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Comparative study of lignin and its fractions as phenol substitutes in phenol-formaldehyde resin formulations for plywood panels

Lignin conference, Wageningen, 31 May – 3 June 2022

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 820735.

Wood-based panels-introduction

Wood-based panels are composite products that contain a significant amount of wood in the form of strips, veneers, chips, strands or fibres, bonded with some resin. The major categories of wood-based panels are:

- plywood panels
- particleboards
- oriented strand board (OSB)
- fibre building boards

Typically, the resins used for their fabrication are petrochemical products like Urea-Formaldehyde, Melamine-Urea-Formaldehyde, Phenol-formaldehyde & pMDI.

Source: [Introduction-to-wood-based-panel-products.pdf (hanson-plywood.co.uk)]

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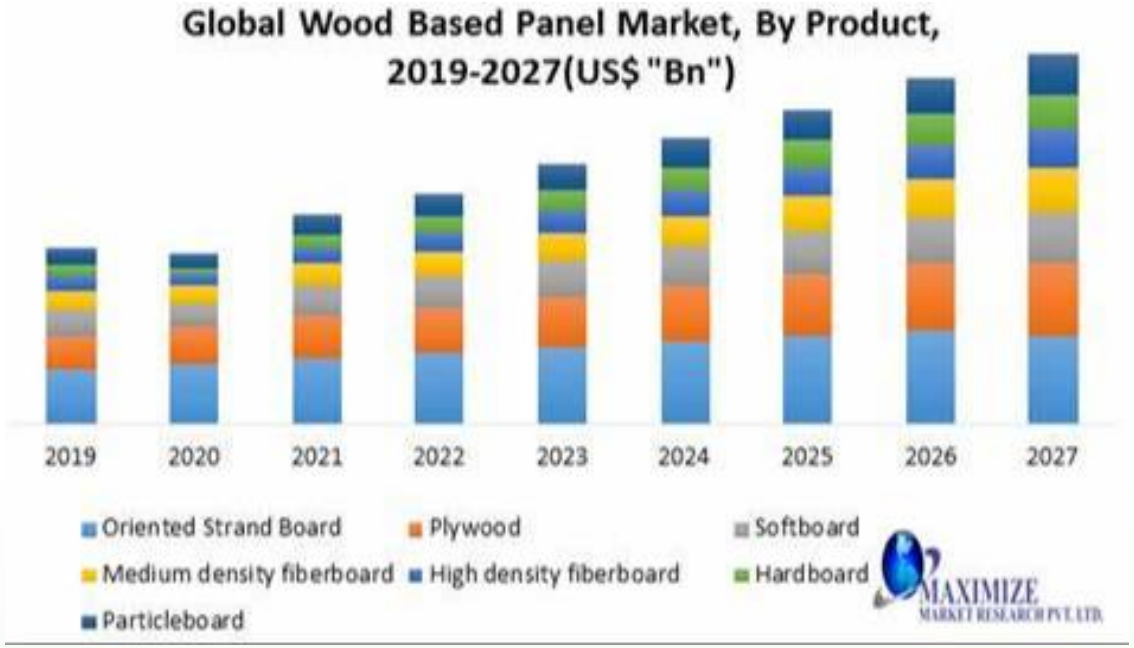
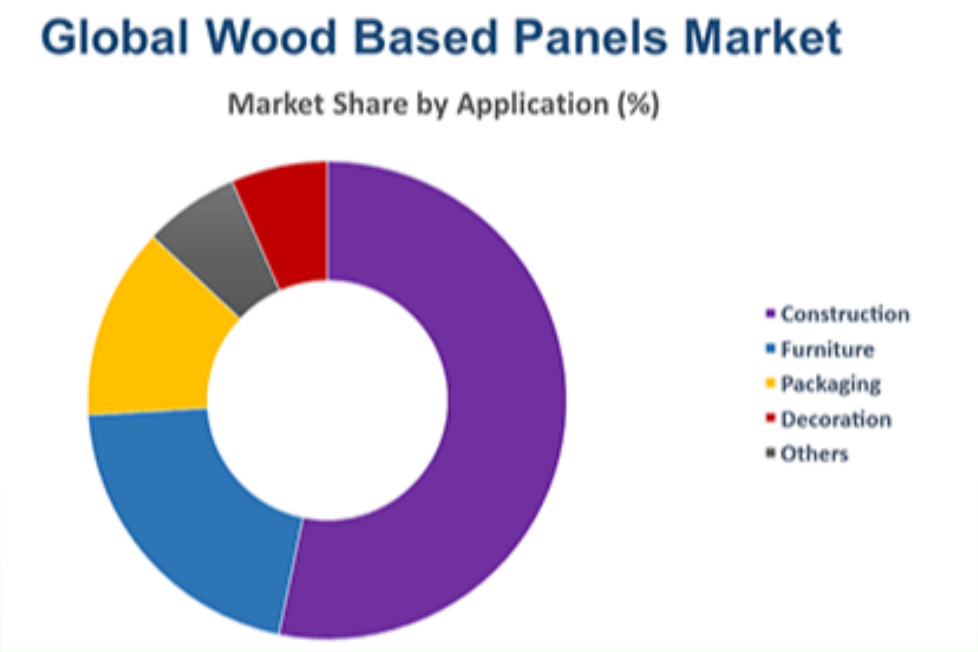
Applications & market of wood-based panels

