3D Printing device adaptable to Computer Numerical Control (CNC)

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Abstract

This article presents the development of a 3D printing device for the additive manufacturing adapted to a CNC machining. The application involves the integration of a specific printing head. Additive manufacturing technology is most commonly used for modeling, prototyping, tooling through an exclusive machine or 3D printer. A global review and analysis of technologies show the additive manufacturing presents little independent solutions [6][9]. The problem studied especially the additive manufacturing limits to produce of ecological product with materials from biomass. The motivation for this work was to develop a new 3d printing device with a solution for formatting pulp or powder materials. Some problems require enslavement to the CNC controller and programming building of model. An implementation on a machine is presented along with some application examples used for its development.

Key words: Additive manufacturing, rapid prototyping, CNC machining, wood pulp, wood powder, green manufacturing.

1. Introduction

Since the appearance of rapid prototyping different technologies have arrived in the market [11]. The layers manufacturing stay the same and the additive manufacturing or 3D printing gets developed to propose several synthetic materials which have an environmental impact. Usually, the professional rapid prototyping systems are improved as a complete unit. These professional machines are expensive and very dependent of manufacturer. Demand for additive manufacturing is increasingly growing since 90's [12] and the essential factor is its flexibility and adaptability to product development requirements with its reduction time. Due to the evolution of rapid prototyping technologies, it has become possible today to obtain parts representative of mass production within a very short time [1].

Today, the research of the best compromise between ecologic materials, economic process and mechanical behaviors is very important to respect the functional product specifications [8]. The use of non-renewable materials and locking additive manufacturing technologies are really problematic to develop more efficient products. These products are related to design methods which, while remaining within the philosophy of concurrent engineering, have their own particularity [10].

The notion of "sustainable" products leads to the use of materials and manufacturing processes compatible with respect of the environment throughout the product lifecycle. Wood can be of critical importance to primary and secondary wood using industry, scientists, ecology, forestry, and wood technology [5]. The wood lifecycle includes some compounds which involve the wood processed as main base such as plywood, particle board, fiber, etc. The interest of these products is based on their economic, technical and commercial assets.

We suggest integrating primary wood products, such as the wood flour from specific species, into additive manufacturing processes to answer to ecological and economical constraints, and mainly create reconstituted wood products. This approach requires the development of wood pulp material.

First of all, the work presents the first technological approach to integrate wood materials into rapid manufacturing machines. Specimens were characterized to obtain and to optimize the mechanical behaviors of material through a Design of Experiments (DOE) [4]. Manufacturing is approached through a first semi-automated tool. Obviously, this first application has limitations which were treated during to a second development.

Secondly, we describe the device development which is fitted on a CNC machining for the wood pulp depositing and we explain the importance of using the manufacturing process about additive manufacturing. The authors describe the solutions which allowed solving the problems by pulp extrusion, to have a rapid manufacturing tool mobile and independent, and to treat the manufacturing control. The approach presented here is cut in four parts between the device design and the control of the equipment:

-The device design and its depositing system;
-The integration of wood material;
-The development of software enslavement and control;
-The tests of a functional prototype set up in a CNC.

The origin of application provided of a first Phd work supported from 2008 to 2011 [3] which led on a new development with several technologies implemented from 2011 to 2013 (Fig 1).

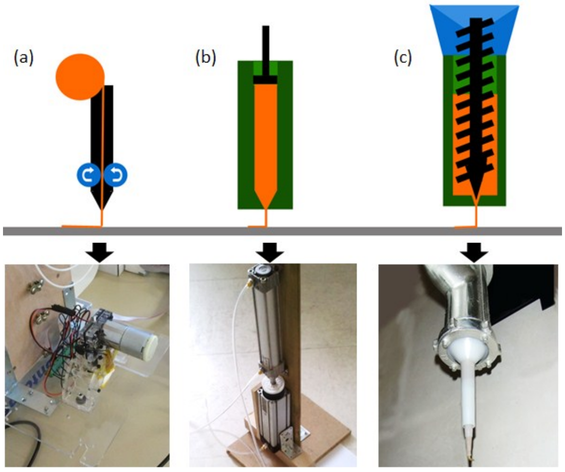

Fig 1. Overview of technologies implemented: a. Fused depositing; b. Piston depositing; c. Screw depositing.

