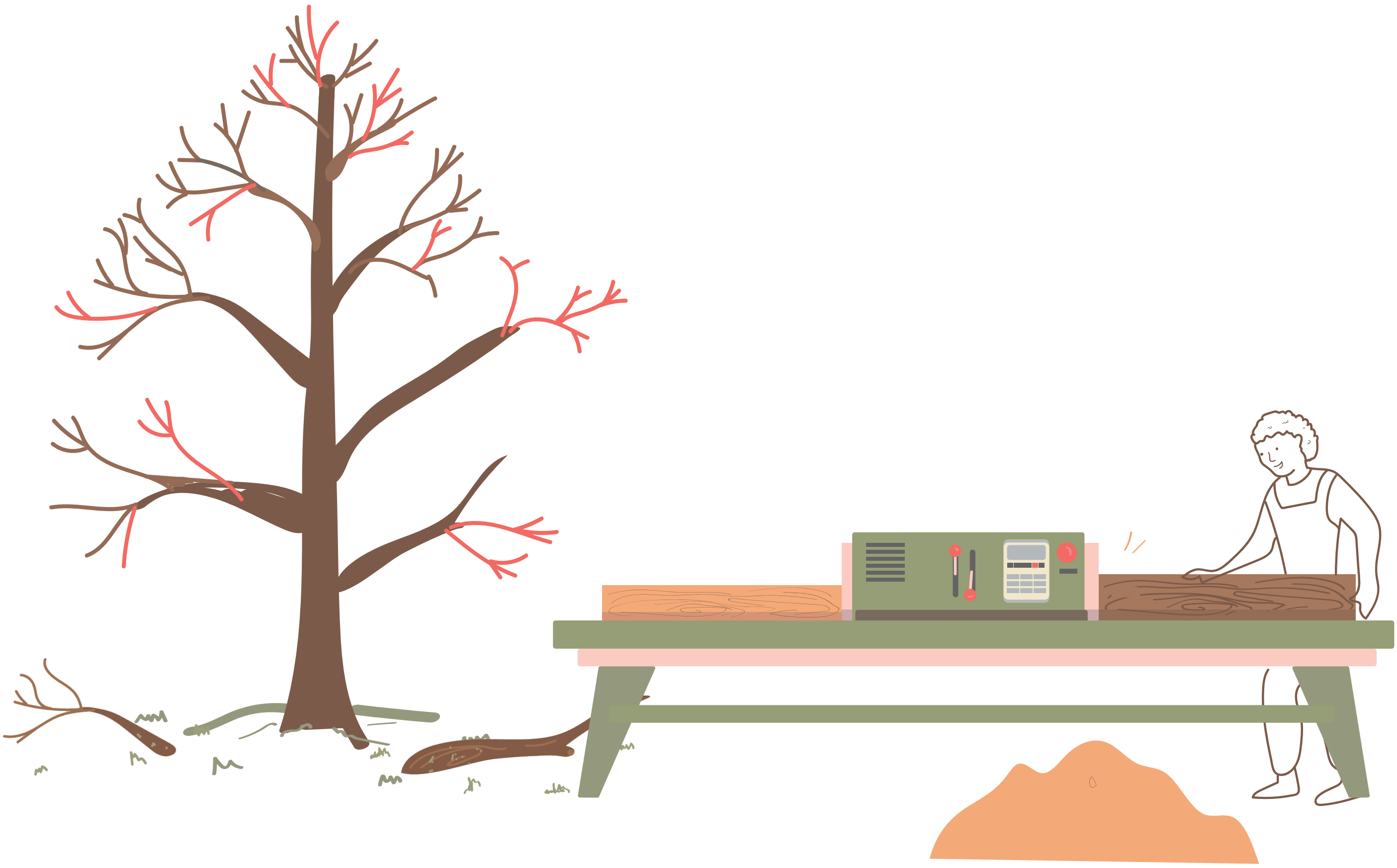
URWOOD

Towards value-added repair in Utrecht Region
with WOOD composite materials

Transforming wood waste into material composites
Material Development, Fabrication Processes, and Characterization



TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

WAGENINGEN UNIVERSITY & RESEARCH

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Contents

INTRODUCTION

The URWOOD project explores how wood waste from local urban and workshop environments can be transformed into valuable bio-composite materials that support circular and repair-focused practices in the Utrecht region. With a growing need for sustainable alternatives to synthetic fillers and virgin wood products, this work focuses on developing composites derived entirely from waste wood particles and natural binders. By examining wood from multiple waste streams such as bark, shavings, and chips and testing biobased polymer systems including cellulose derivatives and alginate, the project seeks to unlock new opportunities for ecological repair, material reuse, and low-impact fabrication.

This report guides the reader through the complete process of developing these materials, beginning with wood waste collection and particle refinement through milling and sieving. It then details the exploratory making phase, initial benchmarking against commercial fillers, and the iterative optimization of binder-to-filler ratios for improved performance and manufacturability. Finally, the report presents comprehensive material characterisation including sensorial, technical, and process-based assessments to evaluate the mechanical viability and application potential of the resulting bio-composites. Together, these chapters provide an integrated account of how waste wood can be repurposed into functional materials suitable for digital fabrication, repair applications, and future circular material systems.

Material Processing

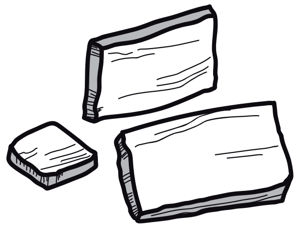
Step 1 Collecting	Step 2 Binders	Step 3 Milling	Step 4 Sieving
connecting with local partners to gather wood waste	sustainbility analysis of biobased binders	finding the right tools to convert wood into dust	isolating particle sizes and analyzing their function

Step 1

Collecting

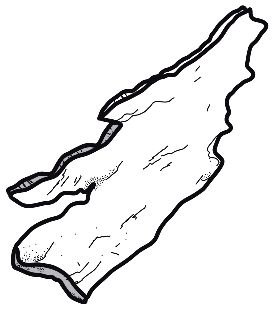
Waste wood was collected from four streams: wood workshops, pet stores, and from trees. Shavings were the most accessible waste material to obtain in high quantities while wood flour is the least accessible.

Wood flour
- ideal for additive manufaturing
- low-volume supply
- Douglas wood flour was collected as waste from Hout van Haar, Eindhoven.
- obtained through sanding



Wood chips
- dense, fibrous
- Often used for pulp
- 6mm Beechwood chips was purchased as bodembedekker from petstores

Mixed / Pure Shavings
- light-weight, fibrous
- high-volume supply
- a mix of douglas and ash wood shavings were collected from Stichting Bouwloods, Utrecht.
- Obtained from mechanical planing of wood planks
- a mix of woodshavings from MDF waste was collected from Uit Buurtfabriek, Eindhoven.

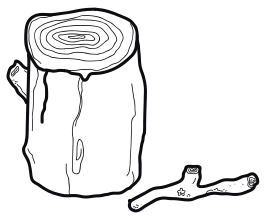


Plane Tree bark
- lightweight, brittle
- naturally dry in comparison to branches
- can be easily milled into powder
- high tannin and resin content
- Plane trees are commonly planted in Dutch cities, and often shed their barks during summer time.
- Abundant in TU/e campus and parks

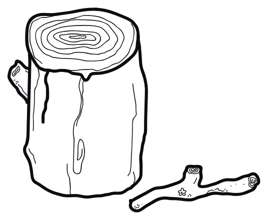
Step 2

Binders

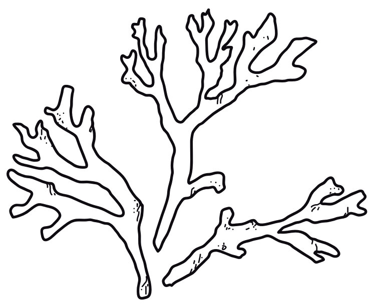
These binders are selected for their renewable origin, low ecological impact, and favourable rheological properties. Each supports the development of a material that is biodegradable, safe to handle, and functionally stable in combination with natural fibers and powders.



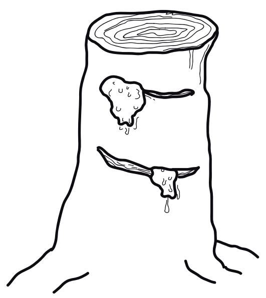
Carboxymethylcellulose
- derived from chemically modifying cellulose from agricultural or forest residues such as wheat straw or sawdust.
- can be sourced from waste biomass
- CMC is fully biodegradable and non-toxic (Rinaudo, 2008)



Methyl cellulose
- produced through methylation of cellulose in an alkaline medium.
- MC is water soluble and compostable.
- It gels when heated and reverts to a liquid when cooled. This reversible behaviour helps maintain shape during processing and drying.
- Its viscosity can be tuned to optimize flow or firmness depending on the application (Dai et al., 2019).



Sodium Alginate
- SA is extracted from brown seaweeds, which grow without the need for fresh water, fertilizers, or agricultural land. This gives it one of the lowest environmental footprints among natural binders (Peteiro, 2018).
- It forms viscous solutions and exhibits shear thinning, which allows it to flow easily during processing but provide structure after application. These properties make it ideal for suspending solids in bio based pastes (Xie et al., 2024).
- SA is biodegradable in both terrestrial and marine environments.