Wood-based panels find many applications in construction sector, roofing, flooring, furniture, packaging, etc.

The global Wood Based Panel market is forecast to reach USD 259.54 Billion by 2027. New players entering the market have focused on making unique and advanced products, which leads to increasing demand for the product [1].





Source: [1] https://www.reportsanddata.com/press-release/global-wood-based-panel-market
[2] wood-based panels market data – Bing

Source: [2]

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Developments in wood-based panels

Research and innovation on wood-based panels has never stopped through the years, because market always asks for products with new properties, like light products, with new properties and more friendly to humans and the environment.

In the past the focus was on the reduction of formaldehyde emissions and indeed through the years they have been dramatically reduced. In the recent years the focus is mostly on the replacement of other petrochemical raw materials by other of natural origin and especially the substitution of phenol by lignin.

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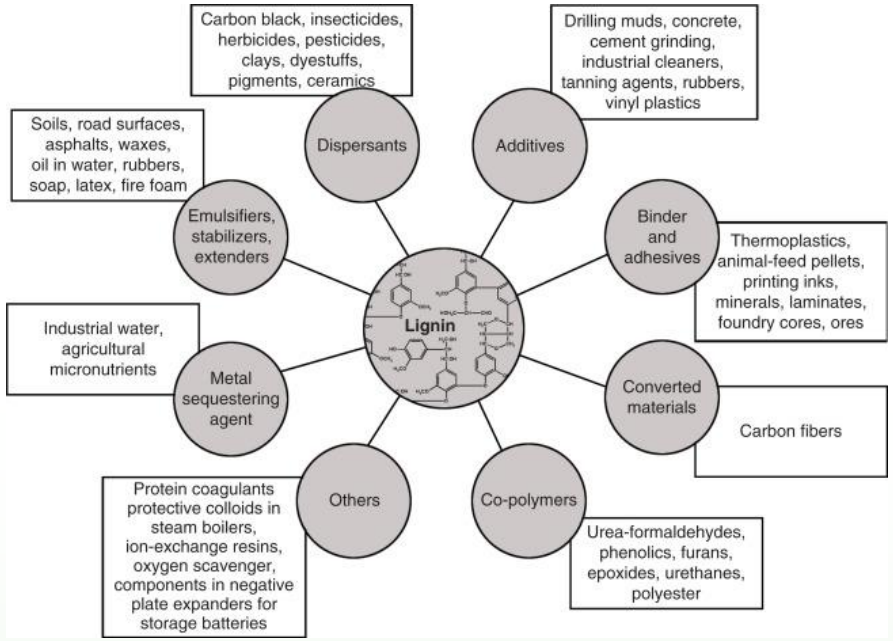
Lignin

- A prominent candidate for phenol substitution is lignin [1]
- Today, Lignin is studied for many applications. Its relatively cheap, abundant & biocompatible nature makes it attractive to manufacturers and increase their desirability to exploit the growing consumer preference for sustainable products [2].
- However, there are still issues to be faced for its effective use as a raw material in the synthesis of bio-based binders for wood-based products and one of them is its low reactivity and high molecular weight.



