Characterisation of beech wood pulp towards sustainable rapid prototyping

Julien Gardan*

Mechanical Engineering and Technology,
4 Pl Henri Manceau – 08390, Marquigny, France
E-mail: contact@aztech-innovation.com
*Corresponding author

Lionel Roucoules

Arts et Métiers ParisTech, CNRS, LSIS,
2 cours des Arts et Métiers–13617 Aix-en-Provence, France
E-mail: lionel.roucoules@ensam.eu

Abstract: Wood has several advantages that are transferable to various derivates allowing the introduction of a sustainable material into the product lifecycle. The objective of this paper is to apply a design for manufacturing approach based on wood flour rapid prototyping, while associating the requirements of the 'mass customisation' in the implementation of a customised product. New collaborative software allows consumers to be involved in the design process. Prototyping processes allow direct manufacturing of products.

Keywords: mass customisation; collaborative product design; design for manufacturing; DOE; design of experiments; modified starch; rapid prototyping; user co-creation; wood flour.

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Biographical notes: Julien Gardan did his PhD on Engineering System at the University of Technology of Troyes (UTT) in France. He works with the Laboratory of Mechanical Systems and Concurrent Engineering (LASMIS) at Charles Delauney Institute (ICD). He founded the company Aztech. His research interests focus on new products, production processes, wood material and industrial applications.

Lionel Roucoules is a Professor at Arts et Métiers ParisTech Insitute (France) in the Department of Design, Industrialisation, Risk and Decision. He received his PhD in 1999 working on collaborative product modelling. He has been promoted as Professor in 2008. The context of his research, realised in the LSIS laboratory, is integrated design and collaborative IT platform in a global PLM vision. His specific interests are product–process interface and he proposed a design for manufacturing synthesis approach which is now part of a larger DFX modelling for virtual prototyping by least commitment supported with MDE platform.

1 Introduction

The market for 'mass market product' has evolved in recent years towards customisable products. This market change has created new offerings not only based on existing markets any more, but also generating new applications. This new behaviour has somewhat changed the decision during the product design process:

- To take into account the notion of sustainable products, prompting use of materials and processes compatible with respect of the environment throughout the products' life.
- To access the technologies, in design as well as in manufacturing, which can be better exploited for manufacture of better product adapted to the market (more scalable considering cost, quality and deadlines).

To make a good product is necessary to be competitive, but unfortunately not enough; one should also make the right product that means the product that fits to the users' real needs and expectations (Sagot et al., 2003). Many domains (automotive domain) then use design methods focused on the user. It is shown that the involvement of users and their perceptions is critical to the design (Bouchard et al., 2009; Poirson et al., 2007). As the manufacturability of the product is also crucial, several intrinsic parameters, related to the manufacturing process, are added to the design process (i.e. design for manufacturing approach). The notion of 'sustainable' products is also an important concept. It leads to the use of materials and manufacturing processes compatible with respect of the environment throughout the lifetime of the product. The environment of a product has an impact on its life cycle. Based on specific life cycle analyses (LCA), Trouy-Triboulot and Triboulot (2001) show that wood has obvious advantages and appears as an 'environmentally responsible' solution.

The business purpose of Aztech company (France – Champagne-Ardenne) is to provide on demand customised products for the 'general public' with a production of unit objects. As the reproducibility of products needs specific tools, Arduinnova has chosen prototyping manufacturing process technologies.

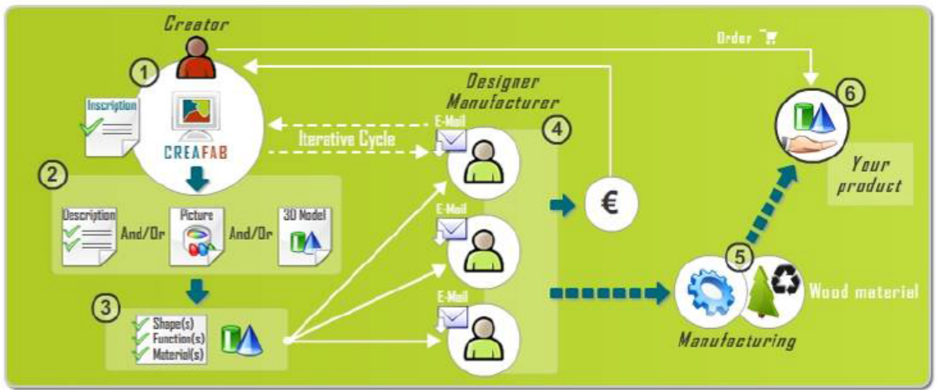
This paper discusses the integration of natural materials in experimentation of beech wood pulp through two processes of prototyping for manufacturing reconstituted wood products: 3D printing and solid freeform fabrication (SFF).