Xanthan Gum
- produced through microbial fermentation of sugars and can be derived from industrial side streams (SOURCE).
- It is biodegradable, safe for users and ecosystems, and highly effective in small amounts.
- XG provides strong viscosity and shear thinning, allowing materials to flow under force but resist slumping when at rest.
- Its branched structure entangles with cellulose and other binders, reinforcing cohesion in complex mixtures (Rinaudo, 2008).

Step 3

MILLING

To process the wood shavings into smaller particle sizes, several milling techniques were used.

ELECTRIC BLADE GRINDER

A coffee grinder was used as a low-cost and accessible tool for initial wood dust processing. The grinder allows for approximately 60 grams of wood input per batch and is capable of quickly reducing small wood chips or shavings into a coarse powder. While it does not achieve very fine particle sizes suitable for paste formulations (size measurements need to be input) or wood flour applications, it offers a simple way to test grinding behavior and collect small amounts of wood dust for prototyping or formulation testing. Notably, the grinder is very effective when used with bark, which breaks down more easily and produces finer, more consistent particles compared to solid wood. Despite its limitations, the grinder offers a simple and effective way to begin working with wood-based biomaterials.

CERAMIC BURR GRINDER

A handheld coffee grinder was tested for producing fine wood particles, with mixed results depending on the type of material used. While the tool is accessible, compact, and does not require electricity, it proved difficult to use for grinding wood. Wood's hardness and fibrous structure make it challenging for the grinder's teeth to process efficiently. The result is often uneven particles, and significant physical effort for only a small yield. Just like the electric grinder, the hand grinder had better results when used with bark. Softer and more brittle materials, such as dried bark, broke down more easily and produced finer, more uniform particles.

CAST-IRON GRAIN GRINDER

A grain grinder was tested as a potential option for producing fine wood flour, but it was not effective enough for researching the desired particle size. The input material had a particle size ranging from 1000-3000 microns. While the grain grinder did manage to break down wood into smaller chips, the output remained largely in the 1000-1500 microns. To obtain even a small amount of usable wood dust extensive sieving was still necessary. After sieving an output of 400g of wood, we were able to filter only 5g of fine particles, which had a size of 250 microns. Overall the grain grinder did not provide sufficient results for creating wood flour, even though the grinding time just takes 5-10 seconds, the output is not ideal nor uniform.

BEAD MILLING

Two types of bead milling machines were used: a cryogenic bead mill and a standard bead mill available at Wageningen University and Research. Both machines produced wood particles with sizes ranging from 144 to 154 microns. Although the desired particle size was achieved, the process was time-consuming. The cryogenic mill produced approximately 25 grams of wood dust in 30 minutes, while the standard bead mill yielded around 100 grams in one hour. This makes the method less suitable for producing large batches of wood dust.

PARTICLE SIZE

To determine which processes and applications yield the best results, it is important to test different particle sizes. Particle size directly influences a material's mechanical performance, aesthetic qualities, and processability across various fabrication techniques. Smaller particles tend to produce more homogeneous mixtures, which can improve consistency, reduce defects, and create smoother surfaces in the final product. This can be beneficial for applications where visual quality or uniform strength is required. In contrast, larger particles can contribute to unique textures, reduced shrinkage during drying, and improved structural rigidity, which may be advantageous for certain functional or decorative purposes. As the wood used in this study was sourced from different places, post-processing through milling and sieving was necessary to achieve the same consistent and desired particle size.

PARTICLE SIZE COMPARISON

MILLING METHOD / MATERIAL	Blade grinder	Burr grinder	Bead mill	Cast-iron
Plane tree bark	500-250µm	500-250µm	not tested	1000-500µm
Beech wood chips	6mm	6mm	154-144µm	500µm
Mixed/Pure shavings	1000-500µm	1000-500µm	not tested	not tested

Above
Bead milling has finest particle size but lowest yield. Several pre-processing methods are yet to be explored. Industrial processing of fine wood dust would be beneficial for the material making process.

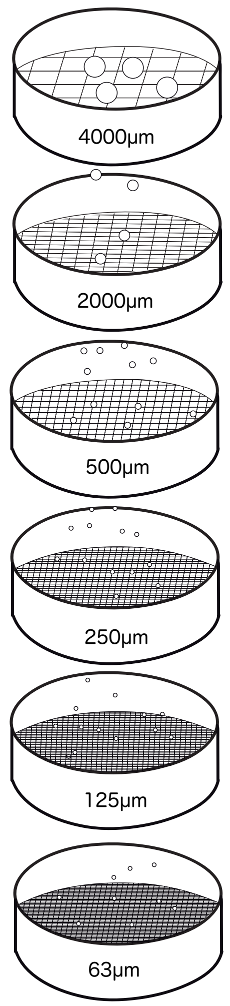
Step 4

SIEVING

Laboratory sieves are essential tools for separating wood dust into specific particle size ranges. Using sieves allows for the usage of particles of the desired size range to allow for repeatability as well as functionality.

SIEVING SIZE DISTRIBUTION

The sieves used range from 4000 microns (4mm) to 63 microns (0.063mm) and can be stacked on top of each other to progressively filter material from coarse to fine. Each sieve retains particles above its mesh size while allowing smaller particles to pass through to the next level. This stacking system makes it possible to isolate fractions of wood dust within a defined range.



4000µm to 2000µm
Offers heterogeneous composites.
Offers rough to porous textures.
Most accessible particle size.

500µm to 250µm
Offers porous textures.
Ideal for 3D paste printing using a Clay Printer and/or Zmorph.
Only accesible after pre-processing methods: milling and sieving.

125µm to 63 µm
Offers homogenous composites.
Offers smooth textures similar to clay. Ideal for 3D paste printing using Zmorph. But it is the least accessible particle size.

Above
Using a laboratory sieve, we were able to filter smaller particle sizes ranging from 4000 microns to 63 microns.

Left
Particle size analysis

Material Exploration

Overview of initial stages	Filler Development	Filler Developmemnt	Intital Conclusions
Exploratory making	Baseline Tests	Biobased Wood Fillers	Insights
Tinkering with materials and different binders	Understanding current solutions	Developing biodegradable and biobased fillers	

The first phase revealed a multifaceted relationship between material sourcing, processing constraints, and fabrication opportunities. Waste wood sourced from workshops, pet stores, and the urban environment varies significantly in accessibility and processing suitability. Shavings were found to be the most accessible in large volumes, whereas wood flour was the least available despite being ideal for additive manufacturing. Bark from trees emerged as a promising resource due to its natural dryness, brittleness, and abundance, making it easier to mill than dense or fibrous wood chips. This variation in feedstock underscores that while urban and workshop waste streams offer valuable pathways for circular material flows, they simultaneously introduce variability that must be managed through further processing.

Particle size emerged as one of the most influential factors affecting material behavior, directly shaping both mechanical performance and surface quality. Fine particles promote homogenized mixtures with smoother finishes and fewer defects, which is essential for applications such as additive manufacturing and paste-based 3D printing. Conversely, larger particles contribute structural integrity and unique textures but may cause increased porosity and reduced consistency. Systematic sieving was therefore required not only to sort materials but to enable repeatable and optimized fabrication outcomes across techniques such as FDM-style thermoplastic extrusion and LDM-style paste deposition.

The milling process exposed significant trade-offs between particle fineness, processing time, and yield. While bead milling achieved the most desirable fine particle range (144–154 microns), it proved highly time-consuming and produced low mass outputs, making it impractical for scaling. More accessible grinding tools like blade and burr grinders delivered mixed particle sizes and struggled with harder wood, while showing better efficiency with brittle bark. Achieving particles suitable for advanced manufacturing technologies required multiple grinding rounds and careful drying, reinforcing that higher refinement comes with rapidly diminishing returns.

Workshop-collected shavings often contained mixed dust and adhesive residues due to centralized vacuum systems, raising the need for improved sourcing protocols. Additionally, sieving fine particles required stringent ventilation and extremely dry conditions to ensure safe and functional handling. The project also revealed gaps in the processing of branches, not due to material unsuitability but because the team lacked reliable methods for drying them. These challenges highlight that circular resource use is not only a matter of material availability but also process compatibility and safety.

Ultimately, the research concludes that a particle size of around 250 microns offers the best compromise for both paste printing (LDM) and thermoplastic printing (FDM-style), balancing homogeneity, mechanical strength, yield, and accessibility of production. Mixed-particle formulations remain relevant where slight increases in porosity or reduction of warping are acceptable.

