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Biocomposites on the Base of Thermoplastic Starch Filled by Wood and Kenaf Fiber

KEYWORDS: Thermoplastic starch, Mechanical & physical properties, Reinforcements
The increasing danger for the environment and people health connected with plastics wastes turned researches attention to plastics from renewable resources which have properties similar to petrochemical polymers but can be biodegradable.

Biopolymers are very often used to combine with natural fiber as well a being a part of biodegradable synthetic plastics.

In recent years, among the functional fillers, natural fibres have become a common material for the manufacture of filled plastics.
biocomposites made of thermoplastic starch were tested to estimate the influence of the wooden or kenaf filler on their based physical and mechanical properties

influence of using two sorts of thermoplastic biobased and biodegradable starch was also estimated

Biocomposites properties (physical, mechanical) were estimated on the basis of several tested including also influence of temperature and soaking in the water

the reinforcement effect was estimated by making SEM micrographs of surface (fractures and polished cross-sections),

Conclusions from the results of tests let to propose and make some products based on thermoplastic starch with natural fillers
Solanyl BP blend 20F (potato starch) – S2
Solanyl BP blend 30R (potato starch) – S3
produced by Rodenburg Biopolymers from the Netherlands.

Solanyl® BP is a patented and commercially available bioplastic, a smart material which is biobased and biodegradable. The word Solanyl is coming from Solanum Tuberosum, which means potato. Polymer is based on a side stream potato starch of the potato processing industry.

Production of Solanyl granules is highly efficiently and for example requires 65% less energy compared to polyethylene production.
The wood fibre CB 120 is produced from pine, has fibrous structure and the length of particles is about 70-150 μm. Lignocel is natural fiber which is “ready-to-use” for direct processing on extrusion plants and injection molding machinery.

The specific shape of wooden (pink) filler manufactured by Retttenmaier Lignocel CB 120.
The kenaf fiber deriving from processing the bark of the kenaf plant is pale yellow in color and is the most highly valued natural product. It has a degree of purity from woody debris and pectins equal to 99% and is highly appreciated in the construction of mats with thermoset natural fibres for the automotive industry and technical applications. The fibers after grinding in our laboratory on Retsch mill machine have approximately 40-50 μm and length 200-300 μm.
<table>
<thead>
<tr>
<th>Fibre</th>
<th>Density [g/cm³]</th>
<th>Elongation [%]</th>
<th>Tensile strength [MPa]</th>
<th>Young’s modulus [GPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>1,5-1,6</td>
<td>7,0-8,0</td>
<td>287-597</td>
<td>5,5-12,6</td>
</tr>
<tr>
<td>Jute</td>
<td>1,3</td>
<td>1,5-1,8</td>
<td>393-773</td>
<td>26,5</td>
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<tr>
<td>Flax</td>
<td>1,5</td>
<td>2,7-3,2</td>
<td>345-1035</td>
<td>27-85</td>
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<tr>
<td>Hemp</td>
<td>-</td>
<td>1,6</td>
<td>690</td>
<td>25</td>
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<tr>
<td>Ramie</td>
<td>-</td>
<td>3,6-3,8</td>
<td>400-938</td>
<td>61,4-128</td>
</tr>
<tr>
<td>Sisal</td>
<td>1,5</td>
<td>2,0-2,5</td>
<td>511-635</td>
<td>9,4-22,0</td>
</tr>
<tr>
<td>Soft wood</td>
<td>1,5</td>
<td>-</td>
<td>1000</td>
<td>40,0</td>
</tr>
<tr>
<td>Glass</td>
<td>2,5</td>
<td>12,5</td>
<td>2000-3000</td>
<td>70,0</td>
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<tr>
<td>Aramid</td>
<td>1,4</td>
<td>3,3-3,7</td>
<td>3000-3150</td>
<td>63,0-67,0</td>
</tr>
</tbody>
</table>
ramie
flax
sizal
kenaf
hemp
Scanning electron micrographs (SEM) of the sisal fiber

Scanning electron micrographs (SEM) of the wood fiber

Scanning electron micrographs (SEM) of the flax - len
SEM micrographs of:

(a) surface of composite with 20% wood fibres (fracture, x1000)

