Wood-derived advanced materials lead sustainable system of material utilization to the future

Dr. Prof. Tatsuhiko YAMADA

☆ Director, Center for Advanced Materials, Forestry and Forest Products Research Institute.
☆ Representative director, “Lignin Network”.
☆ Professor, Cooperative graduate school system, Univ. Tsukuba.

AGRICULTURE IS THE SOLUTION! for climate change

Biwako-hall Otsu-City, Shiga May 13th 2019
Forest in Japan : 250,000 km²

Land area : 378,000 km²

Forest covered about 70% of Japan land area.
Contents

• “Lignin” and “Glycol lignin”
• Glycol lignin based materials
• Concept of local production for local consumption in bio-based materials
Chemical structure of plant cell wall

Japanese cedar, SEM

Model of cell wall of tracheid

Lignin (Aromatic polymers)

Cellulose (Crystalline polysaccharide)

Hemi-cellulose (amorphous polysaccharides)

Terashimaらの模式図

二次壁

外層

中層

内層

一次壁

一次壁

二次壁

外層

中層

内層
What is lignin?

- Lignin is one of the main chemical components of wood.
- The word “lignin” itself comes from the Latin term “lignum”, which literally means wood.
- Based on the meaning of the original word, wood is wood precisely because it contains lignin.
Lignin – Natural aromatic polymer –

• Lignin is the most abundant naturally occurring aromatic polymer on earth.
  – Aromatic compound is a hydrocarbon containing one or more benzene rings that are characteristic of the benzene series of compounds.
  – Aromatic polymers, which wholly or partially include benzene rings and/or pseudoaromatic heterocycles, have been used in a wide field of high-performance or functional materials.

Lignin has a potential to be a source of high-performance materials such as heat-resisting plastics and high-strength plastics.

Plus: Lignin is biodegradable
History of lignin, with evolution of land plants

- **450 million years ago**: First land plant
- **380 million years ago**: Trees, about 20 meters high
- **300 million years ago**: Coniferous
- **150 million years ago**: Angiosperms
- **Appearance of Lignin**
Dilemma of lignin-based materials

For trees, lignin is

- highly evolved high-performance material
- functional material to make tree form flexible and strong
- changing the form to adapt variety of growth condition

*consequently* Lignin is not uniform

Dilemma

Industrial materials should be uniform with a stable property
Solution “Glycol lignin”

“Glycol Lignin” is a series of lignin-derived advanced industrial materials.

- lignin derivatives with unique chemical structure
- high-performance with excellent workability
- variation controlled to be a stable properties as an industrial material

Two key points in the development of Glycol Lignin
Lignin in “Japanese cedar” is relatively homogeneous

Japanese cedar is monotypic genus of cedar, single and endemic species of Japan

Since, Japanese cedar lignin is formed by single type of building block unit, structural variation is relatively small.

Japanese cedar is major and representative wood in Japanese forestry. Stable supply system is certain in Japan.

The system using Japanese cedar wood will make a system using Japan domestic forest resources
Polyethylene glycol (PEG) is a nontoxic chemical with unique properties. Interaction between PEG and plant cell wall components is strong.

**Points**

- Control the physical properties of lignin by the interaction with PEG molecule.
- Control the chemical degradation of wood in PEG to extract lignin.
- Proceed lignin extraction and PEG modification simultaneously.

Glycol lignin was produced by an acid catalyzed PEG solvolysis that proceed lignin extraction and PEG modification simultaneously.

★PEGは、化粧品、洗浄剤等、に多用されている毒性のない水溶性高分子であり、多くの化粧品に添加されています。PEGはリグニンとのなじみがよく、相互作用で物性を変化させることができます。
Freely controllable thermal property of Glycol Lignin by controlling process condition

Thermal properties of the glycol lignin as a function of introduced PEG content in the glycol lignin. ($T_g$: glass transition temperature, $T_f$: thermal flow temperature)

写真：改質リグニンを用いて開発された高付加価値製品
①改質リグニン-粘土ハイブリッド膜、②回路を搭載した改質リグニン電子基板、③タッチセンサー用改質リグニンフレキシブル基板、④鋼箔塗改質リグニンハイブリッド膜（産総研）、⑤改質リグニン繊維強化材（自動車用ドアトリム）（株式会社宮城化成）、⑥改質リグニンガスケット（ジャパンマテックス株式会社）、⑦3Dプリンター用改質リグニンフィラメントと3Dプリンター造形物（ネオマテリア株式会社）、⑧改質リグニン/パルプコンポジット射出成型品（トクラス株式会社）
Glycol Lignin based products

改質リグニン粘土ハイブリッドフィルム
ロール生産技術の成功
銅箔塗工の成功
銅箔塗工型改質リグニンハイブリッドフィルムとその電子基板への展開
スマートメーターへの導入

改質リグニン系コンポジット射出成型品
ヒーティングモジュールの開発
電着技術を開発
絶縁材料の開発

改質リグニン配管シール材
改質リグニン製の不燃材（公的認証取得済）
改質リグニン製 自動車用内装材
改質リグニン製 自動車用外装材（GFRP）
改質リグニン材を 導入した自動車

改質リグニンコンポジット射出成型品
改質リグニン製 3Dプリンター用基材
改質リグニン製3Dプリンター用基材
改質リグニン製の不燃材（公的認証取得済）
改質リグニン製 自動車用内装材
改質リグニン製 自動車用外装材（GFRP）
改質リグニン材を 導入した自動車

アルミ箔塗工型改質リグニンハイブリッドフィルムとその放熱材への展開
銅箔塗工の成功
ロール生産技術の成功
銅箔塗工の成功
銅箔塗工型改質リグニンハイブリッドフィルムとその電子基板への展開
スマートメーターへの導入
Ex.1 Glycol lignin based FRP for automobile

Invent a method of Glycol Lignin based molding resin for fiber reinforced plastics (FRP).