Sources: [1] *https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/wood-based-panels*
[2] *https://www.gminsights.com/industry-analysis/lignin-market*

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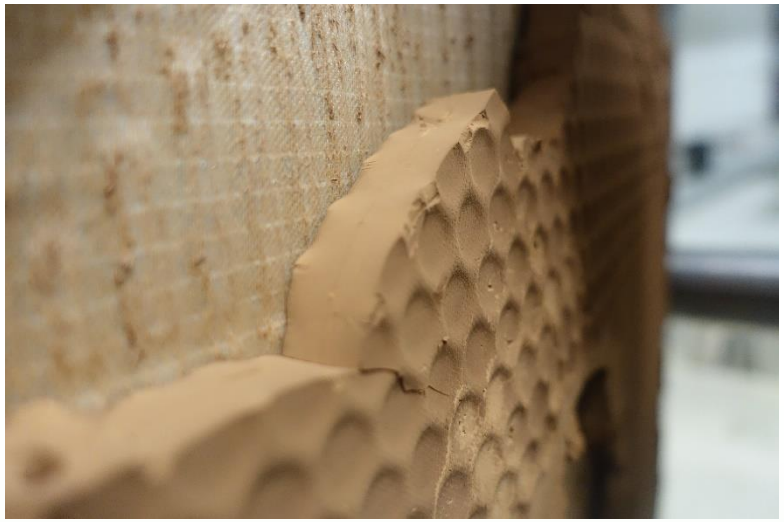
LIBERATE work on lignin

In the framework of the EU Project LIBERATE (Lignin Biorefinery Approach using Electrochemical Flow), Organosolv lignin from beech wood was produced at the pilot plant of Fraunhofer CBP with FABIOLA^{TM} process before it was subjected to fractionation/degradation and finally use by other partners.



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Lignin fractionation

TNO used lignin obtained from beech wood by applying the FABIOLA™ aqueous acetone fractionation process to separate it into fractions of different molecular weights (determination with HPSEC using 0.5 M NaOH).

Molecular weight properties of the tested lignin samples

	FABIOLA™ organosolv	**Fractionated lignin at 41% acetone (F1)**	**Fractionated lignin at 28% acetone (F2)**	**Fractionated lignin at 0% acetone (F3)**
Number Average Mn	824	1099	890	648
Weight Average Mw	2939	5174	2523	1341
Z Average Mz	8444	12464	4837	2278
(Z+1) Average Mz+1	16066	18943	7701	3483
Polydispersity PD	3.57	4.71	2.84	2.07

Results show that the FABIOLA™ lignin has a molecular weight (Mw) of about 2900 g/mol while the three precipitated fractions show a wide range in Mw from about 5200 to 1350 g/mol.