2 Objectives and research approach

This paper proposes to integrate the consumer in creating personal object through an internet-based portal called CREAFAB. This tool would allow the user to consider its purpose and to manufacture the product according to its request. The research work is then based on three steps: the translation of consumer personal requirements, the specification of web-based software to fit the design methodology and the manufacturability of the customised product in rapid prototyping integrating a derivative of wood.

Authors set up a scenario to define the general approach. This scenario shows the different steps which enable to obtain a customised product in reconstituted wood (cf. Figure 1). It also allowed us to locate the scientific and technologic issues to achieve the objectives.

Figure 1 Illustrative research scenario (see online version for colours)



During the global research work, authors discussed areas of research such as the customisable products towards new product, the user-centred design and the rapid prototyping. This paper will only present the results to understanding the behaviour and product–process relation in the context of rapid prototyping based on wood flour.

3 Natural materials used

3.1 Wood flour

Wood is a biodegradable organic material which is more or less long-term reinstated in the natural carbon cycle. The cycle analysis (LCA) reveals the global strengths of the material. LCA takes into account the environmental impact of the subsequent stages of the wood life preparation and extraction, processing, transportation, installation, performance usage and recycling. Information on the life cycle of wood is still new and dispersed (Trouy-Triboulot and Triboulot, 2001), but Trouy-Triboulot and Triboulot (2001) can mention a few advantages:

- Operation is less polluting than the extraction of other materials.
- The transport does not involve any risk and its supply is closer.
- It requires less energy and less water than other materials.
- The exploitation of under-products of wood is in development, and wood energy is neutral in CO_2 production.

Wood takes part in the reduction of carbon dioxide emissions as an alternative to non-renewable materials, the latter leading to energy costs and negative impacts that are hard to be sustained by our ecosystem. The life cycle of wood includes certain compounds that involve all materials using wood material processed as main base, such as plywood, particle board, fibre, etc. The interest of these products is based on their economic, technical and commercial assets. The structural differences that can be found in one essence, lead to a certain amount of qualities and criteria for variable use. The fibrous nature of wood strongly influences how it is used (Miller, 1999). Any material that has little value which can be recycled is collected, crushed, shredded, fiberised and may result in reconditioned wood materials such as the wood flour, with or without the addition of binder to advantageously give paper, cardboard, fibreboard or particles (Plassat, 1994). The timber has a very competitive sale price compared to solid wood although the mechanical performances are lower. Their technical and economic values offer significant opportunities for industry sectors of construction, layout and furniture incorporating recognised decorative techniques. The appearance and aesthetics of wood is undoubtedly an advantage for this material. With the integration of flour as main element in a process like prototyping, it would be possible to obtain a homogeneous and isotropic material, unlike solid wood. Its high sensitivity to humidity forced to limit the use of such material. In their experiments, authors use beech flour with two different grain sizes detailed in Table 1: LIGNOCEL HB 120 and ARBOCEL HW 630.

Table 1 Beech flours

Name	*Structure*	*Grain size (μm)*	*Density ($g\ L^{-1}$)*
HB 120	Fibrous	40–120	140–200
HW 630	Fibrous	20–40	200–300

3.2 Modified starch

Authors also focused on native starches and modified starches to study their behaviour through research in the scientific community. This materiel could indeed be used for rapid manufacturing techniques as previously introduced. Such processes operate at a temperature below 40°C for the 3D printer and at room temperature for the deposition modelling process.

Starch is the main carbohydrate reserve substance of higher plants. It represents a significant mass fraction in a large number of agricultural commodities such as cereals (30–70%), tubers (60–90%) and vegetables (25–50%). In presence of water at a temperature of 50–70°C, depending on the selected starch, viscosity appears on the starches. After cooling, the native starches, as maize or wheat starch and potato starch, transform with a rapid recrystallisation of polymers (amylose and amylopectin) called starch retrogradation (Boursier, 2005).

There are various modified starches that improve their behaviour. The chemically modified starches develop their viscosity and their binding property at low temperature or at normal cooking temperatures in environments where water availability is limited. This category gathers those modified starches obtained by reaction of hydroxyl groups of starch with monofunctional agents to introduce substitution groups. The purpose of this type of treatment is to stabilise the amylose against the retrogradation and prevent intermolecular association of amylopectin fractions. The introduction of ester or ether groups in the starch molecule can stabilise the viscosity, especially at low temperatures (Banks and Greenwood, 1975).