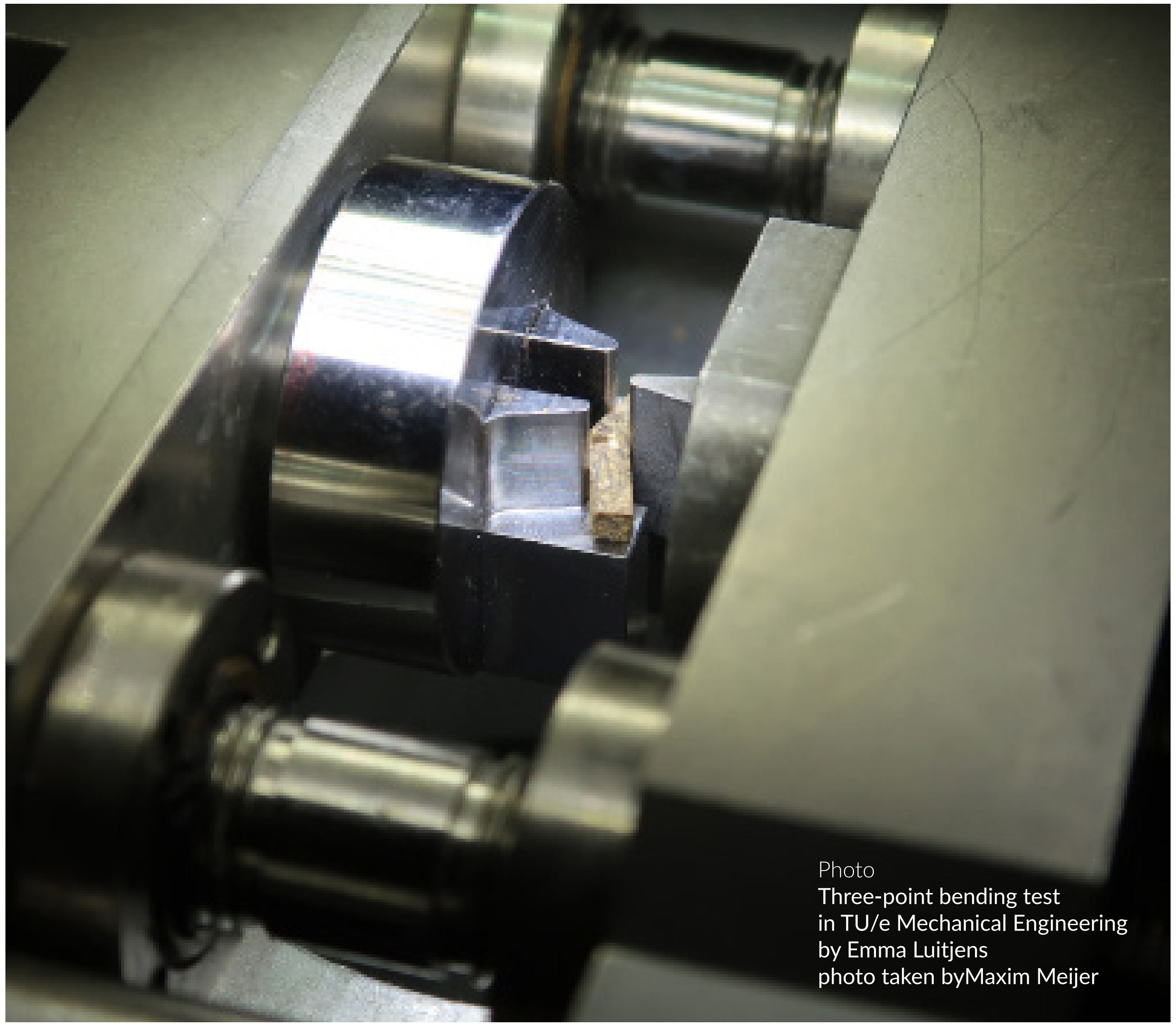
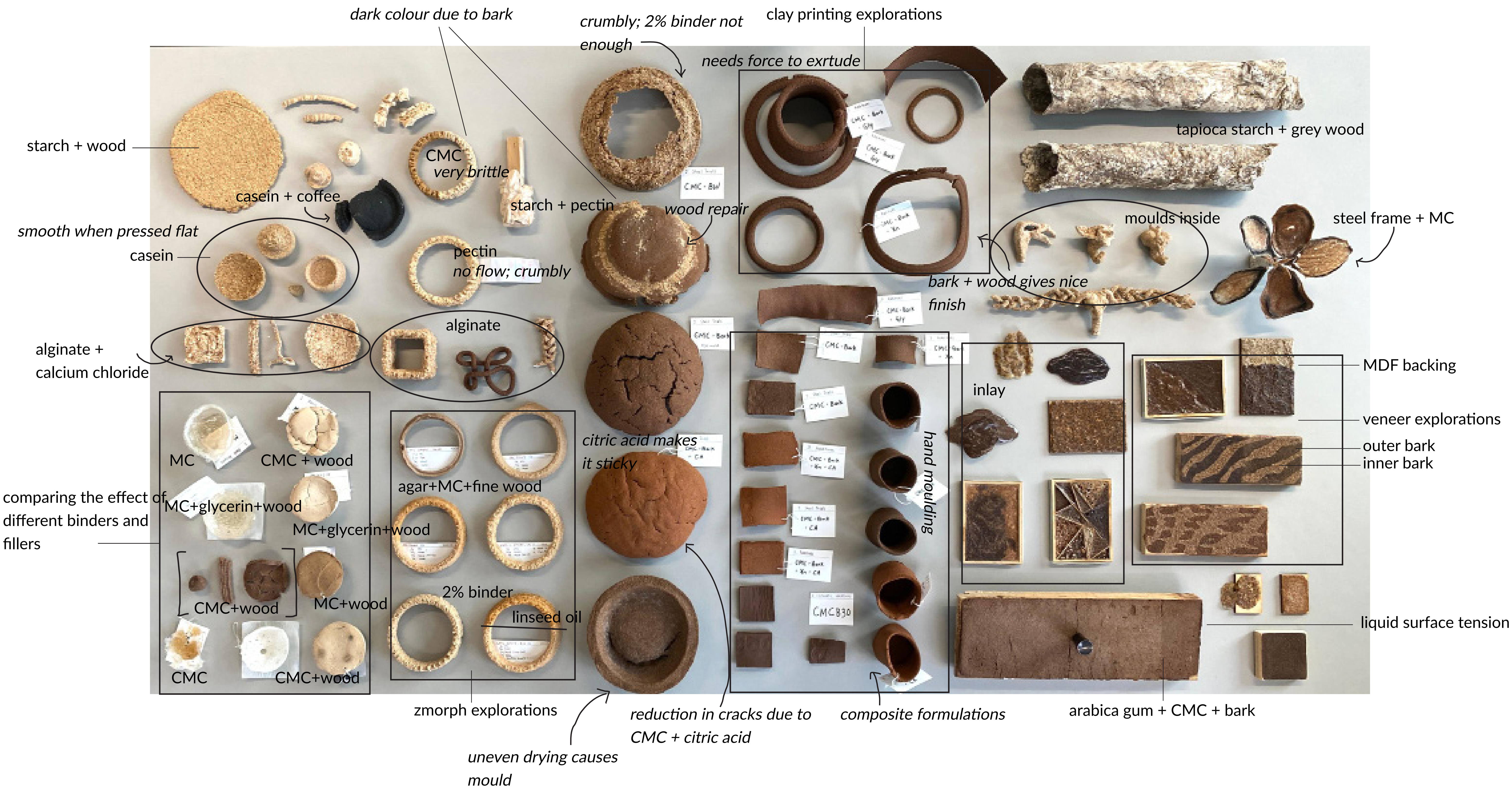


Photo
Three-point bending test
in TU/e Mechanical Engineering
by Emma Luitjens
photo taken byMaxim Meijer

Exploratory making

Overview of Initial stages



BASELINE TESTS FOR FILLER DEVELOPMENT

In many woodworking and repair applications, reference materials such as commercial wood glues or proprietary wood fillers are used to fill voids, repair cracks, or restore surfaces. Some woodworkers also prepare their own filler by combining fine wood dust (or chips) with a binder—commonly epoxy, PVA glue, or similar adhesives. The idea is to create a paste that cures hard, can be sanded, and bonds strongly to surrounding wood. In practice, popular "homemade" recipes often mix roughly one part wood component (dust or chips) with two parts binder (i.e. a 1:2 wood:binder ratio) by volume or mass, though actual proportions may vary.

To produce our own reference fillers, we have followed protocols distilled from woodworking sources: we mix wood dust and small wood chips with epoxy or conventional wood glue in a 1/3 wood component : 2/3 binder ratio. After thoroughly blending, we allow the mixture to cure under ambient room temperature conditions. Once fully set, the specimens are extracted and prepared for mechanical testing.

DESIRED PROPERTIES AND BENCHMARKS

An effective wood filler material should ideally exhibit a number of mechanical and physical characteristics, including:

- High flexural strength and modulus to resist bending deformation
- Strong adhesion to wood surfaces
- Low curing shrinkage
- Sufficient hardness for sanding and shaping,
- Dimensional stability against humidity fluctuations
- Compatibility with coatings and finishes.

From the literature, wood–epoxy composites typically exhibit flexural strengths between 60–120 MPa and moduli between 1–10 GPa, depending on filler content and particle–matrix adhesion (Guo et al., Composites Part B, 2022). Similarly, PVA-based (wood glue) composites generally perform an order of magnitude lower in stiffness and strength (Cai et al., Wood Handbook, USDA Forest Products Laboratory, 2010). These data provide a useful reference framework for assessing our own formulations.

RATIONALE FOR 3 POINT BENDING TESTS

To evaluate mechanical performance, a three-point bending (3PB) test was used. In this setup, a beam specimen is supported at two points while a load is applied at the midpoint, producing tension on the lower surface and compression on the upper. A load cell and displacement sensor record the force–deflection curve, allowing determination of flexural strength, strain at failure, and flexural modulus (stiffness).