2. Additive manufacturing

The first form of creating a three-dimensional object layer by layer using computer-aided design (CAD) was rapid prototyping, developed in the 1980's for creating models and prototype parts. Additive manufacturing allows fast, cost-efficient production, reduces material usage and part counts, and shortens design cycles. This technology was created to help the realization of what engineers have in design mind. It allows the creation of printed parts, not just models. Among the major advances that this process presented to product development are the time and cost reduction, human interaction, and consequently the product development cycle [1], also the possibility to create almost any shape that could be very difficult to machine to validate functionality and aestheticism. Nowadays, these technologies have other names like the 3D printing or the rapid manufacturing, and so forth, but they all have the origins of rapid prototyping. The complex geometries which need a manufacturing held are maintained by support material. This material can to maintain the external and internal surfaces of a part. In most cases, the support material is cleaned during to the finishing or trapped into the model. The cost of consumables is often expensive and the loss of material isn't considered. Environment impact is not negligible for materials made from resin and it isn't compatible with the Eco design thematic.

Study is built around several observations. The rapid prototyping machines are often sold in a complete unit. The second observation is based on size prototype feasibility: manufacturing dimensions are limited. The last is the use of not green material which has an environmental impact with interest to use bio-based material like the wood. We present the achievement of a prototyping device answering these constraints with a functional prototype and associated software.

3. Piston depositing toward 3D printing head

In this section, we give an overview of two ways used to assess the scientific and technologic problems. After describing some approaches and methods, we tried to integrate wood in the form of powder (wood flour, wood powder).

A first experimentation was tested thought a beech floor with a binders projection in 3D printing through a ZCorp[1] printer. A post-treatment was therefore considered by dipping a form in industrial wax to increase our required forms (we also tested a natural wax). Without immersing the piece in the molten wax bath, we introduced the model in surface. The wax rises up by capillary action. The part was intact on the top surface, but its base is degraded by the soaking support. It can be manually manipulated after solidification. We have realized different mechanical tests to obtain the wood model behaviors through specimens [4].

The second experimentation used a syringe to deposit a wood pulp based on wood floor and starch (fig 2). A Design Of Experiment (DOE) has been implementing to reduce the number of tests, and study a large number of factors, but also to detect possible interactions between factors [2]. We optimized the composition of the material through a parameter design optimization [4, 13]. This syringe has been adapting on a CNC machine with an additive scanning manufacture, but it was semi-automatic at one extrusion.

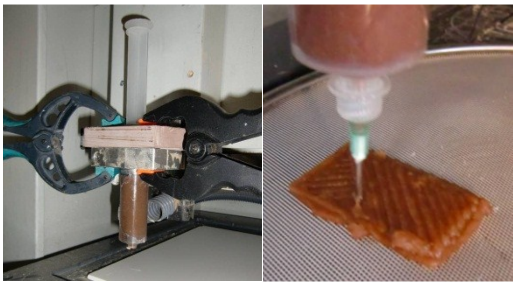

Fig 2. Second syringe experimentation with a wood pulp

We have realized different mechanical tests to obtain the mechanical wood pulp behaviors [4]. The behaviors were used to create a product able to respond to use constraints.

These depositing applications briefly present the first studies before presenting the following work. The connection is very strong between these two stages through the wood studies and possible automation system. In order to work and go further in the process, we have developed an independent print head able to be set on a CNC machine for extruding different pulps.

3.1. 3D printing head for CNC machining.

The aim was to automate the previous system and offer an innovative and interchangeable solution, like machining tools. We have developed a printing head (Fig 3) to deposit the wood pulp with the requirement to support the geometry of model. Indeed, as all adding processes, it must support the complex geometries which require being held. It is for this reason that the head contains two nozzles.