GL based FRP shows better performance in mechanical properties than widely used epoxy resin type of FRP.

Volatile Organic Compound (VOC) emission test

<table>
<thead>
<tr>
<th>测定成分</th>
<th>不饱和ポリエステル (従来仕様品)</th>
<th>改質リグニン使用</th>
</tr>
</thead>
<tbody>
<tr>
<td>ホルムアルデヒド</td>
<td>26</td>
<td>0.06</td>
</tr>
<tr>
<td>アセトアルデヒド</td>
<td>9.1</td>
<td>0.05</td>
</tr>
<tr>
<td>トルエン</td>
<td>0.09</td>
<td>&lt;0.08</td>
</tr>
<tr>
<td>エチルペンゼン</td>
<td>1.7</td>
<td>&lt;0.08</td>
</tr>
<tr>
<td>キシレン</td>
<td>0.35</td>
<td>&lt;0.24</td>
</tr>
<tr>
<td>スチレン</td>
<td>360</td>
<td>&lt;0.08</td>
</tr>
<tr>
<td>テトラデカン</td>
<td>&lt;0.08</td>
<td>&lt;0.08</td>
</tr>
<tr>
<td>フタル酸ジ-n-プチル</td>
<td>&lt;0.08</td>
<td>&lt;0.08</td>
</tr>
<tr>
<td>フタル酸ジ-2-ヘキシル</td>
<td>&lt;0.08</td>
<td>&lt;0.08</td>
</tr>
</tbody>
</table>

360 ÷ 0.08 = 4500
改質リグニンを用いたGFRPの場合は、不飽和ポリエステル樹脂を含浸させる従来品の4500分の一未満

試験方法：トヨタ法「サンプリングバッグ法による揮発成分測定方法」

GL based FRP shows excellent performance in the VOC test.
Press Release Oct. 23, 2018

Starting the practical vehicle test of exterior and interior Glycol Lignin based FRP

World 1st motorcar using Glycol Lignin based FRP

AIST, FFPRI, Miyagi-kasei Co., Ltd., Mitsuoka Motor Co., Ltd.

Ex. 1.

Reported widely by more than 20 web news
**Ex. 2. Hybrid film for printed electronic devices**

Flexible electric substrate film was prepared by Glycol lignin-Clay hybrid material. Glycol lignin-Clay hybrid film shows better performance than commercial polyimide film in gas barrier property and dimension stability. The price becomes a one-third of the commercial polyimide film.
Environmental adaptability

Glycol lignin : Environmental friendly materials

- No harmful volatile organic compounds in the production process
- No accumulation in the environment (biodegradable)
- Favorable in environmental impact assessment (carbon neutral)

- No harmful volatile organic compounds
- Biodegradable
- No microplastic marine pollution
Glycol lignin production for the promotion of local industry

**Use wood waste only**
(Not affect to the lumbering work)

**Point**

*Example*
Operation at a local sawmilling factory

Creating new markets of 100 billion yen scale

**Glycol Lignin based new products**

New companies are entering the market one after another

**Example: Sales increase by 65%**
Conclusion

• Two key points in the development of Glycol Lignin

1. Focus on the Japanese cedar lignin that is relatively homogeneous.

2. Modification with polyethylene glycol (PEG) to control thermal properties

Using Japanese cedar wood will make a system of using Japan domestic forest resources

• Many Glycol Lignin based products has been developed through composite technologies.

• Since glycol lignin is biodegradable, glycol lignin based products will not accumulate in the environment (No microplastic marine pollution).
Sustainable system on domestic resources

Land area, total: 38 million ha

Forest: 25 million ha (67% of the land area)

Farmland: 6 million ha (12% of the land area)

Glycol lignin will lead sustainable system of material utilization to the future

Methane hydrate in the ocean
Lignin in the mountain

Biomass superpower?

Totally about 80% of the land is covered with biomass

Need innovation!

Key words: domestic resources, self sufficiency, energy security, local business, regional revitalization
Thank you!

Tatsuhiko Yamada, Ph.D.

Website

http://lignin.ffpri.affrc.go.jp/

↓YouTube

https://www.youtube.com/channel/UCOF0JebKdA9fmH0MiCi4IUA

This work was supported by SIP-Lignin Project, Technologies for Creating Next-Generation Agriculture, Forestry and Fisheries under the Cross-Ministerial Strategic Innovation Promotion Program (SIP) administered by Council for Science Technology and Innovation (CSTI).