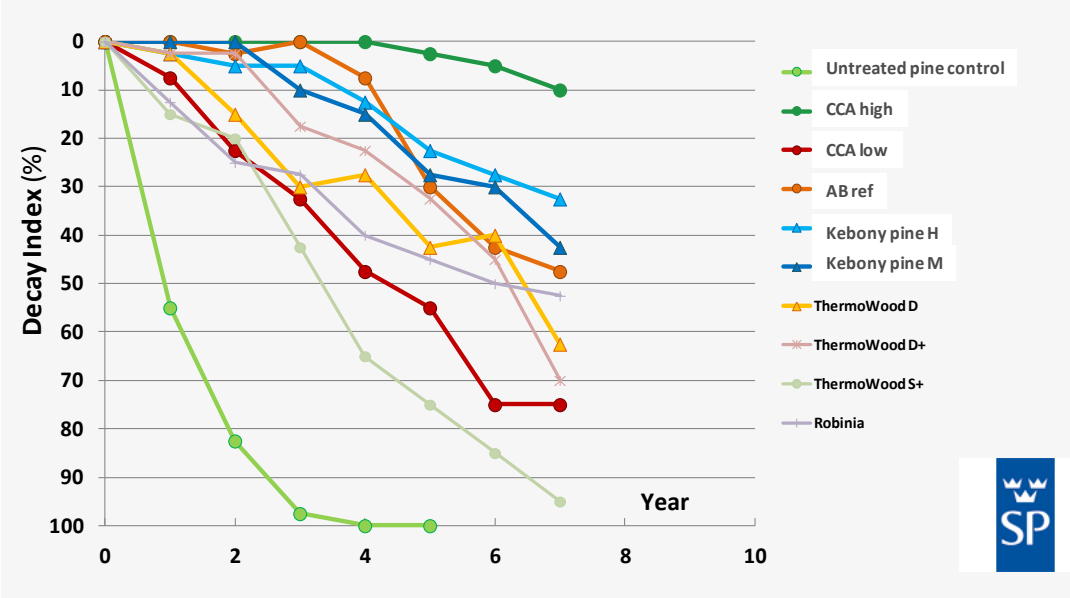
Other samples completely sound:

- Kebony Maple H , Kebony Maple L
- Kebony Beech H
- Kebony Aspen H
- CCA treated pine
- Thermowood D

All Kebony products are sound after 6 years in decking test (above ground)

Product performance – decay resistance

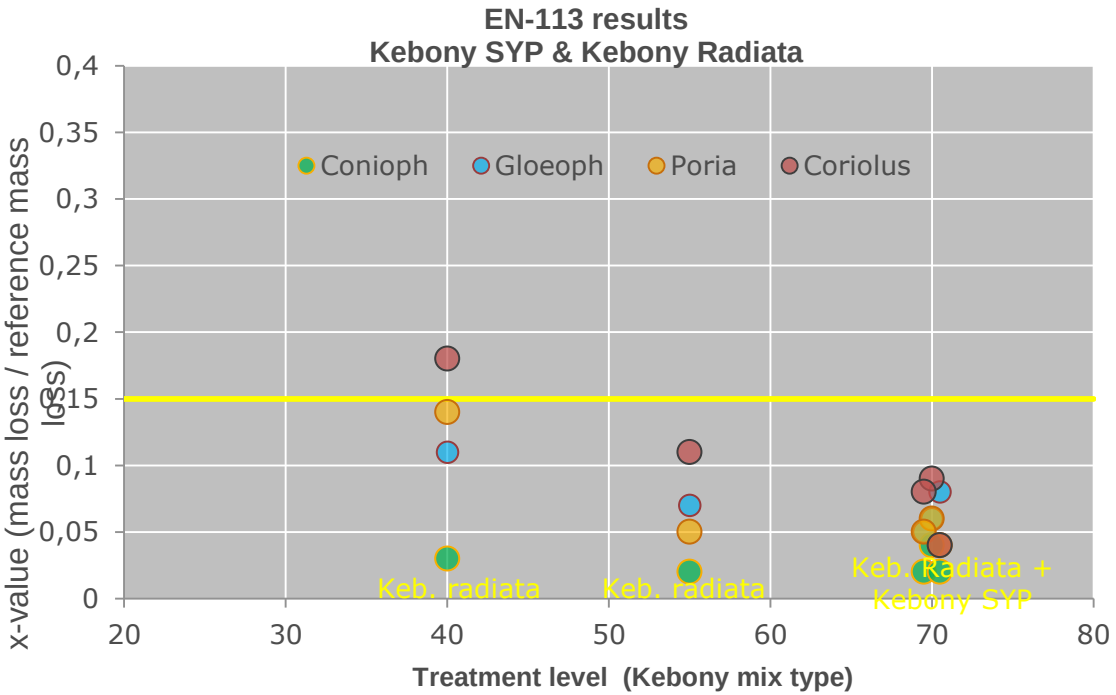
EN 252 (stakes in ground) start 2005. Borås, Sweden