The extra products of the reaction must then be removed by washing to obtain a completely biodegradable starch. Note that starch is sensitive to humidity and its mechanical properties decrease with increasing moisture. For example, potato starch is used in industry to manufacture glue wallpaper, biodegradable by etherification (described in Table 2). The introduction of new hydroxylated functions provides a moisture level equivalent or superior to that of native starch. The chemicals are no longer present in the final modified product, it is completely biodegradable. However, it should be noted that the character of the starch as a natural substance decreases with increasing etherification.

Table 2 Modified starch

Name	*Chemistry*	*Food manufacture*
Ether starch	Hydroxypropyl starch	E 1440

4 Rapid prototyping analyses

4.1 Selection of the manufacturing process

To increase productivity, industries have attempted to apply more computerised automation in manufacturing. Among the latest technologies that have emerged over the past two decades, rapid prototyping technologies also known as SFF, desktop manufacturing or layer manufacturing technologies (Chua et al., 2010) provide a great advantage to provide direct manufactured parts.

4.1.1 3D printing

Authors, in their laboratory, had access to a 3D printer, the ZCorp 510, which by default uses a powder made from gypsum and a binder distributed by ZCorporation. Details of the compounds used are usually secret which will not facilitate the interpretation.

That technique is a mixture of projection of binder and sintering. A print head including several nozzles, to enable colour printing, throws droplets of binder over a tray of powdered material. Binder penetrates the agglomerates and the powder becomes rigid. Post-processing-based glue is necessary to obtain sufficient mechanical strength.

The choice is based on a machine which allows us an easy access to trays containing powder and printing system constituted containers, canals and standard type Hewlett Packard print heads.

4.1.2 Deposition modelling

SFF has the potential to revolutionise manufacturing, even to allow individuals to invent, customise and manufacture profitable goods at homes. The open-source Fab@Home project has been created to promote SFF technology by placing it in the hands of hobbyists, inventors and artists in a form which is simple, cheap and without restrictions on experimentation (Malone and Lipson, 2007).

According to De Rosnay (2006), portable 3D printers will be available on market which finds their applications at homes, garages and small workshops. He introduces this technology like the micro-factory customised (MFC). De Rosnay (2006) predicts a democratisation of MFC around 2020. Technical and skills difficulties are hidden in that principle but the process is described in the literature.

The method is based on the extrusion of material in the form of paste (silicone, chocolate, pastry dough, etc.). One or more needles, guided by three digital axes, lay down a filament. The filament does not solidify immediately. The strata of the object are constructed by stacking a specific track connected with a free open-source (we can find the same type of software on the RepRap (Sells et al., 2010)). The syringe connected to a plunger deposits its filament in a horizontal plane, then the platform is lowered to start the next cycle. This approach could allow us to make a wood pulp to form some objects.

5 First manufacturing experiments by 3D printer using wood flour

5.1 Introduction

Main objective of shaping is to get aesthetical parts and to obtain mechanical properties corresponding to the product specifications. Therefore, this paper now presents the experimental results to assess the mechanical performances and the shape.

5.2 Manufacturing-driven experimentation

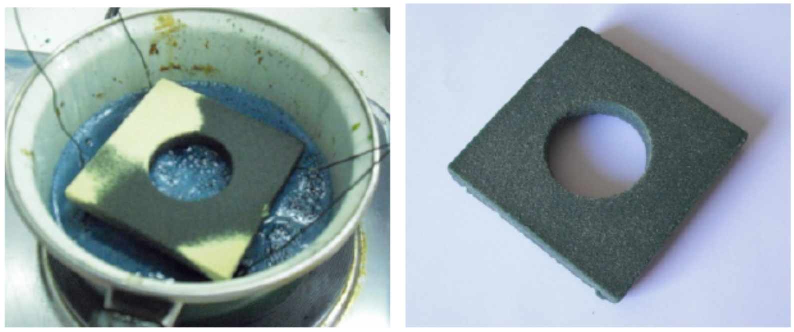
In using the ZCorp 510 printer, authors were able to incorporate the flour Beech HB 120 in the printer and realise the preliminary tests with the binder of the machine (ZB58 transparent). Authors assume the hypothesis that the binder of the machine is not as effective on wood flour. The first test piece ended up with very friable pieces in printer output (cf. Figure 2).

A post-treatment was therefore considered by dipping the obtained part in industrial wax. The part is not really immerged but just laid on the wax. The wax then rises up by capillary action (cf. Figure 3).

