3D printed fiber reinforced lignin
Exploring the options to use wood in an additive manufacturing process

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MASTER THESIS

3D printed fiber reinforced lignin

Exploring the options to use wood in an additive manufacturing process
3D printed fiber reinforced lignin
Exploring the options to use wood in an additive manufacturing process

ADDITIVE MANUFACTURING
RESEARCH QUESTION AND METHODOLOGY
WOOD THEORY

EXPERIMENT PHASE
PROTOTYPE PHASE
APPLICATIONS

CONCLUSION
ADDITIVE MANUFACTURING

- MILLING
- DRILLING
- CUTTING
- PLANING
ADDITIVE MANUFACTURING
ADDITIVE MANUFACTURING

A.M. THEORY

RESEARCH QUESTION

WOOD THEORY

EXPERIMENTS

PROTOTYPE PHASE

APPLICATIONS

CONCLUSIONS
ADDITIVE MANUFACTURING

LESS ASSEMBLY
HIGH CUSTOMIZATION
GEOMETRIC OPTIMIZATION
MATERIAL ECONOMY
RECYCLING POTENTIAL

ADDITIVE MANUFACTURING

A
Material

Subtractive Manufacturing

3D object + Waste

B
Material

Additive Manufacturing

3D object + Waste

ADDITIVE MANUFACTURING

CAD

RESEARCH QUESTION

WOOD THEORY

EXPERIMENTS

PROTOYPE PHASE

APPLICATIONS

CONCLUSIONS
ADDITIVE MANUFACTURING

LESS ASSEMBLY
HIGH CUSTOMIZATION
GEOMETRIC OPTIMIZATION
MATERIAL ECONOMY
RECYCLING POTENTIAL

SLOW BUILD RATES
ONLY COST EFFECTIVE IN SMALL QUANTITIES
POST PROCESSING NEEDED
CONSTANT PRODUCTION COSTS

ADDITIVE MANUFACTURING

A.M THEORY
RESEARCH QUESTION
WOOD THEORY
EXPERIMENTS
PROTOTYPE PHASE
APPLICATIONS
CONCLUSIONS
ADDITIVE MANUFACTURING

A. Material

Subtractive Manufacturing

3D object + Waste

B. Material

Additive Manufacturing

3D object + Waste

ADDITIVE MANUFACTURING

CAD

CONCLUSIONS
ADDITIVE MANUFACTURING CONTAINS UP TO 60 % PLASTIC (PLA)
RESEARCH QUESTION
CAN WOOD BE USED IN AN ADDITIVE MANUFACTURING PROCESS?
BACKGROUND QUESTIONS

WHAT IS WOOD AND WHAT ARE THE PROPERTIES OF WOOD AND ITS COMPONENTS?
BACKGROUND QUESTIONS
WHAT IS WOOD AND WHAT ARE THE PROPERTIES OF WOOD AND ITS COMPONENTS?
HOW CAN THE COMPONENTS OF WOOD BE COMBINED IN A PRINTABLE MATERIAL?
EXPLORING THE OPTIONS TO USE WOOD IN AN ADDITIVE MANUFACTURING PROCESS
EXPLORING THE OPTIONS TO USE WOOD IN AN ADDITIVE MANUFACTURING PROCESS

DESIGN OF PROCESS
EXPLORING THE OPTIONS TO USE WOOD IN AN ADDITIVE MANUFACTURING PROCESS

DESIGN OF PROCESS

FABRICATION OF SAMPLES (SYRINGE BASED)
EXPLORING THE OPTIONS TO USE WOOD IN AN ADDITIVE MANUFACTURING PROCESS

DESIGN OF PROCESS

FABRICATION OF SAMPLES (SYRINGE BASED)

FABRICATION OF SAMPLES (3D printer BASED)
EXPLORING THE OPTIONS TO USE WOOD IN AN ADDITIVE MANUFACTURING PROCESS

DESIGN OF PROCESS

FABRICATION OF SAMPLES (SYRINGE BASED)

FABRICATION OF SAMPLES (3D printer BASED)

PROOF OF PRINCIPLE
WOOD
WOOD

RESULT OF GROWTH CYCLE OF TREE
WOOD

RESULT OF GROWTH CYCLE OF TREE
WOOD CELLULOSE
WOOD

LIGNIN

A.M. THEORY

RESEARCH QUESTION

WOOD THEORY

EXPERIMENTS

PROTOTYPE PHASE

APPLICATIONS

CONCLUSIONS
EXPERIMENTS
EXPERIMENTS
EXPERIMENTS

IDEA

ACETONE 80%
WATER 20%
EXPERIMENTS

SKOGCELL 90Z BLEACHED KRAFT WFBR

INDULIN AT KRAFT LIGNIN
EXPERIMENTS
HOW TO GET FIBERS?