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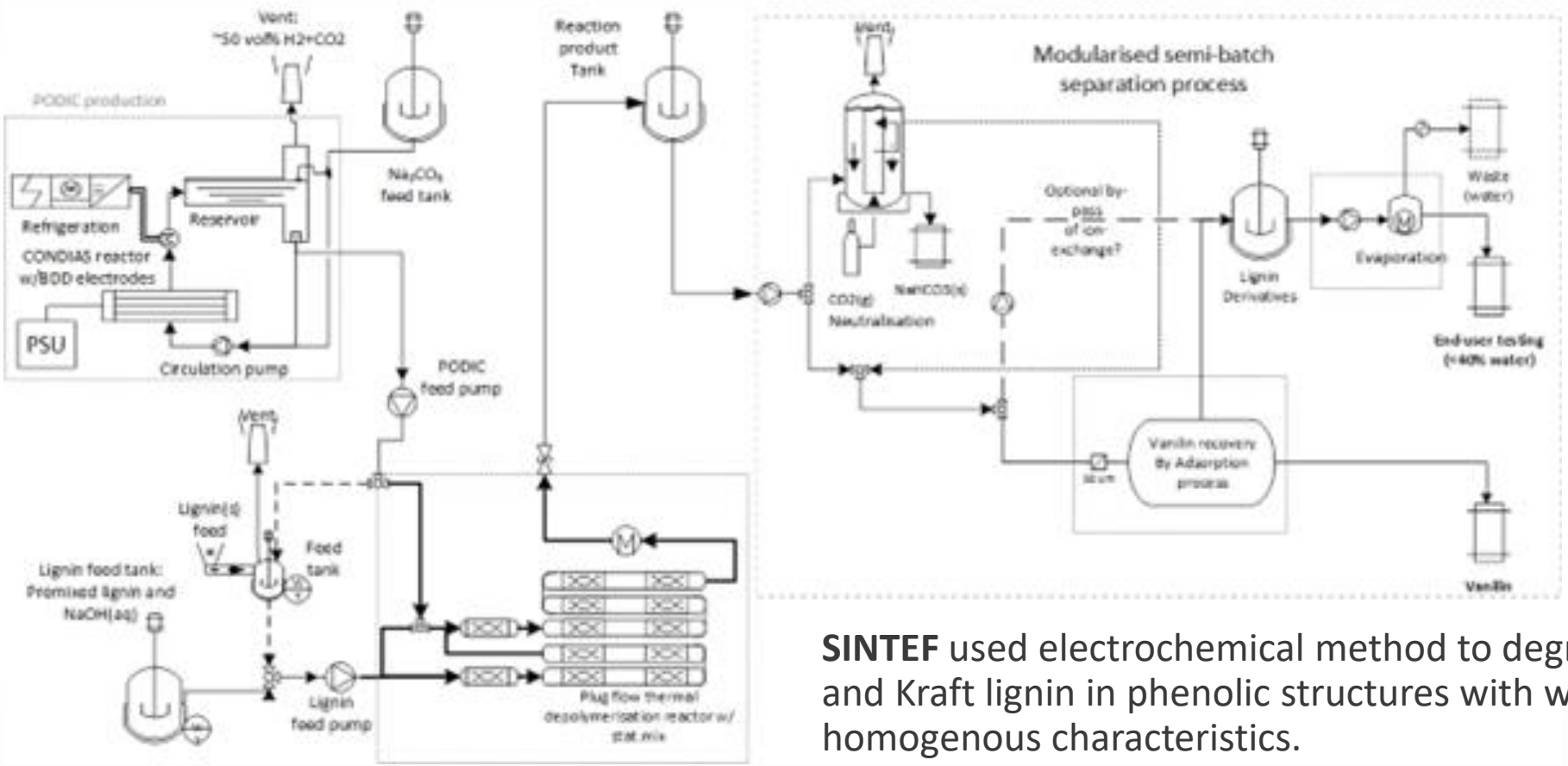
Lignin degradation



SINTEF used electrochemical method to degrade Organosolv and Kraft lignin in phenolic structures with well-defined and homogenous characteristics.

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Evaluation of lignin fractions and derivatives

CHIMAR used both lignin fractions from TNO and lignin derivatives from SINTEF to substitute phenol in the synthesis of phenol – formaldehyde resins. The substitution levels tested are up to 35% w/w.

The results of these resins were evaluated against the performance of relative resins prepared with unfractionated FABIOLA^{TM} lignin prepared by FCBA as well as a typical PF resin.

The lignin – modified resins had properties close to those of a typical PF resin. The bonding ability of the resins was tested via their application in laboratory scale production of 3-layer plywood panels. The panels were considered as products for both interior and exterior non-covered use and their properties were determined according to the European standards EN 314-1:2004 & EN 314-2:1993. The formaldehyde release of plywood panels was determined according to the standard EN ISO 12460-3:2015 (Gas Analysis).

The panels were tested for shear strength and wood failure and the test results after pre-treatments described in the relevant EN standards. Higher shear strength and higher cohesive wood failure values indicate a better performance of the resin.