The 3PB test is particularly suitable for wood fillers, as it simulates real bending stresses experienced in wood repairs—such as those in chair legs, table panels, or other load-bearing components. It is a simple, standardized method (e.g., ASTM D790) and allows direct comparison with wood and composite literature data.

SUMMARY OF EXPERIMENTAL RESULTS

The experimental results demonstrate clear differences between epoxy- and glue-based fillers (Table 1).

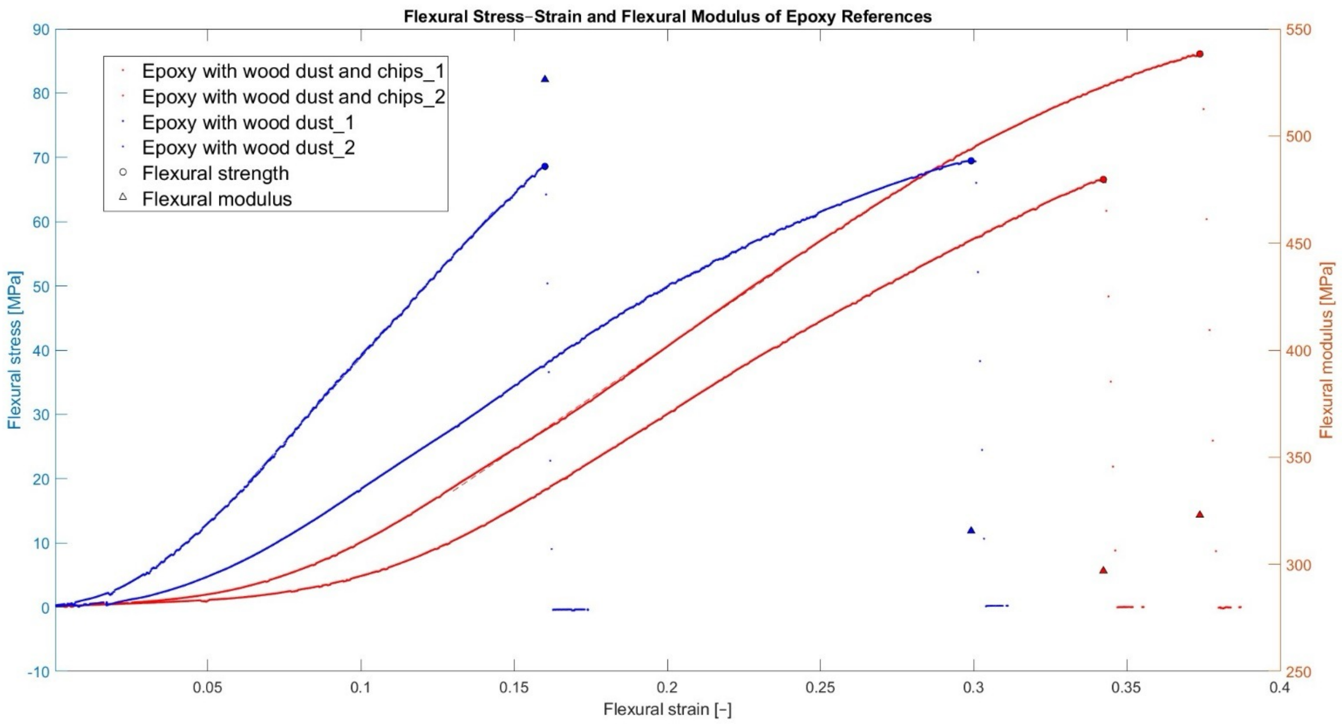
MATERIAL TYPE	FLEXURAL STRENGTH (MPa)	STRAIN AT FAILURE	FLEXURAL MODULUS (MPa)
Epoxy + Wood Dust	69.0 ± 0.4	0.23 ± 0.07	420 ± 105
Epoxy + Wood Dust & Chips	76.3 ± 9.7	0.36 ± 0.02	309 ± 13
Wood Glue + Dust	60.4	0.24	31.4
Wood Glue + Dust & Chips	19.0	0.74	55.0

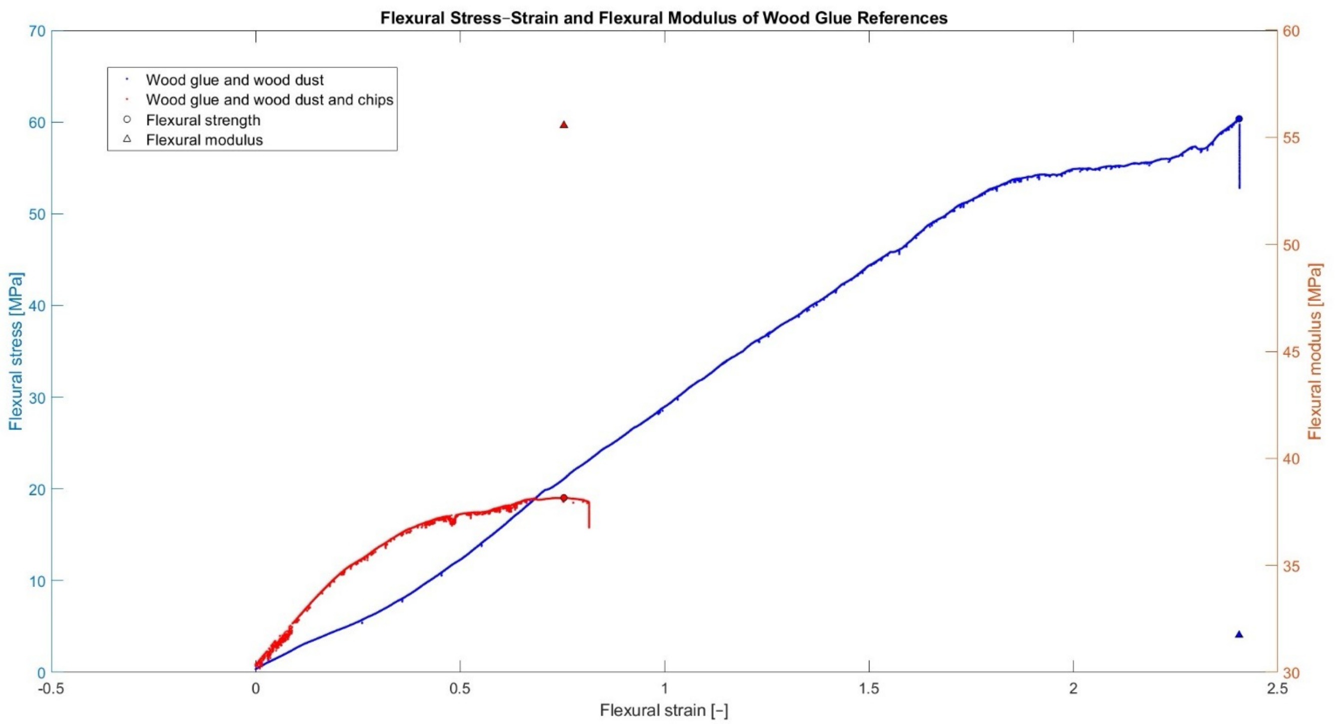
Table 1

Overall, the epoxy-based fillers exhibited substantially higher flexural strength and stiffness than the wood glue-based references, aligning with the known superior mechanical performance of epoxy polymers. Interestingly, the addition of wood chips alongside wood dust increased both the flexural strength and ductility for the epoxy system, while in the glue-based system, the chips decreased strength but increased strain at failure.

These findings suggest that epoxy binders provide a more robust and load-bearing filler material, suitable for structural repairs, whereas glue-based fillers may be more appropriate for non-load-bearing or aesthetic applications. Future work will focus on optimizing particle content and binder formulation to improve stiffness without sacrificing toughness or sustainability.

DEVELOPMENT OF WOOD FILLER IN BIOPOLYMER COMPOSITES





In pursuit of URWOOD's sustainability goals, a series of biobased and biodegradable binders were explored as potential alternatives to conventional epoxy or synthetic wood glue systems. The objective was to evaluate whether natural polymers—derived from renewable sources—could mimic or approach the mechanical performance of epoxy-based fillers while offering improved environmental compatibility.

Natural binders selected for initial trials included methyl cellulose (MC), carboxymethyl cellulose (CMC), sodium alginate (SA), starch, and casein. Each binder was combined with wood dust in various ratios, getting high contents of wood dust, but therefore not enerite ensuring comparability to the reference samples. Two recipes were tested with sodium alginate.

After curing under ambient conditions, all samples were subjected to three-point bending (3PB) tests to determine flexural strength, strain at failure, and flexural modulus. The results have been summarised in table 2.

BINDER TYPE	FLEXURAL STRENGTH (MPa)	STRAIN AT FAILURE	FLEXURAL MODULUS (MPa)
MC + Wood Dust	16.1	0.16	170
CMC + Wood Dust	39.6	0.23	298
SA + Wood Dust (1)	58.6	0.19	423
SA + Wood Dust (2)	3.1	0.16	42
Starch + Wood Dust	18.3	0.02	737
Casein + Wood Dust	9.23	1.36	12.5

Table 2

INTERPRETATION AND COMPARISION

The results reveal a wide performance range across the biobased systems, reflecting the differing chemistries and curing behaviors of each binder. Among the tested formulations, sodium alginate with wood dust achieved the highest flexural strength (58.6 MPa) and modulus (423 MPa), closely approaching the performance of epoxy-based fillers (69–76 MPa, 309–420 MPa). This makes sodium alginate the most promising candidate for further optimization, particularly since it is a natural polysaccharide derived from seaweed and is biodegradable.