Kebonised pine sapwood on par with or better than pine treated to NTR class AB (above ground)

Kebony Pine – Product Performance

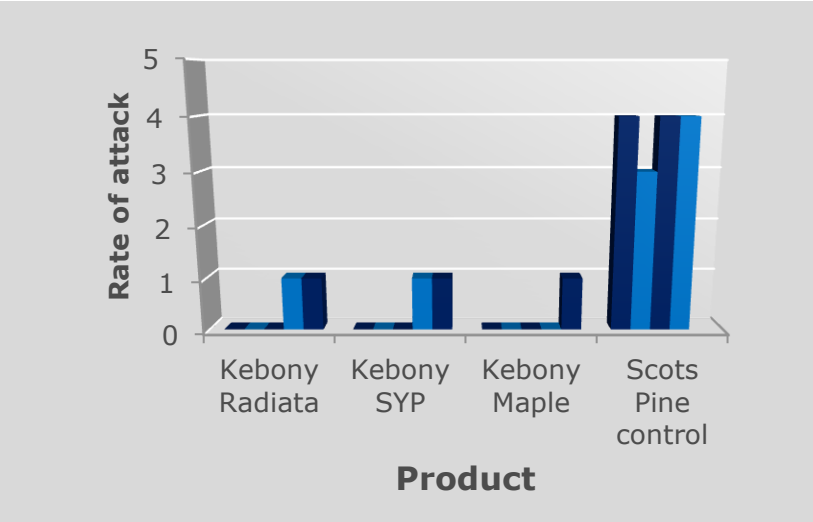
Durability testing at SHR, the Netherlands



Kebony Radiata and Kebony SYP samples with commercial treatment levels fall into Durability Class 1

Product performance – termite resistance

Results from laboratory tests at AIDIMA, Spain, 2011.
Termite species *Reticulitermes spp*.

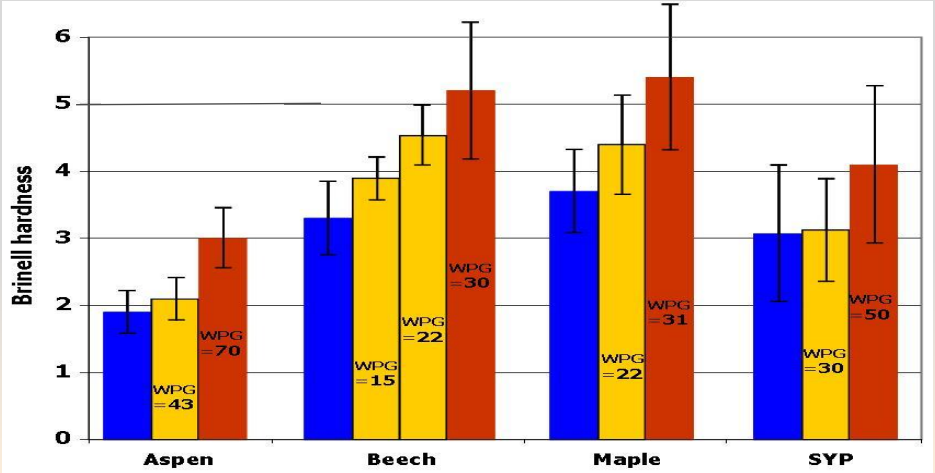


Results after 8 weeks of exposure indicate that Kebony Maple, Kebony Radiata and Kebony SYP are resistant to termite attack

Product performance

Hardness

Brinell hardness (SP, Sweden):