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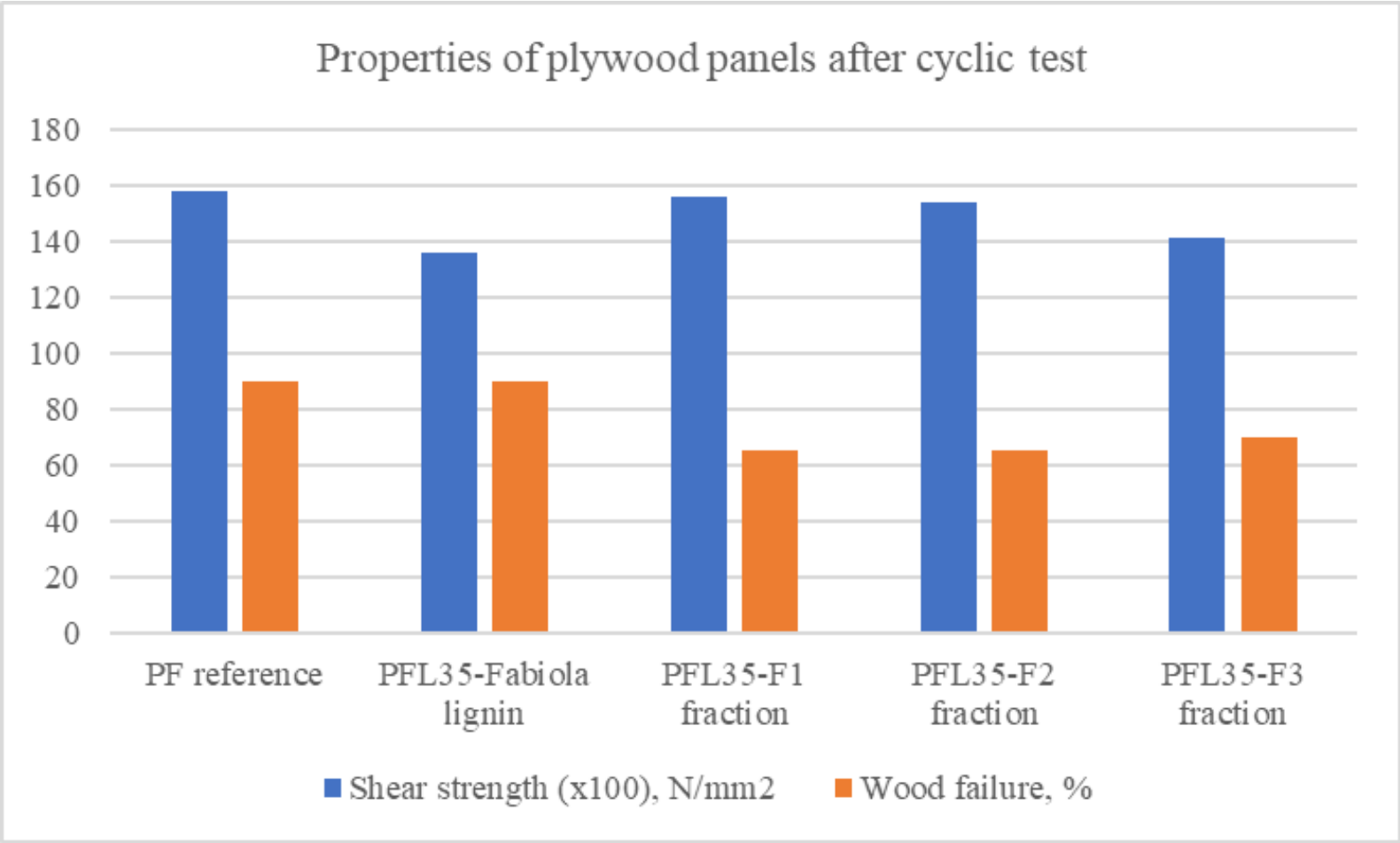
Plywood with lignin fractions



The above results show that panels made with any of the fractions of FABIOLA™ Organosolv lignin have better shear strength, but lower wood failure performance compared to plywood panels made with FABIOLA™ lignin modified PF resin. When their performance is compared to that made with a typical PF resin (PF reference), the shear strength is somewhat lower, but the wood failure lags far behind.