CMC-based fillers also performed respectably, showing moderate strength (39.6 MPa) and stiffness (298 MPa), outperforming methyl cellulose, starch, and casein systems. This suggests that cellulose derivatives can provide sufficient bonding and cohesive strength, especially when properly hydrated and cured.

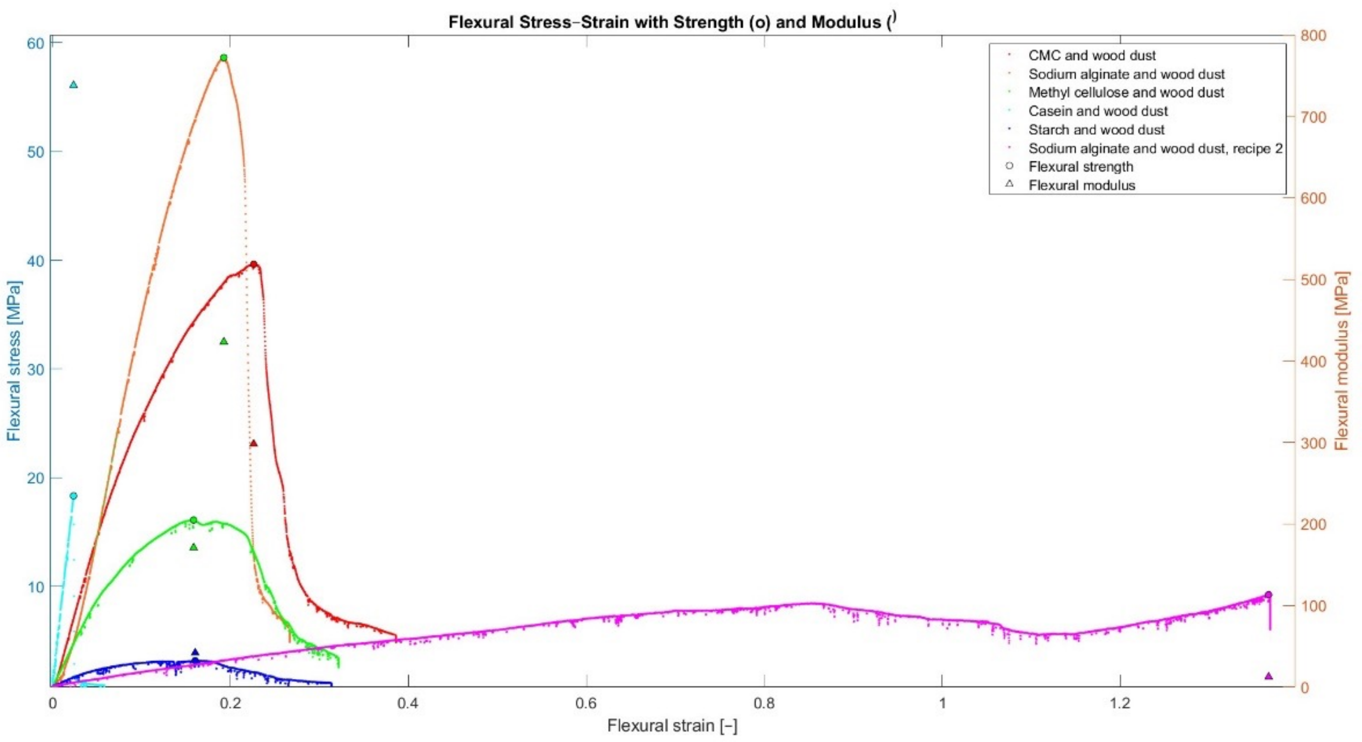
By contrast, methyl cellulose and casein exhibited lower strengths (<20 MPa), while the starch-based filler was notably weak (3.1 MPa), indicating limited suitability for structural repair. Interestingly, casein displayed an unusually high modulus (737 MPa) but an extremely low strain at failure (0.02), suggesting that it is brittle and prone to sudden fracture. The alternative sodium alginate "recipe 2" showed the opposite behavior, with a very low modulus (12.5 MPa) but an exceptionally high strain at failure (1.36), indicating a more ductile, rubber-like behavior but insufficient stiffness for load-bearing applications.

COMPARISION TO EPOXY AND WOOD GLUE

When benchmarked against the epoxy-based systems (69–76 MPa flexural strength; 309–420 MPa modulus), none of the biobased binders yet achieve equal mechanical strength, though sodium alginate comes closest. Compared to wood glue-based fillers (19–60 MPa; 31–55 MPa modulus), several natural binders—particularly sodium alginate and CMC—show comparable or superior stiffness and similar strain behavior, suggesting they could serve as viable alternatives for non-structural or semi-structural repairs.

OUTLOOK

Overall, sodium alginate and CMC emerge as the most promising sustainable binders within this preliminary screening. They balance mechanical strength, stiffness, and ductility reasonably well while being biobased, biodegradable, and non-toxic. Further optimization—such as tuning polymer concentration, drying conditions, and crosslinking—may further close the gap with epoxy performance. These results represent an encouraging step toward developing a fully sustainable, mechanically functional wood filler within the URWOOD project.



Recipe Optimization

A series of recipes are documented to analyze the variations of material composites. MC was investigated because it shows most potential for a wide-range of applications. The amount of water in all recipes remains consistent to 80g. Three recipes are prepared in the following sereis:

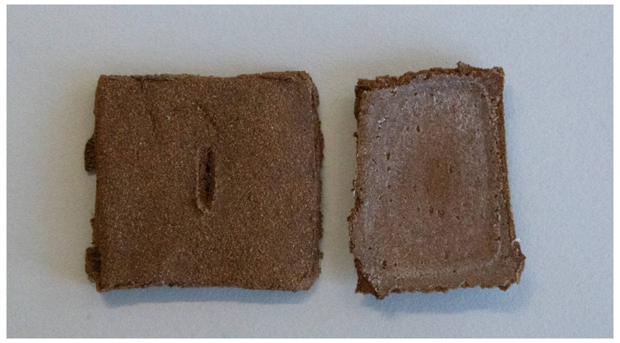
Binder Series	Bark Series	Mix Series	Wood Series
MC10B30	MC15B15	MC15B9W21	MC15W30
MC15B30	MC15B30	MC15B15W15	
MC25B30	MC15B45	MC15B21W9	

MC10B30

Volume	
Wet weight	10g
Dry weight	3.7g

Composition	
CMC	10g
Bark	30g
Water	80g

- Significant adhesion to surfaces and hands
- limited extrudability, notable rigid
- Readily mixable
- Challenging removal from molds post cutting due to adhesion

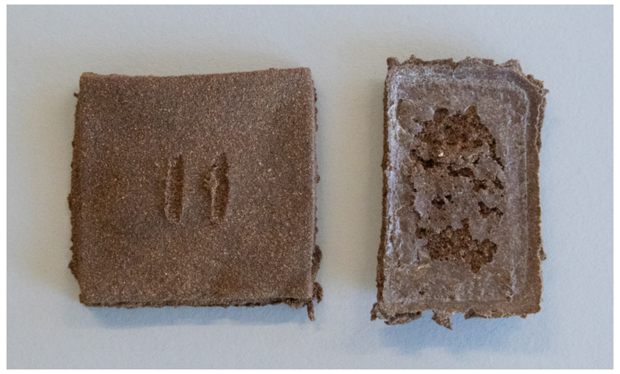


MC15B30

Volume	
Wet weight	10g
Dry weight	3.8g

Composition	
CMC	15g
Bark	30g
Water	80g

- reduced adhesion to surface
- Facilitates easy cutting due to diminished stickiness



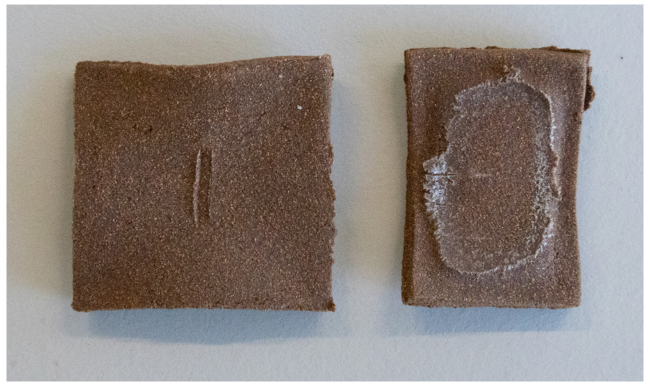
Binder Series

MC25B30

Volume	
Wet weight	10g
Dry weight	4.3g

Composition	
CMC	25g
Bark	30g
Water	80g

- Difficult to mix with minimal water content
- Exhibits a highly favorable clay-like surface texture
- Demonstrates resilience to fracturing during molding
- Putty formulation performs exceptionally well



Constant water and bark, varying amounts of CMC

Bark Series

MC15B15

Volume	
Wet weight	10g
Dry weight	2.8g

Composition	
CMC	15g
Bark	15g
Water	80g

- Consistemcy was liquid-y, difficult to manage with low workability
- Due to high water content, significant reduction in weight was noticed

MC15B45

Volume	
Wet weight	10g
Dry weight	4.4g

Composition	
CMC	15g
Bark	45g
Water	80g

- Less liquid-y, with significantly higher workability. Less reduction in weight noticed.