The part is intact on the top surface, but its base is degraded by the soaking support. Nevertheless, it can be manually manipulated after hardening as expected.

Figure 2 Condition of parts after fabrication (see online version for colours)

Figure 3 Tensile test on a specimen soaked in an industrial wax (see online version for colours)



5.3 *Characterisation of the wax-based material*

To assess the behaviours of the obtain part with respect to specifications, several tests have been done to mechanically and dimensionally characterise our material.

5.3.1 *Mechanical strain assessment*

Test pieces to measure the tensile strength of the material have been realised (cf. Figure 4). The tests were performed using standard specimens and with experimental conditions given on Table 3.

At first, authors realised specimens using the manufacturing exploratory process as previously described: ten specimens in flour spruce by 3D printing by the blinder ZB 58. Then authors have dipped the pieces in a bath of palm wax.

5.3.2 *Results and analysis*

Tensile tests have resulted in usable data. They are summarised in Table 4.

Figure 4 Specimen output printer (in fair) and post-treatment specimen (in dark) (see online version for colours)

Table 3 Experimental conditions

Captor	*10 daN*
Tensile strength	0.1 N
Vesting period	50 ms
Displacement	50 mm mn^{-1}
Specimen dimension	$x = 10.3$ mm/$y = 76$ mm/$z = 5.5$ mm

Table 4 Summed up tests

Tensile test	*Test 1*	*Test 2*	*Test 3*
R_m (MPa)	0.97	1.51	1.26
Modulus E (MPa)	667	728	707

Authors can observe on the tensile curves, the elastic modulus and the rupture limit of the specimens. The three curves are significantly different and show that the material's characteristic is very dispersed. Authors first assume that the sensor is not sensitive enough to measure a material as fragile. Then, the material seems to fall between the jaws of traction machine. Also results can be dispersed and give us insight into the behaviour of the material in tension. Its tensile strength is low (between 0.97 and 1.51 MPa).

5.4 Dimensional variations and geometric distortions

Deformations are visible on test pieces after cooling the wax. The hardening of the wax matrix implies a withdrawal, which leads to dimensional variations and geometric distortions due to surface tension. Authors used a coordinate measuring machine (CMM) to measure these distortions. By using rectangular test piece (as shown on Figure 4), authors can determine various characteristics (cf. Tables 5 and 6).

Table 5 Circular deviation synthesis

Measure CMM	*Specimen 1*	*Specimen 2*
Nominal value (mm)	Ø 37.727	Ø 37.727
Measured (mm)	Ø 37.693	Ø 37.314
Max (mm)	Ø 38.133	Ø 37.929
Min (mm)	Ø 37.238	Ø 36.942

Table 6 Flatness deviation synthesis

Measure CMM	*Specimen 1*	*Specimen 2*
Nominal value (mm)	0	0
Measured (mm)	0.494	1.037
Max (mm)	0.308	0.507
Min (mm)	−0.186	−0.530

5.4.1 Results and analysis

All this information shows the geometry of parts after cooling. However, authors can observe visually curved pieces on the ends (an effect of warping). The diameter of the circular opened hole decreased and a strong deviation of about –0.034 mm for specimen number 1 and –0.414 m for specimen number 2. The representations of actions and deformations show that the hole is not circular and deformed towards the extremity of the model. The flatness of models is also affected by cooling wax. The graphical interpretation allows to easily view the larger strains present at the extremity. The removal of parts after hardening indicates that their internal tensions affect the final geometry. The data allow us to interpret the modifications to be considered ahead of the design for a 'functional geometry'.

5.5 Case study

In this section, authors present the application process by relying on an object for the general public. Authors deliberately chose a simple object because they recognise that early interpretations are of an exploratory nature. They designed a scotch-tape support (cf. Figure 5) according to the process of designing and manufacturing that authors are able to implement.

The realisation of the scotch-tape support followed the manufacturing process as already described. After hardening of the wax, authors get a visually identified part. The absorption of the wax caused some alterations and pellets of wax in the inner edges. The model is relatively brittle and the mastery of the process is delicate, but these results are encouraging for the experimental application.

This section of this paper has allowed to observe the first manufacturing solutions proposed by the authors and to determine its viability. Authors also presented the research results based on the determination of mechanical and geometrical characteristics. Section 6 presents the second (SFF) manufacturing process that has been selected as interesting for wood forming (cf. Section 4.1).