SKOGCELL 90Z BLEACHED KRAFT WFBR

INDULIN AT KRAFT LIGNIN
EXPERIMENTS
HOW TO GET FIBERS?
PULPING

SKOGCELL 90Z BLEACHED KRAFT WFBR

INDULIN AT KRAFT LIGNIN
EXPERIMENTS
HOW TO GET FIBERS?
PULPING

SKOGCELL 90Z BLEACHED KRAFT WFBR
EXPERIMENTS
HOW TO GET FIBERS?
PULPING

ACETONE 80%
WATER 20%

SKOGCELL 90Z BLEACHED KRAFT WFBR
CHIPPED SKOGCELL 90Z BLEACHED KRAFT WFBR
EXPERIMENTS

PULPING

AFTER 48 HOURS
EXPERIMENTS
PULPING
AFTER 48 HOURS

WATER

ACETONE
EXPERIMENTS

PROCESS

RESULT: CELLULOSE INCLUSIONS IN MATERIAL MIX

PROBLEMS WITH EXTRUSION
- MIXING CELLULOSE WITH LIGNIN IN NEARLY DRY STATE

EXPERIMENTS

PROCESS

Use scale to take needed amount of demi water in laboratory beaker

Use scale to take needed amount of acetone in laboratory beaker

Cutting cellulose chips

Take needed amount of chips

Use the shredder to create cellulose fibers

Take scale and determine needed amount of cellulose fibers and put it in a laboratory beaker

Take scale and determine needed amount of lignin and put it in a petri dish

Adding Lignin to cellulose fibers

Mix the shredded fibers and lignin with the needed amount of water

Add the needed amount of acetone to the mix

Mix the materials with a mixer

Shake mix in petri dish

Put little amount of mix in a syringe of 20 ml

Try to extrude the material from the syringe

Cot test with the drilled and extruded material
EXPERIMENTS

PROCESS

- MIXING CELLULOSE WITH LIGNIN IN NEARLY DRY STATE

Use scale to take needed amount of demi water in laboratory beaker

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Take scale and determine needed amount of lignin and put it in a petri dish

Adding Lignin to cellulose fibers

Mix the shredded fibers and lignin with the needed amount of water

Add the needed amount of acetone to the mix

Mix the materials with a mixer

Shape mix in petri dish

Put little amount of mix in a syringe of 20 ml

Try to extrude the material from the syringe

Dry tests with the extruded and extruded material

A.M THEORY RESEARCH QUESTION WOOD THEORY EXPERIMENTS PROTOTYPE PHASE APPLICATIONS CONCLUSIONS
**EXPERIMENTS**

**PROCESS**

- **MIXING CELLULOSE WITH LIGNIN IN NEARLY DRY STATE**
  - Use scale to take needed amount of demi water in laboratory beaker
  - Use scale to take needed amount of acetone in laboratory beaker
  - Cutting cellulose chips
  - Take needed amount of chips
  - Use the shredder to create cellulose fibers
  - Take scale and determine needed amount of cellulose fibers and put it in a laboratory beaker
  - Take scale and determine needed amount of lignin and put it in a petri dish
  - Adding Lignin to cellulose fibers
  - Mix the shredded fibers and lignin with the needed amount of water
  - Add the needed amount of acetone to the mix
  - Mix the materials with a mixer
  - Shape mix in petri dish
  - Put little amount of mix in a syringe of 20 ml
  - Try to extrude the material from the syringe
  - Dry tests with the extruded and extruded material

