Development of a Parafin Wax deposition Unit for Fused Deposition Modelling (FDM)

D'Angelo, Greta; Hansen, Hans Nørgaard; Pedersen, David Bue

Published in:
Proceedings of AEPR'14

Publication date:
2014

Citation (APA):
D'Angelo, G., Hansen, H. N., & Pedersen, D. B. (2014). Development of a Parafin Wax deposition Unit for Fused Deposition Modelling (FDM). In Proceedings of AEPR'14: 19th European Forum on Rapid Prototyping and Manufacturing

Proceedings of AEPR’14, 19th European Forum on Rapid Prototyping and Manufacturing
Paris, France, 24-26 June 2014

DEVELOPMENT OF A PARAFFIN WAX DEPOSITION UNIT FOR FUSED DEPOSITION MODELLING (FDM)

Greta D’Angelo
Technical University of Denmark
Mechanical Engineering
gredan@mek.dtu.dk

Hans Nørgaard Hansen
Technical University of Denmark
Mechanical Engineering
hnha@mek.dtu.dk

David Bue Pedersen
Technical University of Denmark
Mechanical Engineering
dbpe@mek.dtu.dk

ABSTRACT

During the last decade Additive Manufacturing (AM) witnessed a big development in terms of technologies, processes and possibilities. However of materials and their use still represents a big challenge. In fact availability of materials is rather limited if compared to conventional manufacturing. This project illustrates the redesign of an extrusion unit for the deposition of paraffin wax in Fused Deposition Modelling (FDM) instead of the conventional polymeric materials. Among the benefits and brought by the use of paraffin wax in such system are: the possibility to make highly complex and precise parts to subsequently use in a Lost Wax Casting process, multi-material Additive Manufacturing and the use of wax as support material during the production of complicated parts. Moreover it is believed that including waxes among the materials usable in FDM would promote new ways of using and exploring the technology and opening to new challenges. The design presented in this paper represents a step towards the development of a multi material deposition unit, able to selectively depose specific materials on demand in the same product, according to needs. In order to achieve that, waxes and respective designs are tested iteratively by alternating different methods in order to find the best configuration. The use of an open source platform, namely a Reprap Prusa Mendel allows to perform quick changes to the system without significant modifications to the major frame of the machine. During the design of the new extruder principles of modularity and reconfigurability are also taken into account in order to ease up a subsequent integration with a more complex system.

KEYWORDS

Paraffin wax, Fused Deposition Modelling (FDM), Extrusion unit, Multi Material

1. INTRODUCTION

By overlapping thin layers of material, Additive Manufacturing (AM) allows the manufacturing of products with complex geometries in one process and without the need of an expensive production infrastructure (Serope Kalpakjian, 2010). With the constant development of areas such quality, accuracy of production, process and materials, AM is elevated from the level of mere preproduction, known as Rapid Prototyping, to the level of industrial production(Jhon Excell, 2010) (Ian Gibson, David W. Rosen, 2010). However the range of materials available is extremely limited if compared to the traditional manufacturing techniques, e.g. injection moulding or milling (Wolers, 2012), therefore the introduction of new materials becomes a necessity in order to broaden the potential of this promising technology. An additional challenge for AM is the handling of the materials. The majority of the machines are only able to handle one material at the time, maximum two. The second material is often used as support structure and therefore not serving to any functional purposes. The production of functional products in different types of material within a build is only possible by moving semi-finished parts from one machine to another or by the use of a tool change system. This makes the production of complex, multi material parts difficult and in most cases impossible. Nowadays the production of multi material semi-functional products is only possible with the use of the so called digital materials (ref. stratasys webpage). They are photopolymers emulating the properties of real materials by being mixed in different quantities directly in the machine.

Nevertheless it can be envisioned that if an AM platform could ideally handle deposition of materials with different nature, such as polymeric substances, ceramic substances and composites of these constituents according to their compatibility, not only would production eliminate several refinement processes from natural resource to bulk material, but it would also allow for production of complex, fully functional, products without the need of product assembly. (David Bue Pedersen, 2013).