(b) “Channels” of wood fibres filled by polymer (polished cross-section, x500)
COMPARABLE FIBRE CHARACTERISTICS

B. COMMON CHARACTERISTICS - PHYSICAL

- High tensile strength
- Low extension
- High modulus of elasticity
- High coefficient of friction
- Excellent heat, sound, electrical insulation properties
- Biodegradable
- Combustible

C. COMMON CHARACTERISTICS - COMMERCIAL

- Abundant global supply
- Renewable, sustainable raw material resource
- Recyclability
- Potential for comparable weight reduction
- Potential for comparable cost reduction
Possibilities of Processing

70-90% **wooden profiles**
outside, construction,
high stiffness, image
*conical machines*

40-70% **wood like** profiles
Strandex or similar (USA: decking market)
*conical machines*

5-40% **wood filled** profiles
basically conventional equipment; stiffness, marble effects
*twin (also parallel) or single*

60+20% and higher **Fasalex**
MDF, interior, image,
100% organic feasible
*conical machines*

Calibration
Water cooling
No Calibration
Air cooling
Specimens

Specimens were made according to EN ISO 527-2 using injecting-moulding machine Wh80 Ap with double mold form at laboratory of University of Technology and Life Sciences - Bydgoszcz (Poland).

Additionally, for preparing and better homogenization of Solanyl granulates with the fillers, there was used roll stand machine (roll length – 380 mm and diameter – 200 mm) for making composites. The rolling was conducted in the temperature of 160 °C. Then granulated fraction was injected.

The weight content of fibers in composites was 25 and 40% of wood and kenaf fibers (specimens indicated 25C, 4C and 25K, 4K).
The injection-molded tensile bars were tested at 21°C and 65% RH on a universal testing instrument (Instron type 4465) according to PN-EN ISO 527.

Using a constant crosshead speed of 5 mm/min, five tensile bars were tested for each composite and the mean and range of the specific modulus of elasticity, specific ultimate tensile strength and strain at break.

<table>
<thead>
<tr>
<th>Type of biopolymer</th>
<th>wt of fibre [%]</th>
<th>Density (kg/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solanyl 20F</td>
<td>0</td>
<td>1.2997</td>
</tr>
<tr>
<td>Solanyl 20F</td>
<td>25 wood</td>
<td>1.3270</td>
</tr>
<tr>
<td>Solanyl 20F</td>
<td>40 wood</td>
<td>1.3413</td>
</tr>
<tr>
<td>Solanyl 20F</td>
<td>25 kenaf</td>
<td>1.3275</td>
</tr>
<tr>
<td>Solanyl 20F</td>
<td>40 kenaf</td>
<td>1.3522</td>
</tr>
<tr>
<td>Solanyl 30R</td>
<td>0</td>
<td>1.3040</td>
</tr>
<tr>
<td>Solanyl 30R</td>
<td>25 wood</td>
<td>1.3388</td>
</tr>
<tr>
<td>Solanyl 30R</td>
<td>40 wood</td>
<td>1.3500</td>
</tr>
<tr>
<td>Solanyl 30R</td>
<td>25 kenaf</td>
<td>1.3342</td>
</tr>
<tr>
<td>Solanyl 30R</td>
<td>40 kenaf</td>
<td>1.3546</td>
</tr>
</tbody>
</table>
Results of Tests

The influence of the filler

Comparison of modulus of elasticity for tested composites
(C - wood, K – kenaf)
In case of biopolymers filled by kenaf fibers, the values of modulus of elasticity and tensile strength are higher than for wood fibre composites, but processing composites with kenaf is more difficult.

Comparison of tensile strength for tested composites (C - wood, K - kenaf)
SEM image

JEOL 5510LV (low vacuum) scanning electron microscope (SEM) with an accelerating voltage of 10 kV

Solanyl BP 20F, fragile fracture after break in liquid N2

It’s interesting that producer used two form of granulate: one of them is more stiffness and harder, melts in higher temperature and another one is more plastificate and easy melting

Solanyl BP 30R, fracture after elongation test with pulled out elements of thermoplastic starch
We can observe the differences between morphology of chosen natural fiber – kenaf fiber seems to be more coherent but both has good adhesion to thermoplastic starch.

kenaf fiber broken during elongation test, fracture Solanyl 30R filled by 40% of fiber.
This stress transfer efficiency largely depends on the fiber-matrix interface and mechanical properties of the fiber and polymer.

typical fracture of composite on the base of Solanyl 30R (with two phase matrix of biopolymer) filled by 40% of kenaf fiber (observed like second phase) fracture after elongation test.
Absorption of water - first effect of biodegradation

We can observe that adding wood and kenaf fibres caused increase of absorbed water by composites. The values of absorbed water for composites with wood fibre and on the base of Solanyl 30R are higher.