- **DRY MIX COMBINED WITH ACETONE WATER SOLUTION**
### EXPERIMENTS

#### MATERIAL SAMPLES

<table>
<thead>
<tr>
<th>Sample</th>
<th>Lignin</th>
<th>Cellulose</th>
<th>Cellulose</th>
<th>Fluid</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20 gr</td>
<td>5 gr</td>
<td>20%</td>
<td>80 gr</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20/80 (h2o/acetone)</td>
</tr>
<tr>
<td>2</td>
<td>5 gr</td>
<td>7.5 gr</td>
<td>60%</td>
<td>75 gr</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20/80 (h2o/acetone)</td>
</tr>
<tr>
<td>3</td>
<td>10 gr</td>
<td>2.5 gr</td>
<td>20%</td>
<td>75 gr</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20/80 (h2o/acetone)</td>
</tr>
<tr>
<td>4</td>
<td>7.5 gr</td>
<td>5 gr</td>
<td>40%</td>
<td>75 gr</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20/80 (h2o/acetone)</td>
</tr>
<tr>
<td>5</td>
<td>11 gr</td>
<td>1 gr</td>
<td>8.3%</td>
<td>75 gr</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20/80 (h2o/acetone)</td>
</tr>
</tbody>
</table>
EXPERIMENTS
MATERIAL SAMPLES

Sample 1
Lignin 20 gr
Cellulose 5 gr
Cellulose 20%
Fluid 80 gr
20/80 (H2O/acetone)
- TOO MUCH FLUID
- NON HOMOGENEOUS

Sample 2
Lignin 5 gr
Cellulose 7.5 gr
Cellulose 60%
Fluid 75 gr
20/80 (H2O/acetone)
- LOW ADHESIVE STRENGTH
- NOT EXTRUDABLE

Sample 3
Lignin 10 gr
Cellulose 2.5 gr
Cellulose 20%
Fluid 75 gr
20/80 (H2O/acetone)

Sample 4
Lignin 7.5 gr
Cellulose 5 gr
Cellulose 40%
Fluid 75 gr
20/80 (H2O/acetone)

Sample 5
Lignin 11 gr
Cellulose 1 gr
Cellulose 8.3%
Fluid 75 gr
20/80 (H2O/acetone)
EXPERIMENTS

MATERIAL SAMPLES

Sample 6
Lignin 10 gr
Cellulose 0 gr

Fluid 10 gr
0/100 (H2O/acetone)
## EXPERIMENTS

### MATERIAL SAMPLES

<table>
<thead>
<tr>
<th>Sample</th>
<th>Lignin</th>
<th>Cellulose</th>
<th>Fluid</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>40 gr</td>
<td>1 gr</td>
<td>60 gr</td>
<td>66,6/33,3 (w2o/acetone)</td>
</tr>
<tr>
<td>8</td>
<td>40 gr</td>
<td>3 gr</td>
<td>60 gr</td>
<td>66,6/33,3 (w2o/acetone)</td>
</tr>
<tr>
<td>9</td>
<td>40 gr</td>
<td>4 gr</td>
<td>42 gr</td>
<td>61,9/38,1 (w2o/acetone)</td>
</tr>
<tr>
<td>10</td>
<td>40 gr</td>
<td>5 gr</td>
<td>46 gr</td>
<td>43,5/56,5 (w2o/acetone)</td>
</tr>
<tr>
<td>11</td>
<td>40 gr</td>
<td>10 gr</td>
<td>75 gr</td>
<td>60/40 (w2o/acetone)</td>
</tr>
</tbody>
</table>

- **Sample 7**: Lignin 40 gr, Cellulose 1 gr, Cellulose 2.4%
- **Sample 8**: Lignin 40 gr, Cellulose 3 gr, Cellulose 6.98%
- **Sample 9**: Lignin 40 gr, Cellulose 4 gr, Cellulose 9.09%
- **Sample 10**: Lignin 40 gr, Cellulose 5 gr, Cellulose 11.1%
- **Sample 11**: Lignin 40 gr, Cellulose 10 gr, Cellulose 20%
EXPERIMENTS

MATERIAL SAMPLES

- IMPROVED HOMOGENEITY
- FIRST EXTRUDED SAMPLES WITH GOOD RESULT
- LIGNIN USED AS MEDIUM FOR EXTRUSION

Sample 7  
Lignin 40 gr  
Cellulose 1 gr  
Cellulose 2.4%  
Fluid 60 gr  
66.6/33.3 (h2o/acetone)

Sample 8  
Lignin 40 gr  
Cellulose 3 gr  
Cellulose 6.98%  
Fluid 60 gr  
66.6/33.3 (h2o/acetone)