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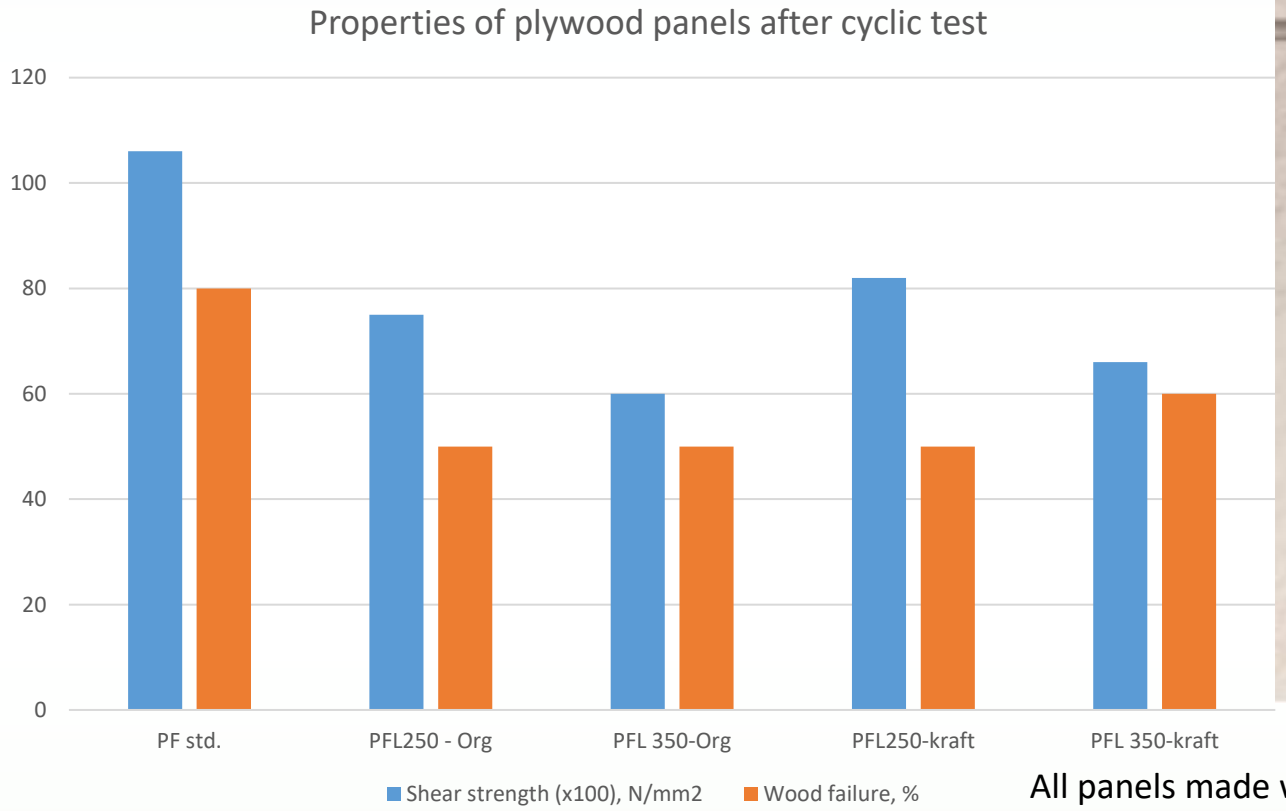
Plywood with electrochemically depolymerised lignin




Wood failure test

All panels made with depolymerized lignin have lower performance than the PF reference resin. The higher the phenol replacement level the lower the performance of the resin (especially shear strength).

At the same substitution level, Kraft lignin derived material, seems to have better performance than that of Organosolv lignin.

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Overall conclusions

- The fractionation of Fabiola™ Organosolv lignin, gives materials which lead to resins with somewhat higher shear strength than unfractionated lignin, but lower wood failure.
- The materials from electrochemically depolymerised lignin give resins with satisfactory performance at the phenol substitution level of 25% and 35% w/w. However, optimisation of their performance is needed.

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THANK YOU!!

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