Several experiments, for example Fab@Home (Malone & Lipson, 2007) or from the University of Bath (Jones, R. O., Irvani, P., Bowyer, 2012) have demonstrated the possibility to extend the capabilities of extrusion based platform by using multiple materials, to make parts with materials such as ceramics, metallic, electrically conductive composites materials, thermoset polymers, and others (Malone & Lipson, 2007). Paraffin wax is chosen especially for its low chemical reactivity with nearly all materials , for its stability up to 250^{O} C (Carlen & Mastrangelo, 2002) and for its fairly high coefficient of volume expansion, that ranges between 8% and 15% of the initial volume when heated (Carlen & Mastrangelo, 2002; Freund, Csikos, Keszthelyi, & Mozes, 1982; Templin, n.d.). Benefits for using paraffin wax in AM are the possibility of making highly complex, precise, customized parts to use in Lost Wax Casting (Serope Kalpakjian, 2010), e.g. in jewellery. Another example is the embedment of paraffin wax elements to use as actuators (Liu, 2004) taking advantage of the high coefficient of expansion when heated (Carlen & Mastrangelo, 2002; Freund et al., 1982; Olfmeier, Aktiengesellschaft, & Gersthofen, 2012) and finally, the use as support structure in FDM produced parts, preventing the scarring of the surface or difficulties of the removal of the same.

This report presents the design and testing of the nozzle's prototype and its extrusion system for the extrusion and the deposition of paraffin wax on a FDM platform. The machine set up it is only considered as a mere support tool and will not be accounted as material of study in this paper. The design takes place upon initial study on the material properties in order to get an overview on the material behaviour (Section 2.1). Subsequently an iterative design stage follows up, where different solutions are prototyped and tested (Chapter 4). The final prototype is then built and tested. Experiments are made with regard to: nozzle temperature, feed ratio, speed of deposition. The design is based on the filament extrusion typical of FDM machines. If the thermoplastic nature of paraffin wax is considered, it can be assumed that wax can as well be printed with a geared extrusion resampling the one commonly used in polymer extrusion (Figure xx)

2. MATERIALS AND METHOD

2.1. PARAFFIN WAX

Wax's family is indubitably very big and variegated. Because of their big variation in composition it is difficult to group them under a unique definition (Olfmeier et al., 2012). However few common characteristics can be used for their identification and distinction from other materials. For example a melting point between 50^{o} and 90^{o} C without decomposition; melt viscosity not exceeding 10000 MPa.s at 10^{o} C above the drop point, they should be polishable under slight pressure and have a strongly temperature-dependent consistency and solubility (Olfmeier et al., 2012). Among all the existing waxes, They belong to the family of the petroleum waxes and they are categorized as natural waxes (Olfmeier et al., 2012). Paraffin wax consists of a straight chain hydrocarbons (Cn+H2n+2) with a carbon-number distribution of n-alkanes from 18 to 45 (Templin, n.d.). And it comes from a refining process of the crude oil during the process for producing lubricant oil. When heated paraffin wax does not have a linear transition from solid to liquid, but it goes through two main phase changes before completing the transition. Additionally these transitions are very sharp and occurring in a very small range of temperature variation (Freund et al., 1982; Templin, n.d.). This behavior can be compared to the phase change of the thermopolymers, when they reach the glass transition temperature. Only difference is that paraffin wax have this happening in a very sharp way and in a quite small range of temperature (circa 10^{o}C against the xx of the polymers). (see pic below for comparison). Therefore assuming the thermoplastic behavior of paraffin wax it can be argued that wax can be extruded as a conventional thermopolymer if treated carefully and if a special care is given to the control of the temperature. Also if the transition temperature is not trespassed the expansion of the material would be contained. Temperature becomes one of the most critical parameters to take into account when designing and using the system. Together with transition temperature, transition time, viscosity-temperature.