Figure 5 Scotch-tape support: computer-aided design model and manufacturing process (see online version for colours)

6 DOEs for process and product characteristics identification based on solid free form manufacturing process

6.1 Introduction from deposition modelling

To find a solution to previous limitations of the first manufacturing process (3D printing), the authors discuss a new manufacturing approach. Since authors do not have the fab@home system, they decided to kit the manufacturing process. Authors are therefore using open-source software for the RepRap (i.e. 'replication rapid') that generates a first file describing the filament trajectory from a stereolithography model of the part. Then authors translated this specific file into G code applicable to a numerical control (NC) machine. By adapting a syringe instead of an end mill, authors could realise the manufacturing operation. The application is done by manual pressure on the syringe to lodge a 'wood pulp'.

The first tests show that the automation of the filament deposit does not seem to be a technological lock. The adjustment of extrusion parameters generated thanks the RepRap software allow to parameter the NC machine for trace a model with the wood pulp. Authors can use this manufacturing method to try to realise wooden products. The first issue relies upon the pulp's consistency and notably its rheological characteristics to obtain a filament that will not collapse during the lay down. The second issue is to respond to geometric and use constraints of the product after filament drying.

Authors propose to implement a design of experiments (DOE) focused on the wire to get the best possible deposit in the manufacture and on its geometrical and mechanical characteristics after drying.

6.2 Principles of DOE approach

The method of DOE can both reduce the number of tests and study a large number of factors, but also to detect possible interactions between factors. The study of the influence of one factor at a given level is done by comparing the average responses obtained at this level to the overall average (Hinkelmann and Kempthorne, 2008). According to the definition of full factorial, one has an answer for each combination.

6.3 Application

Authors chose to apply this method to discover the effects of the process and of the chosen material (thanks to the first experiences plan) on various predefined geometrical shapes without increasing tests.

Our literature search has identified influential factors like high sensitivity of the materials to moisture (wood and starch).

Objective: To assess the various factors that makes up pulp from its mechanical behaviour and rheological criteria.
Consequently, the studies are made on parameters that have a significant influence, namely:

- The grain sizes of beech flour: 40 and 120 μm.
- The mass of beech flour: 20 and 40 g.

- The mass of ether starch: 10 and 40 g.
- The volume of demineralised water: 200 and 300 ml.

6.4 Samples for experiments

Test pieces are samples with non-constant geometry (cf. Figure 6). The structure can vary from one specimen to another. Three samples per dough type have been realised and the average of every set of results have been calculated to avoid the dispersions.

Figure 6 Samples geometry (see online version for colours)

6.5 Manufacturing conditions

Authors produced the test manually without NC machine. Technically the filing of the wire is feasible, but the resources do not permit to automate the descent of the plunger. Nevertheless, authors assume the independency of that issue on the results.

Manufacturing parameters of specimens are:

- Wire diameter: 2 mm.
- Temperature: 20°C.
- Humidity: 55% RH.
- Material: Beech flour 20 and 120 μm (deciduous).

6.6 Measures conditions of the mechanical properties

The measurement of mechanical strain is performed on a machine for strain compression with a sensor 100 daN. The deformation is measured on the initial length (L0%); the measure of stress is MPa. The tests are conducted in an environment at a temperature and humidity of *42% RH*.

6.7 Rheological criteria conditions

Authors did not have tool to directly measure the rheology of the pulp. Authors then applied the criteria of observations to assess the wire held: good behaviour: criterion no. 1; medium behaviour: criterion no. 2; worse behaviour: criterion no. 3.

6.8 Practical method

The DOE is performed on a tension and compression machine using the conditions mentioned in Section 6.6. Authors have a two-level plan, with the study of all the possible bilateral interactions per sample type, which corresponds to an L 16 table. The levels chosen are shown in Table 7. The conditions were chosen on both sides of the test conditions of reference presented in Section 6.6.

The construction of the DOEs is shown in Table 8. The specified outcomes are the averages of measurements performed in tension on a family of three identical specimens. To summarise, authors have three outcomes: the maximum strain in MPa named A, the elasticity modulus in MPa named B and the rheological criteria assessed during the extrusion performed with a syringe named C.