Comparison of absorption of water for composition with kenaf (K) and wood fiber (C) on the base of two sorts of thermoplastic starch on trade name - Solanyl.
Examples of elongation curves for Solanyl 20F and wood fibre (dry and soaked 7 days in water – W7)
<table>
<thead>
<tr>
<th>Type of biopolymer</th>
<th>wt of fibre [%]</th>
<th>Tensile strength [%]</th>
<th>Modulus of elasticity [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solanyl 20F</td>
<td>0</td>
<td>1.6</td>
<td>6.2</td>
</tr>
<tr>
<td>Solanyl 20F</td>
<td>25 wood</td>
<td>14.0</td>
<td>7.3</td>
</tr>
<tr>
<td>Solanyl 20F</td>
<td>40 wood</td>
<td>19.0</td>
<td>28.5</td>
</tr>
<tr>
<td>Solanyl 20F</td>
<td>25 kenaf</td>
<td>8.8</td>
<td>7.4</td>
</tr>
<tr>
<td>Solanyl 20F</td>
<td>40 kenaf</td>
<td>31.7</td>
<td>33.9</td>
</tr>
<tr>
<td>Solanyl 30R</td>
<td>0</td>
<td>28.8</td>
<td>31.3</td>
</tr>
<tr>
<td>Solanyl 30R</td>
<td>25 wood</td>
<td>36.7</td>
<td>17.5</td>
</tr>
<tr>
<td>Solanyl 30R</td>
<td>40 wood</td>
<td>27.4</td>
<td>41.0</td>
</tr>
<tr>
<td>Solanyl 30R</td>
<td>25 kenaf</td>
<td>20.1</td>
<td>25.5</td>
</tr>
<tr>
<td>Solanyl 30R</td>
<td>40 kenaf</td>
<td>20.7</td>
<td>29.7</td>
</tr>
</tbody>
</table>
Influence of Temperature

![Graph showing the influence of temperature on displacement and force. The graph compares different materials (S3, S3 40 oC, S3 60 oC, S34K, S34K 40 oC, S34K 60 oC) at various temperatures.]
When a polymer specimen is tension tested at elevated temperatures, its modulus and strength decrease with increasing temperature because of thermal softening. In a polymeric matrix composite, the matrix-dominated properties are more affected by increasing temperature than the fiber-dominated properties.
Comparison of tensile strength for Solanyl 20F and wood fiber tested in three temperatures.
The increase of temperature of testing caused decrease of tensile strength and modulus and elongation increased. In case of composite with 40% of kenaf fiber tested in 60°C, elongation was about 62 mm.
Comparison of tensile strength for Solanyl 30R and wood fiber tested in three temperatures.
Conclusions

Biocomposites on the base of thermoplastic starch filled by natural fibers, both from renewable material, can be interested alternative for conventional polymeric material based on gas or oil modified hand-mad fiber like glass or carbon.

We can examine that this composites can obtain strength on the level 50 MPa and very good stiffness with modulus of elasticity coming to 10,000 MPa.

Polymer composites on thermoplastic starch filled with kenaf had highest increase of stiffness on the same level of fiber than composites on the base of polyolefines.

On the fracture images, we can observe regular distribution of the fibres in the matrix and two-phase character of the starch matrix.
It seems that we can process this biocomposites on classical plastic machine like injection-moulding machine or conventional extruders. It is important that we can used less electric energy with the same efficiency of processing because melting temperature of based thermoplastic starch is lower than polyolefin’s or other traditional plastic (PCV, PS or PA).

Soaking in the water especially for longer time and higher temperature caused decreasing of mechanical properties and this is a opportunity for some technical application but it isn’t a problem for many every-day product with short time life cycle.