Sample 9  
Lignin 40 gr  
Cellulose 4 gr  
Cellulose 9.09%  
Fluid 42 gr  
61.9/38.1 (h2o/acetone)

Sample 10  
Lignin 40 gr  
Cellulose 5 gr  
Cellulose 11.1%  
Fluid 46 gr  
43.5/56.5 (h2o/acetone)

Sample 11  
Lignin 40 gr  
Cellulose 10 gr  
Cellulose 20%  
Fluid 75 gr  
60/40 (h2o/acetone)
EXPERIMENTS

MATERIAL SAMPLES

Sample 12
Lignin 10 gr
Cellulose 2,5 gr
Cellulose 20%
Fluid 15 gr
33,3/66,6 (h2o/acetone)

Sample 13
Lignin 10 gr
Cellulose 2 gr
Cellulose 16,67%
Fluid 6,5 gr
23,1/76,9 (h2o/acetone)

Sample 14
Lignin 8 gr
Cellulose 4 gr
Cellulose 33,33%
Fluid 19 gr
31,6/68,4 (h2o/acetone)

Sample 15
Lignin 10 gr
Cellulose 4 gr
Cellulose 28,57%
Fluid 21 gr
28,6/71,4 (h2o/acetone)

Sample 16
Lignin 160 gr
Cellulose 12,5 gr
Cellulose 7,25%
Fluid 86 gr
46,5/53,5 (h2o/acetone)
EXPERIMENTS

MATERIAL SAMPLES

Sample 12
Lignin 10 gr
Cellulose 2,5 gr
Cellulose 20%
Fluid 15 gr
33,3/66,6 (h2o/acetone)

Sample 13
Lignin 10 gr
Cellulose 2 gr
Cellulose 16,67%
Fluid 6,5 gr
23,1/76,9 (h2o/acetone)

Sample 14
Lignin 8 gr
Cellulose 4 gr
Cellulose 33,33%
Fluid 19 gr
31,6/68,4 (h2o/acetone)

Sample 15
Lignin 10 gr
Cellulose 4 gr
Cellulose 28,57%
Fluid 21 gr
28,6/71,4 (h2o/acetone)

Sample 16
Lignin 160 gr
Cellulose 12,5 gr
Cellulose 7,25%
Fluid 86 gr
46,5/53,5 (h2o/acetone)

- TOO MUCH CELLULOSE RESULTED IN EXTRUSION PROBLEMS
- TOOLS NEEDED IN ORDER TO EXTRUDE SAMPLES
# Experiments

## Material Samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>Lignin</th>
<th>Cellulose</th>
<th>Fluid</th>
<th>Cellulose %</th>
<th>H₂O/Acetone</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>40 gr</td>
<td>5 gr</td>
<td>27 gr</td>
<td>11.1%</td>
<td>18.52/81.5</td>
</tr>
<tr>
<td>18</td>
<td>40 gr</td>
<td>5 gr</td>
<td>36 gr</td>
<td>11.1%</td>
<td>27.8/72.2</td>
</tr>
<tr>
<td>19</td>
<td>40 gr</td>
<td>5 gr</td>
<td>32 gr</td>
<td>11.1%</td>
<td>31.2/68.8</td>
</tr>
<tr>
<td>20</td>
<td>60 gr</td>
<td>5 gr</td>
<td>38 gr</td>
<td>7.69%</td>
<td>26.3/73.7</td>
</tr>
</tbody>
</table>
EXPERIMENTS

MATERIAL SAMPLES

- LESS CELLULOSE RESULTED IN BETTER EXTRUSION QUALITY (surface quality)
- AMOUNT OF FLUID DETERMINES STRENGTH (less fluid > higher strength = more extrusion problems)
- CELLULOSE COUNTERACTS BRITTLENESS OF LIGNIN
EXPERIMENTS

MATERIAL SAMPLES
EXPERIMENTS

MATERIAL SAMPLES
EXPERIMENTS

MATERIAL SAMPLES FOR PRINTING

Sample 9
Lignin  40 gr
Cellulose 4 gr
Cellulose 9,09%

Fluid  42 gr
61,9/38,1 (H2O/acetone)

Sample 10
Lignin  40 gr
Cellulose 5 gr
Cellulose 11,1%

Fluid  46 gr
43,5/56,5 (H2O/acetone)