Table 7 Levels table

Factors	*Level 1*	*Level 2*
Ether starch (g)	10	40
Beech flour (g)	20	40
Grain size (µm)	40	120
Demineralised water (mL)	200	300

Table 8 DOE construction and results

No.	*Ether starch (g)*	*Beech flour (g)*	*Water (mL)*	*Grain size (µm)*	*A (MPa)*	*B (MPa)*	*C*
1	40	20	300	40	7.30	719.0	2
2	40	40	200	40	2.69	289.0	3
3	10	20	200	40	0.16	21.6	2
4	40	40	300	40	1.01	113.3	3
5	40	40	200	120	0.53	65.0	3
6	10	40	200	120	0.31	45.6	3
7	10	40	300	120	0.01	2.00	2
8	10	20	300	40	0.29	39.33	1
9	40	20	200	40	1.11	98.33	3
10	10	40	300	40	0.01	2.00	2
11	40	20	200	120	2.49	274.3	3
12	10	40	200	40	0.41	64.3	3
13	10	20	300	120	0.00	0.0	1
14	40	20	300	120	3.81	332.6	2
15	10	20	200	120	0.30	52.0	2
16	40	40	300	120	1.17	160.6	3

6.9 Study effects

The relative importance of a parameter is estimated using graphs like those in Figure 8. The importance of the slope on each parameter gives information on the importance of the influence of this parameter. The more the factor's effect is important, the stronger the segment's slope is. It was therefore a means of quick visual assessment on the same graph of the relative influence of representative factors detailed in Figure 7.

Figure 7 Graph of main effects (see online version for colours)

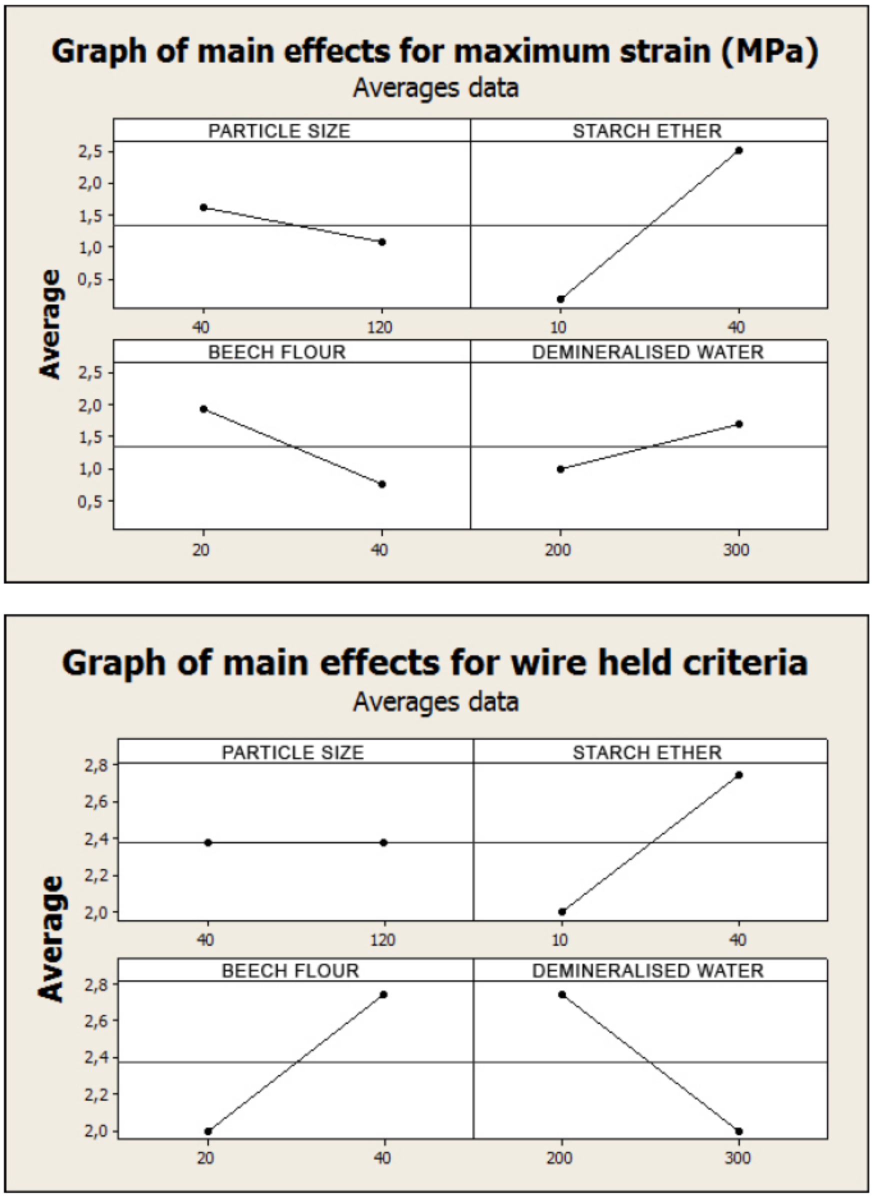


Figure 8 Syringe set on the computer numerical control (see online version for colours)

6.10 Study interactions

An interaction between factors occurs when the modification of the response obtained on minimum level or on maximum level of a factor differs from the modification of the response on two identical levels of a second factor. In other words, the effect of a factor depends on another factor. You can use interaction diagrams to compare the relative strength of the effects of different factors.