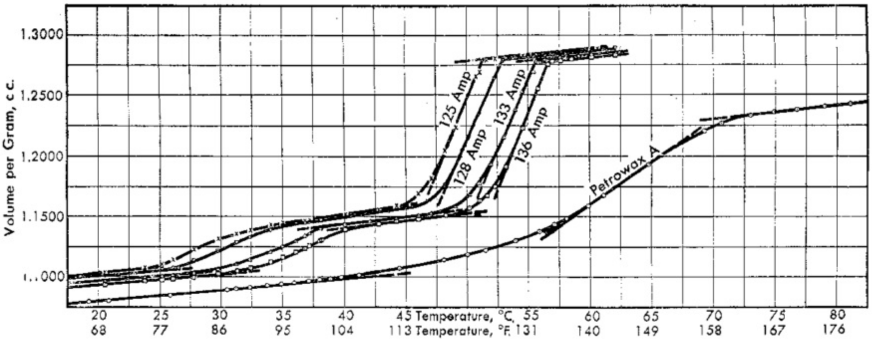


Figure 1 - Specific volumes compared to temperature of different paraffin waxes. (Freund et al., 1982)

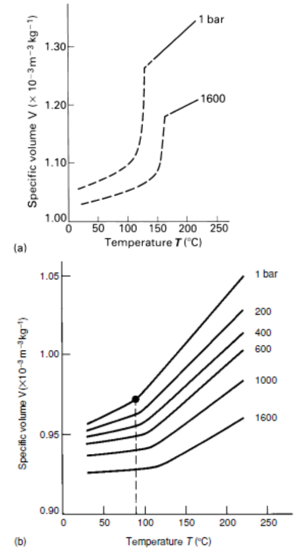


Figure 6.10 Pressure–volume–temperature relationships for: (a) Polyethylene and (b) polystyrene (from Wang K.K., *Polym. Plast. Technol. Eng.*, **14**, 88, 1980, Marcel Dekker Inc., NY and Menges G., *Polym. Eng. Sci.*, **17**, 760, 1977, Soc. Plastics Eng. Inc.).

Figure 2 - Specific volume compared to temperature for different kind of polymers. (Mills, 2005)

For the experiments the paraffin wax STRACK NORM W 8995 was selected. This has an electric blue color and a melting temperature of ca. 100ºC and a reasonable lower coefficient of expansion. It is hard and brittle. This kind of paraffin wax is conventionally used for replicating mold cavities and for measuring their accuracy, therefor it has a higher stability and predisposition for replicating small details.

2.2. NOZZLE DESIGN AND MANUFACTURING

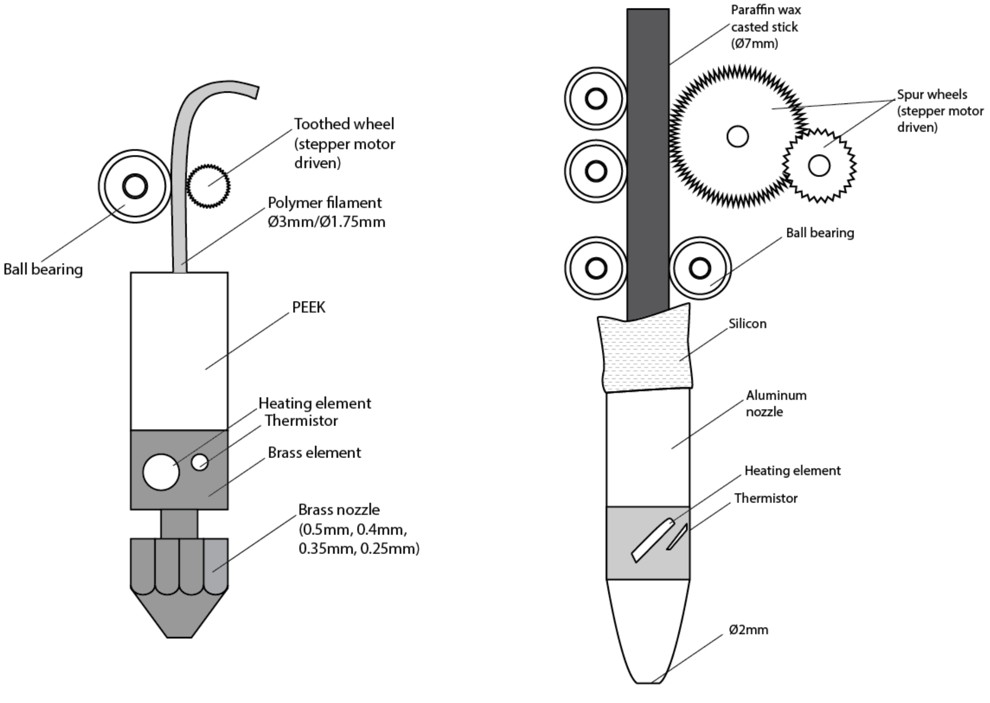
The design of the nozzle presented in this paper is based primarily on the study of the paraffin wax behavior. However a contribution was also given by few iterative design stages. These are:

- Pneumatic actuated extrusion though an aluminum nozzle (D’Angelo, 2012);
- 5cc medical syringe heated up with a resistance and using a stepper motor for the extrusion (D’Angelo, 2012);

These experiments were relevant for understanding some of the key aspects driving the wax extrusion and they contributed to the collection of meaningful information for the progress of the design. Figure 4 shows two prints accomplished with the tests run on the medical syringe.

The nozzle’s prototype is made by removing the aluminum nozzle from a mini hot glue gun and replacing the original heating system with a resistance and a thermistor. The resistance uses a 6Ω Nichel-chrome wire. To ensure insulation, both the resistance and the thermistor are fixed to the nozzle with thermal concrete. The resistance is wired mechanically and the thermistor is instead soldered to the wires. The wires are secured and insulated with Kapton tape. The nozzle is then placed on a testing set up. The nozzle has an inlet diameter of 8mm and an outlet diameter of 2mm, and 50mm of length.

A schematic of the extruder is shown in Figure 3. The extruder is composed by a set of spur gears, driven by a stepper motor; opposed are two ball bearings lining on the same vertical axe, creating some load and allowing the progress of the wax’s stick; at the back of the nozzle there are two additional ball bearings facilitating the entrance of the wax in the nozzle (see Figure 3). For the extrusion, paraffin wax sticks are casted using aluminum molds. They have a diameter of 7mm and a length of 100mm. The system resembles the extrusion system of the polymer in FDM (comparison in Figure 3). For controlling the extrusion, the heating system, the thermistor and the motor are connected to a circuit board (in this case a Printrboard) which is conventionally used in desktop open-sources FDM printers.



a- Polymer nozzle and extruder

b- Paraffin wax nozzle and extruder

Figure 3 comparison of the a- polymer nozzle and extruder with the b-paraffin wax nozzle and extruder

2.3. NOZZLE TESTING

The system is interfaced with a computer through a software called Pronterface. This allows the control of the main printing parameters during the testing of the extrusion and especially the following parameters:

- Change the temperature of the nozzle
- Monitor the temperature of the nozzle
- Move the axes of the machine (not used in this case)
- Control the speed of the movements
- Control the feed ratio
- Load files for the print of full geometries (not used in this case)

Only the extrusion process is tested and monitored, leaving deposition in geometries for a future investigation. Tests are carried out to study the extrusion behaviour of paraffin wax through the current design. Therefore, aim for the study is to collect data in order to generate a higher understanding of the process. The nozzle is tested at different temperatures, starting form 55ºC, and increasing of 5ºC each time. For each different temperature the wax is extruded at four different speeds, in a constant interval of time of 30 seconds. The speed used during the experiments are listed in Table 1.

Table 1 Speeds used for the experiments

	Speed
Speed 1	12mm@24mm/min
Speed 2	24mm@48mm/min
Speed 3	36mm@72mm/min
Speed 4	48mm@96mm/min

In order to understand the impact of the printing parameters on the extrusion process of paraffin wax two specific measurands are observed:

- Diameter of the threads extruded (mm)
- Weight of the specimen after print and after cooling (g)

The weight is measured by using a precision balance Shimadzu, model AW220. Material from each extrusion is collected, stored and then measured individually. Thickness is measured with the use of a micrometer in 3 different points of the thread: the thinnest spot, the thicker spot and a random spot. The average of these three values is used during the data analysis. The results will be then plot and compared in Chapter 3.

3. RESULTS

After the collection of the measurements, they are processed, compared and analyzed. Figure 5 shows a collection of extruded material with different parameters. As mentioned, it is not given particular attention to the geometry the material is extruded into. However, it is possible to appreciate that a continuous thread is extruded from the nozzle.

The main parameters involved in the experiments are:

- Temperature (ºC)
- Speed of extrusion (mm/min)

The following charts show how the temperature affects weight and thread diameter at constant speeds (Figure 6 and Figure 7) and how the speed influences the weight and the thread thickness as well (Figure 8 and Figure 9). Reference information for the speed values can be found in Table 1.