[1] http://www.3dsystems.com/

Values added are the adaptation of CNC without monopolizing a specific additive machine and the opportunity to try different pulp extruded.

Fig 3. 3D Printing head on CNC.

A prototype has been designed to answer the problems of automation and we realized this prototype in extruded polystyrene by Stratoconception© method[2]. We have identified a solution which integrates the CNC machining spindle instead of the bur. This solution has proven original compared to existing solutions:

-It allows manufacturing of large prototype thanks to board of the CNC machining;

-It is useful to assess some other pulps;

-It requires to simply changing the machining tool (the bur).

We used an electronic card (Arduino®) and a pneumatic switch connected to a compressor to control a pneumatic cylinder (fig 3). We chose a pneumatic solution instead of an electric solution because it was cheaper, but it implies a less good reactivity. The pneumatic cylinder was sized to a pressure drop and a minimum flow (cylinder Ø 40mm, cylinder stroke 200 mm, force 80 Newton for a pipe of Ø 4mm and 1 meter long). The piston is provided with a valve and a container for the pulp. The container is connected to the pipe until to the printing head and the nozzle. To use the second nozzle and integrate a support material, the piston depositing system must be duplicated.

This additive depositing system is linked to a manufacturing process which is defined between the material behaviors and manufacturing parameters. When we combine use of wood pulp, the piston depositing and the NC machining, all product parameters are linked for the metier rules or constraints. To control the whole, we must combine all the parameters while driving the CNC machining and the pneumatic depositing system through specific software.

3.2. Specific additive manufacturing software

The interoperability between all components is controlled by specialized software. Recall that the goal is not to physically change the machine, beyond the existing the CNC machining spindle. So we had to adapt the native control system without using invasive techniques for the CNC machining. We chose to pilot this machine without modification, that is to say, into believing it continues to operate a standard machining. We needed to control the CNC system and the extrusion system. Dedicated computer software was developed to generate a G Code understandable by all CNC machining, corresponding to the course that the machine must follow to manufacture a model by material depositing. While the CNC was able to move the nozzle along its theoretical course, we had to synchronize the pressure applied by the pneumatic cylinder to actually deliver the wood along said course.
We developed software that was able to import geometry (STL, CAD Import). Generating a route for the CNC machine needed to take into account the new production process. The CNC is able to follow a path easily to remove material, but using a depositing head, we had

[2] http://www.stratoconception.com/

to carefully identify a relevant path for additive-based solution (only one pass per point, etc). That being said, such a path was still not suitable enough to be followed directly. We had to find a non-invasive solution to synchronize to position of the CNC over this path and the pneumatic pressure. This synchronization is held by the rotary tool of the CNC. A visual 3D simulator has been developed to help us check the quality of the path. Full software suite is visible on Fig 4. All the material behaviors are encapsulated into software controls which provide at the device the properties material and method necessary to make the manufacture by layers.
For example, the device is capable of working with different materials which can be extruded under pressure from a wire pulling. The proper settings and configurations will be different for each material and processed by the software. They will also vary according to things such as temperature, pressure, humidity, nozzle size, etc. Therefore, you are self-sufficient and you need to determine the proper settings yourself depending on your material.

Fig 4. Additive manufacturing software for CNC machining and piston depositing system.

3.3. Review of produced models

We formed some geometry after realizing the mechanical characterization. Firstly, the integration of wood powder in 3D printing leads to brittle parts, but are hardened by soaking in a wax. Secondly, we have developed a wood pulp based on starch to extrude it through a depositing system (fig 5). These two approaches have an advantage and a weakness, the material is durable but the involvement of water induces a high shrinkage. Due to hydrophobic materials used.

After making several models, we observed some irregularities in their geometries. During the scan of pulp depositing, the changing of directions of tool generates protrusions mainly due to poor control of the run extrusion. Nevertheless, the shape of the model corresponds to the initial geometry and the manufacturing process has functioned according to the approach. Subsequently, internal tensions gradually deform the geometry during the drying.