6.11 Optimisation

The responses optimisation function searches a combination of input variables that jointly optimises a set of answers while satisfying the required conditions for each response of the set (Wu and Hamada, 2009). To optimise the manufacturing conditions of forms, individual desirability is defined for each response. We must therefore increase our desire to obtain the best possible wire place during manufacture while maintaining a tensile high stress. We keep the goals while maximising the responses.

The optimisation diagram illustrates the effect of each factor on the responses or composite desirability. For the individual desirability, authors select a weight (between 0.1 and 10) to define the importance of reaching the target value. The composite desirability is the weighted geometric mean of individual desirability of different answers. Table 9 summarises the results and 'best' configuration to simultaneously maximise the outcomes.

Table 9 Optimisation responses

Composite desirability	0.86
Maximum strain	3.5 MPa
Wire-held criteria	1.35
Grain size	40 µm
Ether starch	40 g
Beech flour	24.64 g
Water	246.46 mL

In this study, the composite desirability (0.86) is fairly close to 1, indicating that the settings seem to achieve favourable results for good performances of the thread during the manufacturing and it responds to using features.

6.12 DOEs synthesis

Modified starch used is the most important factor affecting the tensile strength of the material. The flour beech fibre size may affect the resistance in our setup, contrary to what authors thought. The starch needs enough water and does not need a high load of flour to achieve its characteristics.

For holding the wire on filing, it is more stable when the pulp is made up of less water and more flour. Starch is undeniably the invariant factor in our composition. This study shows that interactions of beech flour and starch have a strong responsibility to hold the wire in the presence of demineralised water. With the aim to improve our wood pulp, authors headed towards the responses optimisation to be closer to the best of our terms of use and manufacture.

6.13 Shaping of the wood pulp

In this section, authors present the shaping applied to filing of a wire to wood pulp. In substituting the end mill of NC machine by a syringe, authors implement a system for extruding the wood pulp. The piston is temporarily manually activated, but the extrusion is a function already present in the software (RepRap). Authors add an arm multiplier to simply extrude the wire (cf. Figure 8).

From a processing G code manufacturing using the RepRap software, the G code is readable for the NC machine (cf. Figure 9). Note that the approach does take into account the path of the tool, especially the stratification. Authors must press on the piston to extrude the pulp. This method involves a semi-automatic extrusion speed occasionally random. However, the initial setup is accurate enough to evaluate the construction of model (wire diameter, thickness of layers, etc.) and manually control the flow of wood pulp (scan speed).

After making at least ten pieces, authors observed some irregularities in their geometries. During the scan, the changing of directions of tool generates protrusions mainly due to poor control of the manually run extrusion. Nevertheless, the shape of the model corresponds to the initial geometry and the manufacturing process has functioned according to the approach (cf. Figure 10).

Authors did not observe any collapse of the shape. However, the material has strong adhesive power, which requires a smooth surface allowing us to take off the piece after drying (cf. Figure 11). After 48 hr drying at ambient temperature, authors get a highly distorted piece with a tendrilled effect. The irregularities observed on the fresh piece are accentuated. After hardening and salting of the water content in the material, the wire diameter narrows from 2 to 1 mm.

Authors observed the deformation during a specified time. At first, authors have a fresh model that does not collapse. Subsequently, internal tensions will gradually deform the geometry. Part of the wire being in contact with the support has stuck on it, while the rest of the surface tends towards the interior of the model by creating cavities. The edges have gradually bent to the heart of the material. The mass of the piece and its removal of material imply the deformations through the geometry centre.

Figure 9 Trajectory model (see online version for colours)