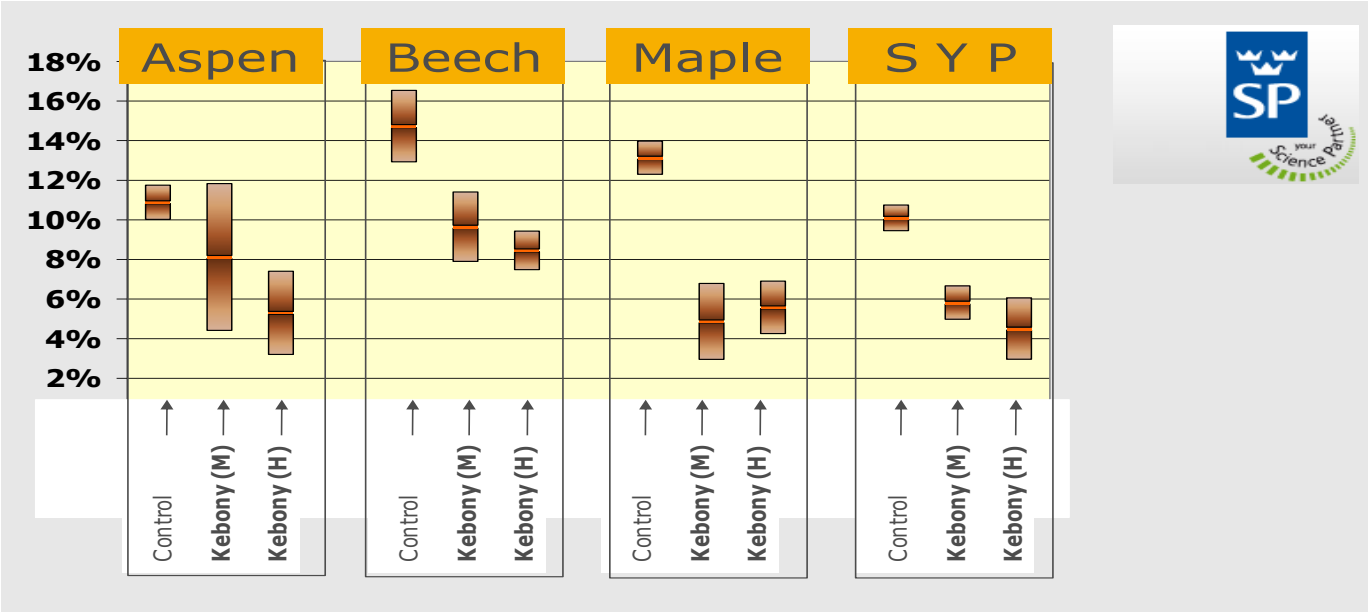


Kebonisation turns softwoods into hardwood

Product performance

Dimensional stability

Vol. swelling @ 20% - 85% RH (SP, Sweden):



Kebonisation reduces shrinkage and swelling by 40 to 60%

Kebony is durable and stable

Wood species	Maximum movement (%)	Hardness	Durability
Kebony Maple	**6**	**Very hard**	**Very durable**
Maple	9	Hard	Not durable
Massaranduba	6 - 11	Very hard	Very durable
Ipe	6	Very hard	Very durable
Teak	4 - 6	Hard	Very durable
Bangkirai	11	Very hard	Durable
Merbau	5	Hard	Durable
Iroko	6	Hard	Durable
Garapa	4 - 8	Hard	Durable
Oak	4 - 6	Hard	Durable
Kebony SYP	**5**	**Hard**	**Very durable**
Red Cedar	8	Soft	Durable
Untreated SYP	8	Soft	Slightly durable
Kebony Pine	**6**	**Hard***	**Very durable* / durable**
Siberian larch	7	Soft	Durable / moderately durable
Scots pine	8	Soft	Moderately to slightly durable

*) treated sapwood

Product Characteristics

Installation and weathering

- Kebony Pine cladding and decking - NTA
- Kebony is wood and will weather like wood
- Kebony substrate is slightly acidic.
- Use ss fasteners instead of galvanized steel
- Care with runoff onto zinc

Product Characteristics

Gluing and surface coating

- Kebony can be glued and laminated with several glue types (PUR, PRP, epoxy)
- Kebony can be coated with different paint types
  - High dimensional stability gives good coating adhesion and durability
- Kebony can be stained and oiled
  - Make sure that oils are not film forming.
  - Use high quality oils with high content of non-volatile components, e.g. Jotun Wood Oil.

Early furan resin wood modification

1920s	**The principle of forming furan polymers**
1950s	**Early attempts of wood furfurylation**
1990s	**Prof. M. Schneider's inventions**

Before Schneider's inventions, attempts to use furan resins in wood modification had met several weaknesses and obstacles, mainly from the choice of initiators (catalysts).

A known citation against Schneider is US 2909450 (Goldstein / Koppers), where zinc chloride was used as an initiator. This technique has important weaknesses.

- Impregnation must be done twice, with initiator and furfuryl alcohol in separate solutions. And zinc will remain in the product as an unwanted metal ion.
- Lack of homogeneous impregnation in real-life lumber sizes.

  This obstacle limits the technology to thin and small samples.