Sample 11
Lignin  40 gr
Cellulose 10 gr
Cellulose 20%

Fluid  75 gr
60/40 (H2O/acetone)

Sample 16
Lignin 160 gr
Cellulose 12,5 gr
Cellulose 7,25%

Fluid  86 gr
46,5/53,5 (H2O/acetone)

Sample 20
Lignin  60 gr
Cellulose 5 gr
Cellulose 7,69%

Fluid  38 gr
26,3/73,7 (H2O/acetone)
PROTOTYPE PHASE
Material
Sample 20
Lignin 60 gr
Cellulose 5 gr
Cellulose 7,69%

Fluid 38 gr
26,3/73,7 (h2o/acetone)

Layer height = 2 mm
Shell thickness = 3 mm
Print speed = 5mm/s
Printing temperature = 0 degrees
Support type = none
Platform adhesion type = none
Filament diameter = 29 mm (inner diameter syringe)
Flow = 800%
Nozzle size = 1,6 mm

Layer height = 0,2 mm
Shell thickness = 3 mm
Print speed = 5mm/s
Printing temperature = 0 degrees
Support type = none
Platform adhesion type = none
Filament diameter = 29 mm (inner diameter syringe)
Flow = 200%
Nozzle size = 1,6 mm

Layer height = 0,5 mm
Shell thickness = 3 mm
Prints peed = 5mm/s
Printing temperature = 0 degrees
Support type = none
Platform adhesion type = none
Filament diameter = 29 mm (inner diameter syringe)
Flow = 500%
Nozzle size = 1,6 mm

Layer height = 0,5 mm
Shell thickness = 3 mm
Prints peed = 5mm/s
Printing temperature = 0 degrees
Support type = none
Platform adhesion type = none
Filament diameter = 29 mm (inner diameter syringe)
Flow = 500%
Nozzle size = 1,6 mm
PRINTER BROKE DOWN

PRINTER NOT SUITABLE FOR EXTRUDING MATERIAL

MECHANICAL SYSTEM NEEDED TO EXTRUDE THE MATERIAL
PROTOTYPE PHASE

THE SOLUTION
APPLICATIONS
APPLICATIONS

WHO WANTS THIS?
APPLICATIONS

WHO WANTS THIS?

WHAT CAN BE DONE WITH THIS?
APPLICATIONS

WILL IT BE USED TO PRINT A TREE?
APPLICATIONS

WILL IT BE USED TO PRINT BEAMS?
APPLICATIONS
APPLICATIONS
APPLICATIONS
APPLICATIONS
APPLICATIONS

LESS ASSEMBLY
HIGH CUSTOMIZATION
GEOMETRIC OPTIMIZATION
MATERIAL ECONOMY
RECYCLING POTENTIAL
APPLICATIONS

LESS ASSEMBLY
HIGH CUSTOMIZATION
GEOMETRIC OPTIMIZATION
MATERIAL ECONOMY
RECYCLING POTENTIAL

COMPLEX SHAPED OBJECTS
REPLACEMENT PARTS FOR WINDOWFRAMES
FURNITURE
TOYS

EXTRUDE PANELS
EXTRUDED PROFILES (HOLLOW)
CONCLUSION
CONCLUSION

CAN WOOD BE USED IN AN ADDITIVE MANUFACTURING PROCESS?
CONCLUSION

BACKGROUND QUESTIONS
WHAT IS WOOD AND WHAT ARE THE PROPERTIES OF WOOD AND ITS COMPONENTS?
HOW CAN THE COMPONENTS OF WOOD BE COMBINED IN A PRINTABLE MATERIAL?
CONCLUSION

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WHAT IS WOOD AND WHAT ARE THE PROPERTIES OF WOOD AND ITS COMPONENTS?
CONCLUSION

CAN WOOD BE USED IN AN ADDITIVE MANUFACTURING PROCESS?

RESOURCES OF RAW MATERIAL
MORE TESTS NEEDED WITH 3D PRINTER
MORE TESTS WITH DIFFERENT PRINT PARAMETERS
STRENGTH OF MATERIAL SHOULD BE TESTED
DIFFERENT FIBER LENGTHS SHOULD BE TESTED
MORE RESEARCH IS NEEDED ON THE ESTHETICS OF THE MATERIAL
THANK YOU