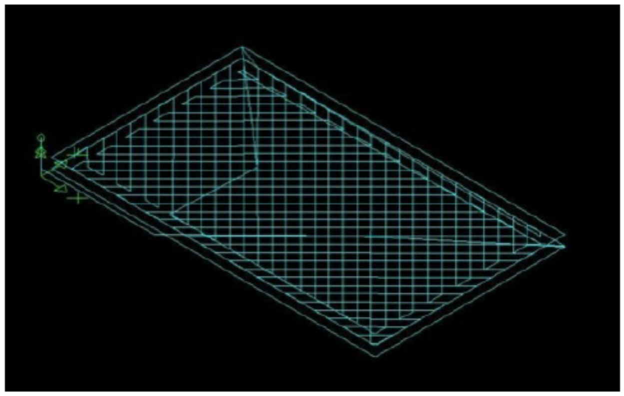
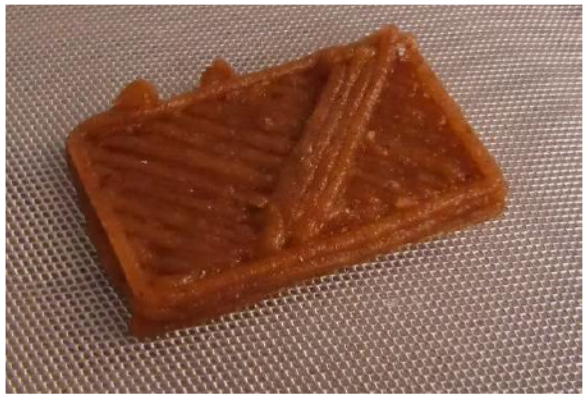


Figure 10 Model after manufacturing (see online version for colours)

Figure 11 Model after hardening (see online version for colours)

At the 'aesthetic' and surface condition of the model, reducing the diameter of the nozzle has improved the recovery of the layers. We do find more holes or cavities due to deposition of semi-automatic wire (cf. Figure 12).

Figure 12 Decrease of wire diameter (see online version for colours)

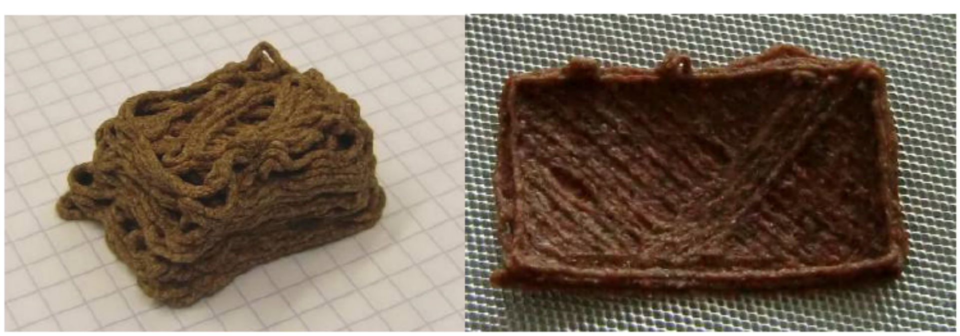


6.14 Synthesis

In this section, authors exploited solutions by depositing a wire wood pulp. Authors first proposed a method applied on a NC machine. Then, they propose the experimental method which allows obtaining wood filler to answer manufacturing constraints. The proposed approach allows specifying professional rules specific to the process. The mechanical results do not exactly correspond to the data announced by the experimental plan, but the overall results seem consistent. When authors visually compare the parts produced at the beginning and at the end of the project, it is easy to observe the structural changes (collapse, respect of the geometry) and aesthetic models (object rendering) (cf. Figure 13).

In addition, the aesthetics should be improved to achieve the general public product expected. Opportunities for improvement are possible, such as reducing the diameter of the nozzle which requires a mechanisation of the piston and the establishment of a research phase deeper on the composition of the pulp (study the removal through the hardening, etc.).

Figure 13 Models' evolution (see online version for colours)



7 Conclusion and recommendations for future work

Authors proposed two approaches for making ‘objects’ in reconstituted wood. Authors introduced an application to use a flour spruce from a 3D printer involving a post-processing, stabilising the pieces tested. Authors realised a case study using our design and manufacture method. It concerns a scotch-tape support, which perfectly matches the consumers’ products family. The importance of measuring the roughness of the material to foresee the friction of the rolling is all the greater that it will apply to our case study. One of the goals is to automate the manufacturing process.

In a second application, authors have submitted an application involving a NC machine and a filing system of wire. This deposit uses a syringe and specialised software in the generation of the model. The approach is essentially guided by experiments using a DOE. The solutions that arise from these applications allowed us to tackle some scientific and technical issues. The involvement of a renewable material opens up interesting ecologic and economic possibilities. However, a subsequent phase would be necessary to complete those applications. At the end of this section, authors can consider applications to reveal the viability of the general approach, namely:

- The use and integration of a wood derivative in rapid manufacturing.
- Obtaining processes of shaping and interpretation of their mechanical and geometrical characteristics.

In the long term, authors want to develop applications related to manufacturing by rapid prototyping wooden parts. Convinced of the economic and ecological potential of process, several research projects are expected to lead to more reliable tools. The prospects for this work are numerous. They can focus on the user interface, the method and material, the virtual product development (modelling, simulation, etc.) and the manufacturing process study.

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