Kebony Patented Technology

Main inventions
(Methods and products)

- Initiators of furfuryl alcohol polymerisation that travel uniformly through wood with FA.
- Stabilisers and initiators that provide uniform impregnation and effective in-situ polymerisation in aqueous FA solutions. This provides control of chemical loading in the end products.
- Solvent diluted system as an alternative to water dilution for control of chemical loading
- Products produced by the methods
- Several defensive patent applications

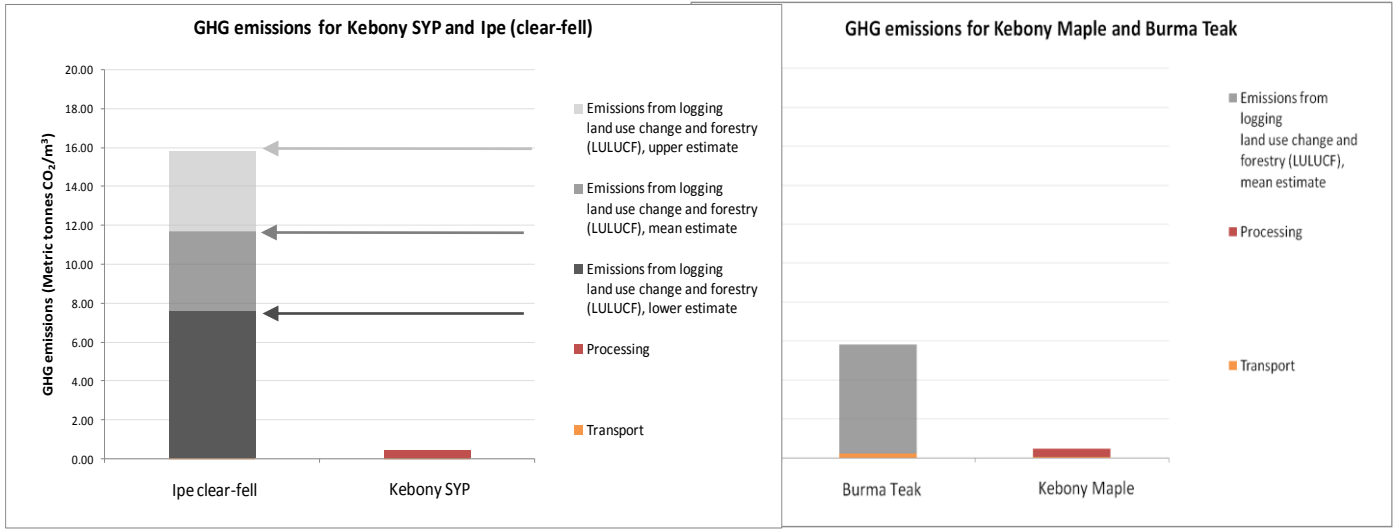
Sustainability

Certification of wood starting material – sustainably managed forests (Pine; Yellow Pine; Maple)

Documentation of Sustainability
- The Nordic Eco-label – The Swan
- Environmental Product Declaration EPD (Kebony Nordic Pine)

Documentation of environmental impacts:
- "Carbon Footprint" – Global Warming Potential
- Other Environmental impacts

Sustainability – Carbon Footprint



Awards and recognition

- The Guardian and Cleantech Group LLC 2013, 2011, 2010 **Global Cleantech 100** (100 companies selected among 5800 candidates for the 2013 listing)
- World Economic Forum **- Technology Pioneers 2014**
- 20th in CNBC Business`s ranking of **Europe's most creative companies**, July 2010
- **The Glass Bear 2004** Kebony won two prizes for "Innovation" and "Eco design" , awarded by the Norwegian Ministry of Environment and the Confederation of Norwegian Business and Industry (NHO)
- **European Environmental Press award** for environmentally friendly innovations 2004

Kebony v ThermoWood and Accoya
– other modified wood products

Parameter	Kebony	ThermoWood	Accoya
Modification principle	Furan polymer grafting	Heat treatment	Acetylation
Appearance	Brown, greying on weathering	Brown, greying on weathering	Pale, good colour stability on weathering but vulnerable to staining fungi.
Strength parameters	Improved stiffness.	Reduced bending strength	Bending strength unchanged from parent wood
Hardness	***	*	**
Dimensional Stability	**	**	***
Fastener holding strength	***	*	**
Durability / Decay resistance	***	**	***

Total economy

- Durability
- Dimensional stability
- Hardness
- Stiffness

- Low demands on maintenance

- Good service life economy

Conclusion

Kebony's key advantages

Natural wood – environmentally friendly
- Green Chemistry – bio based
- no leakage or emissions in use
- no restrictions when disposed
- can be used as firewood

Durability – decay resistance

Dimensional stability

Low maintenance requirements

Gluing and coating like ordinary wood

Solid patent protection

- Superior product properties
- Sound environmental profile
- Working production concept
- Documentation at **www.kebony.com**