Constant water and CMC, varying amounts of bark

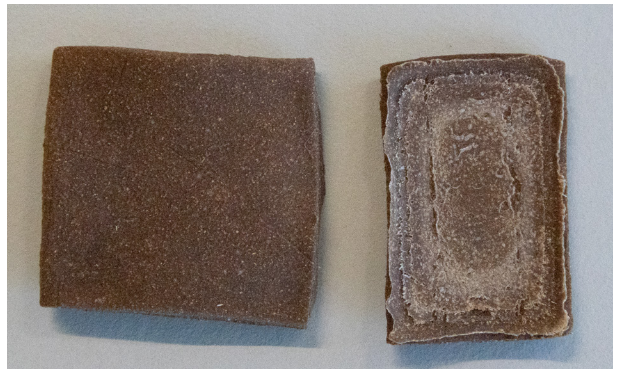
Mix Series

MC15B9W21

Volume	
Wet weight	10g
Dry weight	3.8g

Composition	
CMC	15g
Bark	9g
Wood	21g
Water	80g

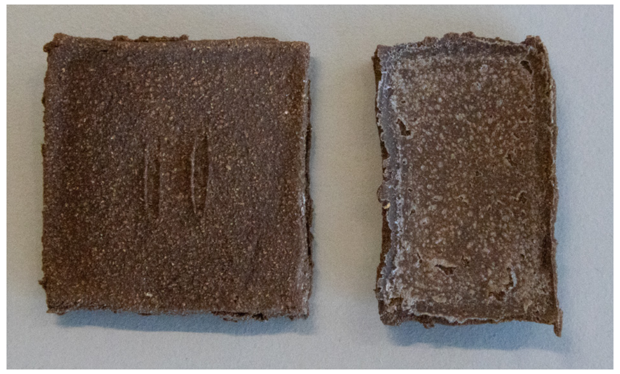
- very stiff dough
- very good balance of stickiness – stucky enough to hold together, while not affecting workability
- ideal for additive manufacturing



MC15B15W15

Volume	
Wet weight	10g
Dry weight	3.9g

Composition	
CMC	15g
Bark	15g
Wood	15g
Water	80g



Constant water and CMC, varying amounts of bark and wood

Mix Series

MC15B21W9

Volume	
Wet weight	10g
Dry weight	3.7g

Composition	
CMC	15g
Bark	21g
Wood	9g
Water	80g

- less stiff than MC15B9W21
- very good balance of stickiness – stucky enough to hold together, while not affecting workability
- ideal for additive manufacturing

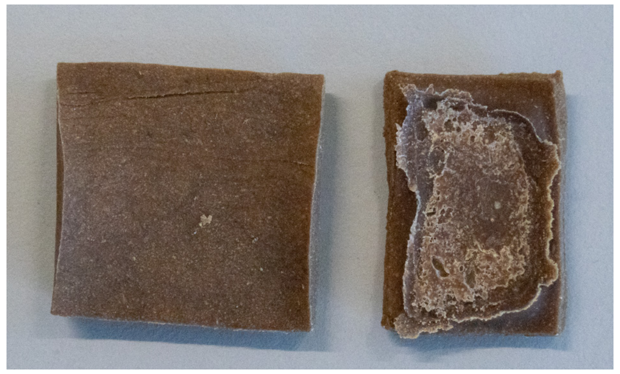
Wood Series

MC15W30

Volume	
Wet weight	10g
Dry weight	3.7g

Composition	
CMC	15g
Wood	30g
Water	80g

- Very difficult to mix the wet and dry ingredients.
- resutlingmixuture has high workability, being soft and mouldable.
- less fracturing due to elasticity



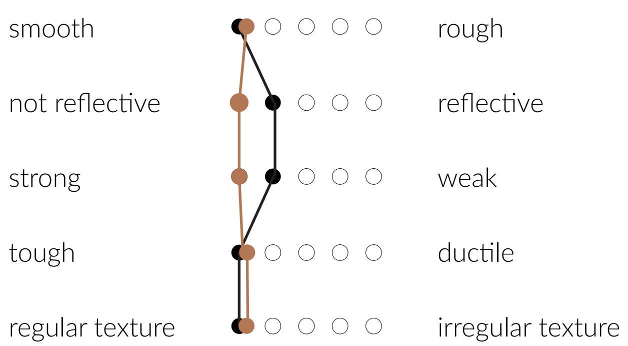
Material characterisation

Sensorial Characterisation	Process Characterisation	Technical Characterisation	Conclusions