Fig 5. Review of models produced: wood powder and wood pulp.

To measure these geometrical deformations, we used a three-dimensional measuring machine. The diameter of the circular hole has a decreased high deviation in the range from -0.034 mm to-0.414 mm for the wood powder and wax specimen. The strain representation and measures show that the hole is not circular and is deformed toward the ends of the workpiece.

According to DFM approach, the data allow us to consider the knowledge changes in early CAD for a "functional geometry." Modeling software can interpret such data by setting model or creating design rules.

4. Conclusion and perspectives

The main purpose of this paper was to development of a 3D printing device for the additive manufacturing adapted to a CNC for depositing of a wood pulp to produce reconstituted wood product. Based on a first application and model examples, we have shown that many parameters, from different components, are important. We have realized mechanical tests to assess the mechanical behaviors of wood pulp through a Design Of Experiment. The research results then lead to new applications of additive manufacturing trough a piston depositing which required an extrusion system. This piston depositing has got a printing head which is interchangeable on the NC machining instead of the machining tools. The interoperability has been resolved through specialized software. The cost is more interesting with an interchangeable device than with a single machine. The development of rapid manufacturing machines with specific business-oriented applications is primordial for some sector. One demand for patent was filed to secure the intellectual property.

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6. Bibliography

[1] Bernard, A. and Fischer, A. 2002. New Trends in Rapid Product Development. *CIRP Annals - Manufacturing Technology*. 51, 2 (2002), 635–652.

[2] Condra, L. 2001. *Reliability Improvement with Design of Experiment, Second Edition,*. CRC Press.

[3] Gardan Julien 2011. *Application to use of a wood derivative in rapid prototyping for the emergence of general public product*. UTT - ICD-LASMIS.

[4] Gardan, julien and Roucoules, lionel 2011. Characterization of beech wood pulp towards sustainable rapid prototyping. *International Journal of Rapid Manufacturing (IJRapidM), Inderscience*. (2011).

[5] Handbook, W. 1999. Wood as an Engineering Material, United States Department of Agriculture, Forest Service. *General Technical Report FPL-GTR-113*. 24, (1999).

[6] Malone, E. and Lipson, H. 2007. Fab@Home : the personal desktop fabricator kit. *Mechanical and aerospace Engineering, Cornell University, Rapid Prototyping Journal*. Emerald Group Publishing, (2007).

[7] Miller, R.B. 1999. Structure of wood. *Wood handbook : wood as an engineering material.* Madison, WI : USDA Forest service, Forest Products Laboratory, (1999), 2.1–2.4.

[8] Sagot, J.-C., Gouin, V. and Gomes, S. 2003. Ergonomics in product design: safety factor. *Safety science*. 41, 2 (2003), 137–154.

[9] Sells, E., Smith, Z., Bailard, S., Bowyer, A. and Olliver, V. 2010. RepRap: The Replicating Rapid Prototyper : Maximizing Customizability by Breeding the Means of Production. *Social Science Research Network*. (2010).

[10] Skander, A., Roucoules, L. and Klein Meyer, J. 2007. Design and manufacturing interface modelling for manufacturing processes selection and knowledge synthesis in design. *International Journal of Advanced Manufacturing Technology*. (2007).

[11] Wang, H. and Zhang, H.G. 2012. State of the Art in Rapid Prototyping. *Advanced Materials Research*. 549, (2012), 1046–1050.

[12] WOHLER, T. 2012. *Wohlers Report 2012. Wohlers Associates*. Inc.

[13] Wu C.J., Hamada M.S. 2009. *Experiments : Planning, Analysis, And Parameter Design Optimization*. Willey.

[14] Zhao, Z. and Shah, J.J. 2002. A normative DFM Framework Based On Benefit-Cost Analysis. *Design Engineering Technical Conferences - Design For Manufacturing*. DETC2002/DFM-34176, Montreal, Canada, ASME, (2002).