Sensorial Characterization

Wood series

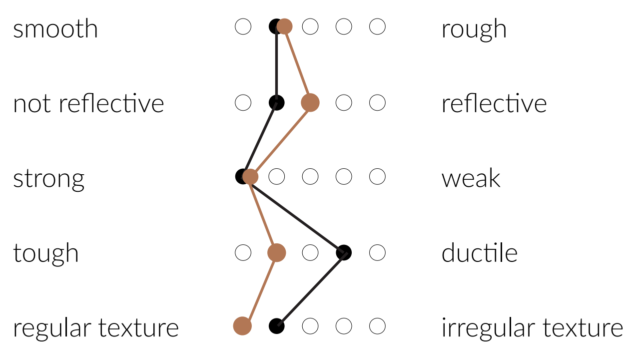
MC15W30



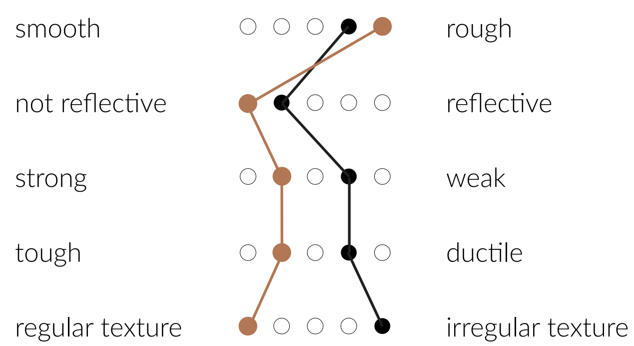
Sensorial Characterization

Mixed series

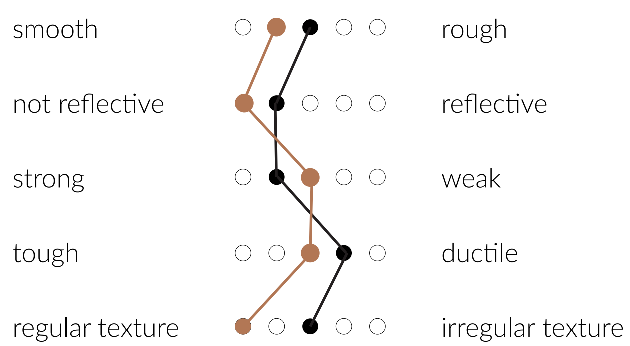
MC15B9W21



MC15B15W15

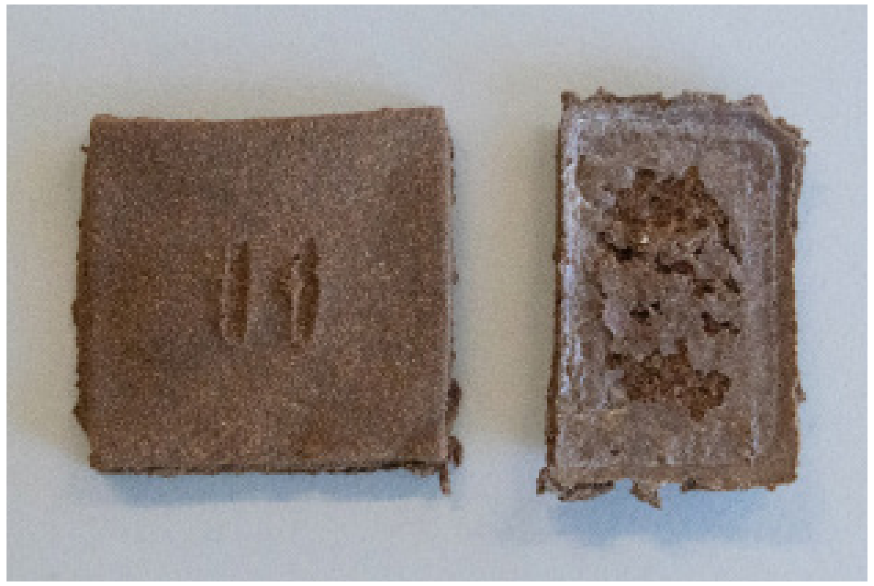


MC15B21W9

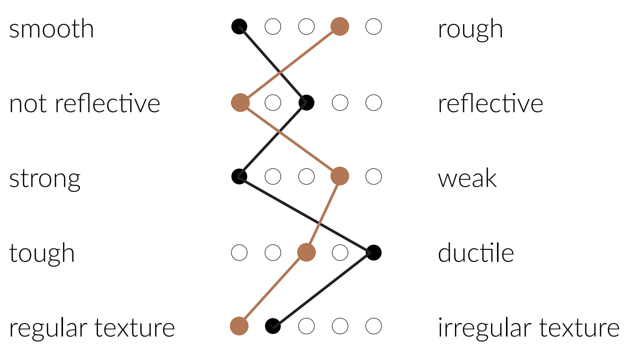


Sensorial Characterization

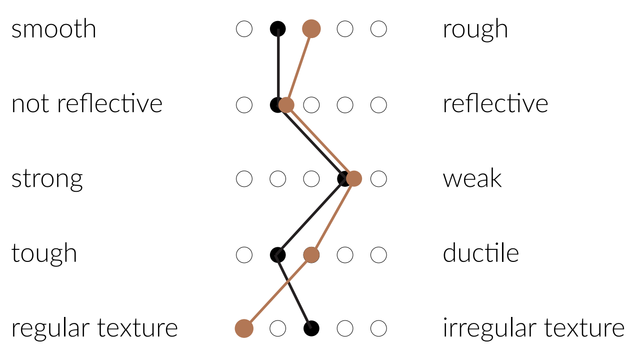
Bark series



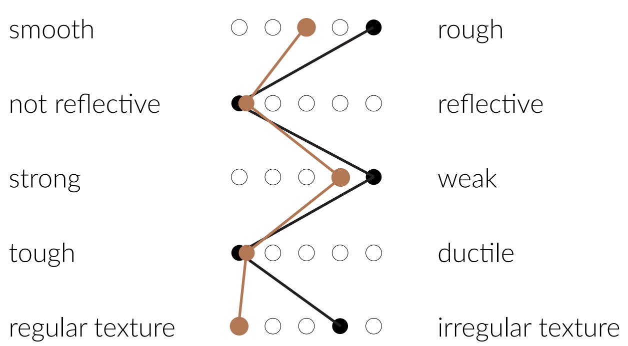
MC15B15



MC15B30



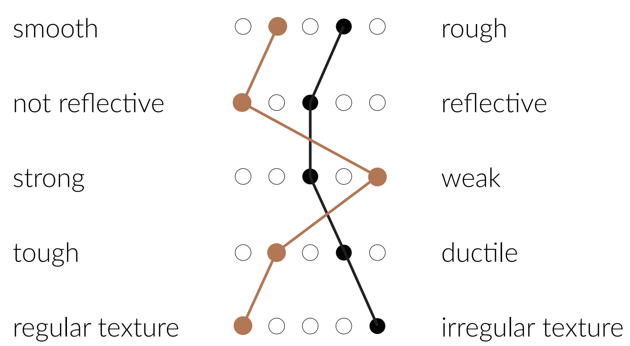
MC15B45



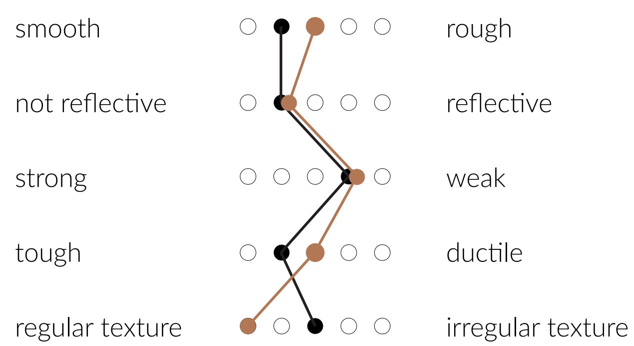
Sensorial Characterization

Binder series

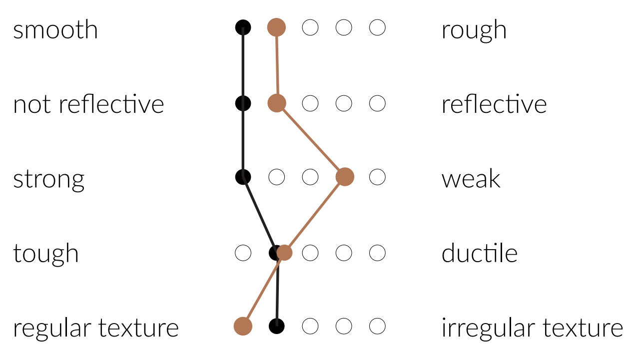
MC10B30



MC15B30



MC25B30



Process Characterization

Warping

WOOD SERIES

MC15W30

- Smaller particle size of wood in comparison to bark increased the warping.

MIX SERIES

MC15B9W21 MC15B15W15 MC15B21W9

- Due to the same amount of MC, all samples stuck to the plate evenly. Warping amounts noticed were similar. Small differences can be attributed to different particle sizes of wood and bark.

BARK SERIES

MC15B15 MC15B30 MC15B45

- MC15B10 was very liquid-y, resulting in extremely thin sheets. this caused more warping of the first sample.
- In MC15B30 and MC15B45 it was noticed that if the filler amount is changed, water must be adjusted. Water ratio influences warping, therefore the ratio should be application specific.

BINDER SERIES

MC10B30 MC15B30 MC2530

- Warping heavily depends on how the sample sticks to the plate. For MC10 the viscosity of the wet composite is lower and therefore the binder sinks to bottom, sticking better to the plate. This lead to lower warping
- As MC increases, warping increases, because MC is hydrophilic, so more water results in more warping.

**the beams are not the same size, weight, and shape.*

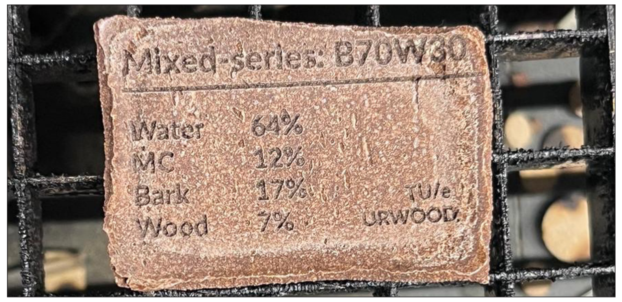
Finishing

SEAMS

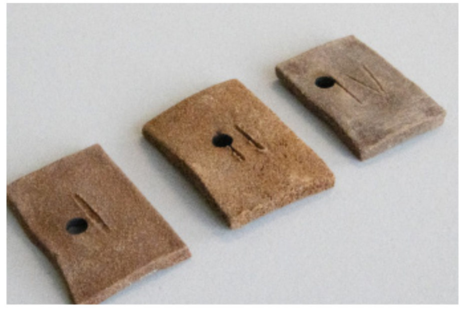
- Smaller particle size of wood in comparison to bark increased the warping.

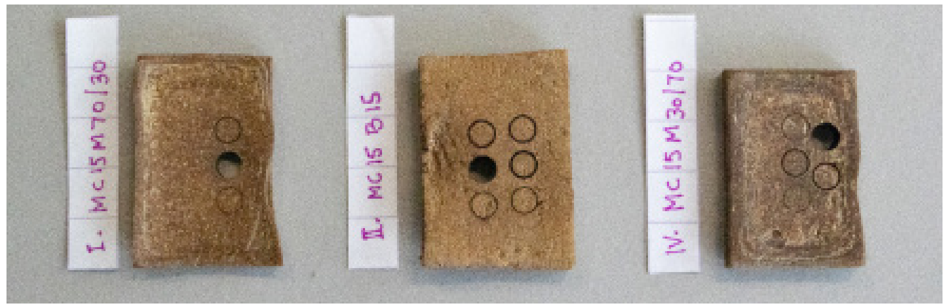
SANDING

- Sanding as a process steps allows for correcting warping/cracks during repair processes, while also making the surface smoother

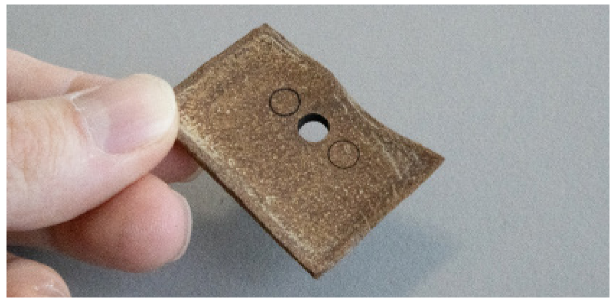


LASER CUTTING

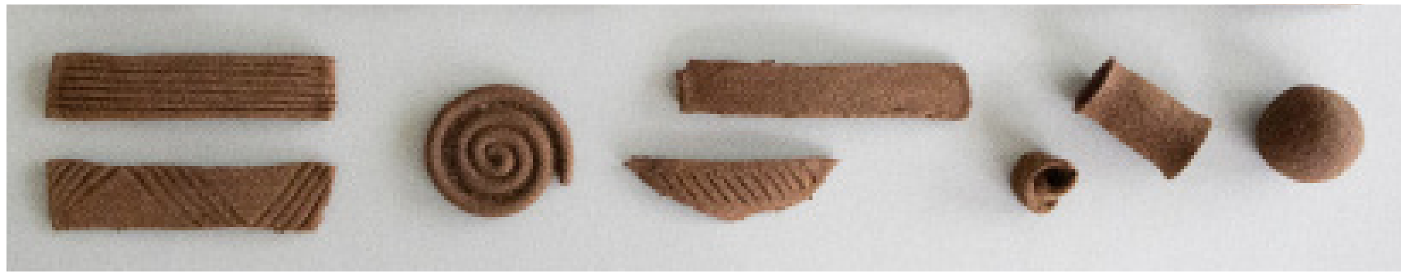




- Homogenous materials with finer particle size and less air-pockets, provides a smoother and even surface suitable for lazercutting.
- MC15B21W9 had the most clear and legible engraving due to the smoothened/sanded surface as well as the burn aspect of the lasercutter.

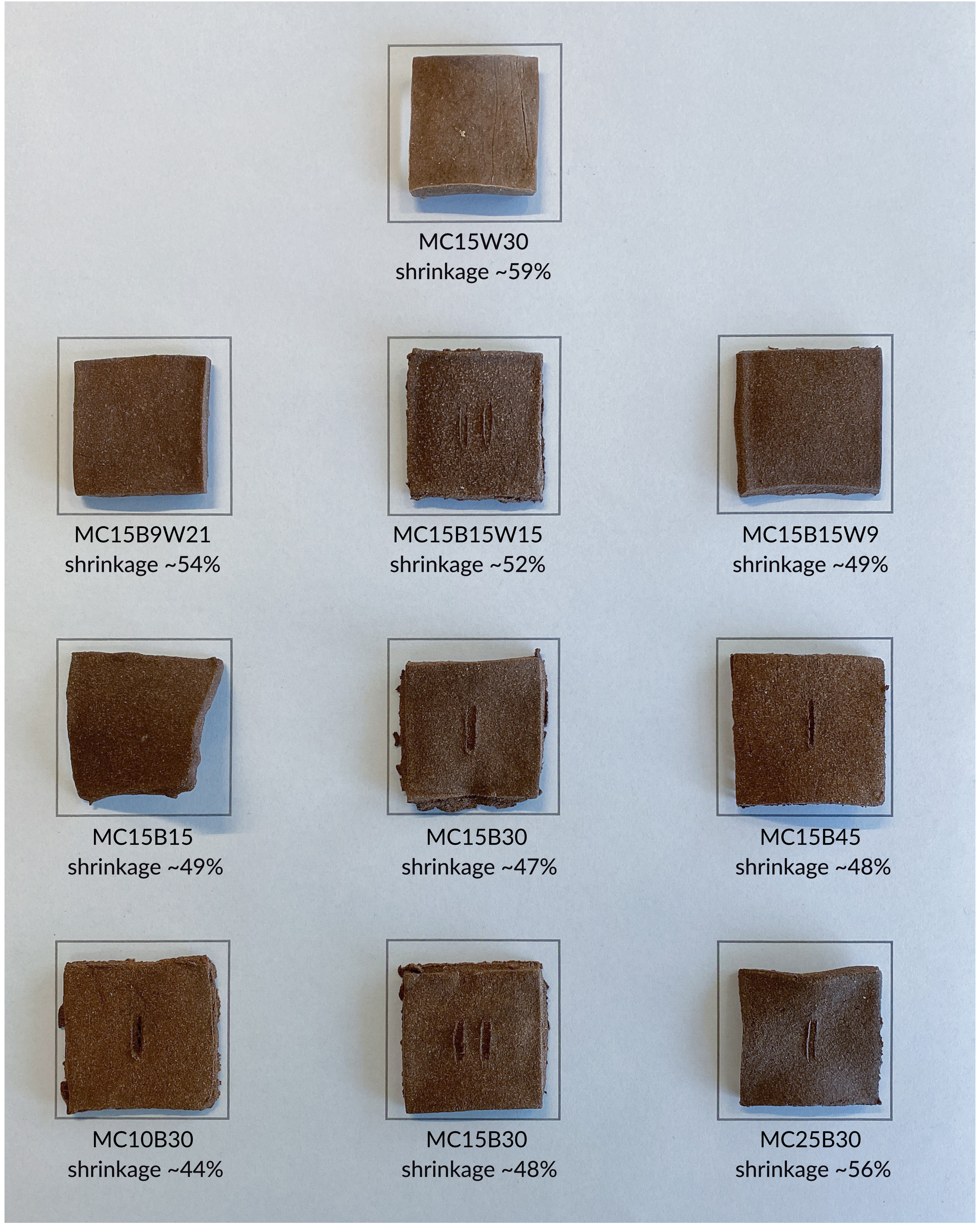


SURFACE MODULATIONS



- Since the wood soaks up MC and has fine particle size, it is homogenous and has elasticity to it, making it suitable for surface modulations when wet. However due to warping it gets deformed when dried.
- The addition of bark in the composite can mitigate the deformation.

Shrinkage



Technical Characterisation

Final testing of biobased formulations has yielded promising results, particularly within the Mixed and Wood series. These formulations demonstrate mechanical properties that approach or even exceed those of traditional epoxy-based fillers, suggesting their potential as sustainable alternatives.

Experimental Results
The following table (table 3) presents the average values and standard deviations for flexural strength, modulus, and strain at failure across four formulation series:

Sample	Flexural Strength (MPa)	Standard Deviation (MPa)	Flexural Modulus (MPa)	Standard Deviation (MPa)	Strain at Failure (%)	Standard Deviation (%)
MC10B30	13.79	0.73	108.61	24.55	0.14	0.00
MC25B30	36.02	6.35	284.89	105.55	0.17	0.04
MC15B21W9	30.15	2.56	345.21	76.60	0.11	0.04
MC15B15W15	36.74	7.84	540.78	230.72	0.07	0.06
MC15B9W21	58.62	6.36	521.24	5.97	0.13	0.05
MC15B15	24.88	0.84	224.90	6.89	0.12	0.00
MC15B30	26.14	0.41	250.26	5.73	0.12	0.02
MC15B45	15.87	0.28	176.89	44.72	0.11	0.01
MC15W30	69.12	0.44	492.88	28.78	0.20	0.01

Table 3

Anlaysis and Discussion
Binder series: The MC10B30 formulation exhibited a flexural strength of 13.79 MPa, while MC25B30 showed a significant increase to 36.02 MPa. The latter also demonstrated a higher modulus of 284.89 MPa, indicating improved stiffness. However, both formulations had relatively low strain at failure (~0.14%), suggesting brittleness.

Mixed series: Formulations in this series displayed notable improvements. MC15B21W9 achieved a flexural strength of 30.15 MPa and a modulus of 345.21 MPa. MC15MB15W15 further increased these values to 36.74 MPa and 540.78 MPa, respectively. The MC15B9W21 formulation reached the highest flexural strength of 58.62 MPa, with a modulus of 521.24 MPa and a strain at failure of 0.13%. These results indicate a balance between strength, stiffness, and ductility.

Bark Series: The MC15B15 and MC15B30 formulations showed moderate performance with flexural strengths of 24.88 MPa and 26.14 MPa, respectively. The MC15B45 formulation had a lower strength of 15.87 MPa but a higher modulus of 176.89 MPa, suggesting increased stiffness but reduced strength.

Wood Series: The MC15W30 formulation exhibited the highest performance, with a flexural strength of 69.12 MPa and a modulus of 492.88 MPa. The strain at failure was 0.20%, indicating a material that combines strength, stiffness, and ductility effectively.

Comparison with Reference Materials
When compared to traditional fillers:

- Epoxy-based fillers typically exhibit flexural strengths ranging from 69–76 MPa and moduli between 309–420 MPa.

- Wood glue-based fillers have flexural strengths between 19–60 MPa and moduli of 31–55 MPa.

- Wood (e.g., Red Oak) has a modulus of rupture (flexural strength) of 68 MPa and a modulus of elasticity ranging from 800,000 to 2,500,000 psi.

The MC15W30 formulation's performance is comparable to that of Red Oak, indicating its potential as a structural material. The MC15B9W21 formulation also shows promising strength and stiffness, suggesting its suitability for various applications.

Material Properties and Implications
The observed mechanical properties of these biobased binders suggest that they can serve as effective alternatives to traditional epoxy and wood glue-based fillers. The balance between strength, stiffness, and ductility is crucial for applications requiring load-bearing capacity and durability. The ability to tailor these properties through formulation adjustments offers flexibility in meeting specific performance requirements.

Furthermore, the use of biobased materials aligns with sustainability goals by reducing reliance on synthetic polymers and promoting the use of renewable resources. The promising results from the Mixed and Wood series formulations warrant further investigation into their long-term performance, including durability under various environmental conditions and compatibility with different wood substrates.

CONCLUSION

The first phase of URWOOD demonstrates that local wood waste can be transformed into high-value composite materials capable of supporting repair and circular manufacturing goals. Through systematic experimentation with particle size, binder chemistry, and mixture ratios, the project successfully identified material formulations that not only approach but in some cases equal the mechanical performance of conventional epoxy-based fillers. Fine-particle materials processed through bead milling proved essential for advanced fabrication techniques such as paste-based 3D printing, while mixed particle sizes showed advantages for controlling warping and tailoring texture. Sodium alginate and methyl-cellulose-based systems in particular emerged as strong candidates, combining biodegradability with flexural strengths comparable to commercial benchmarks.

Beyond mechanical performance, this project revealed important practical insights into sourcing, pre-processing, and fabrication behavior. Challenges such as contamination in workshop shavings, low yields of fine particles, and sensitivity to drying conditions underscore the need for continued development in supply chain cooperation, safe handling, and scalable processing. Nonetheless, the ability to generate structurally capable composites such as the MC15W30 and MC15B9W21 formulations marks a significant step toward fully biobased repair materials. By converting overlooked waste streams into functional, digitally manufacturable composites, URWOOD advances the transition toward circular and regenerative material ecosystems in the built environment, setting a strong foundation for further exploration and implementation in real-world repair practices.