Figure 4 Collection of extruded samples with paraffin wax

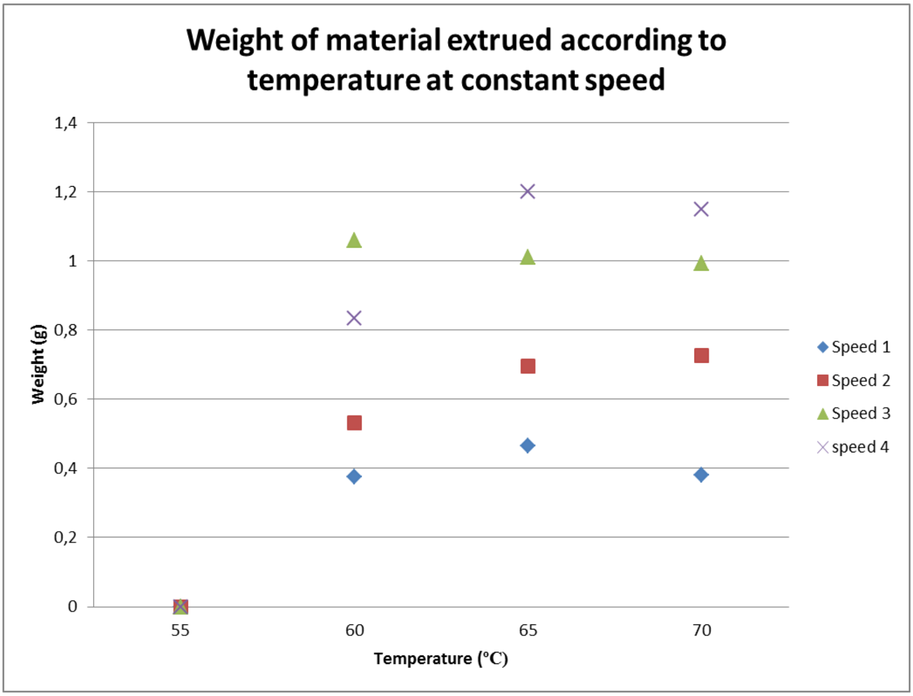


Figure 5 Weight of material extruded according to temperature at constant speed. Standard deviation of the order of ±0,712 mm were observed.

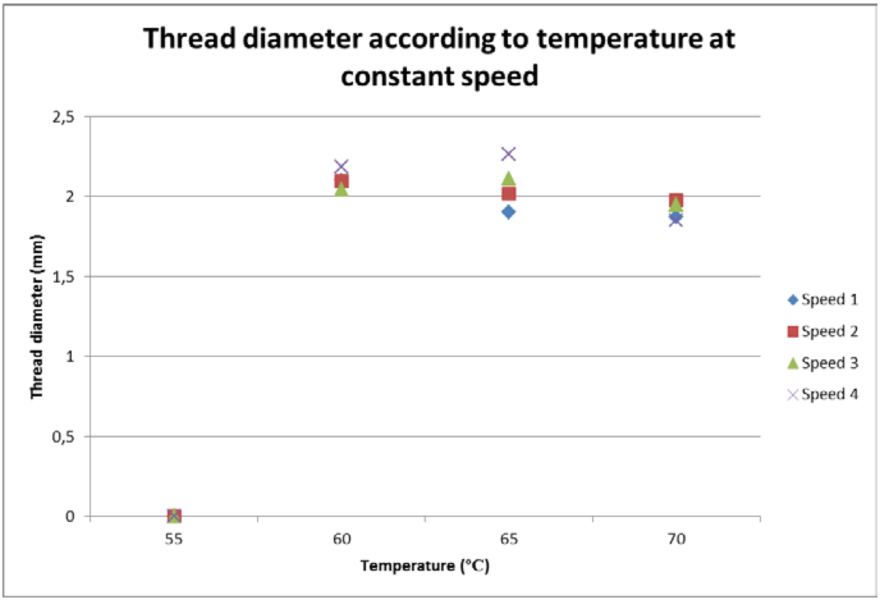


Figure 6 Thread diameter according to temperature at constant speed

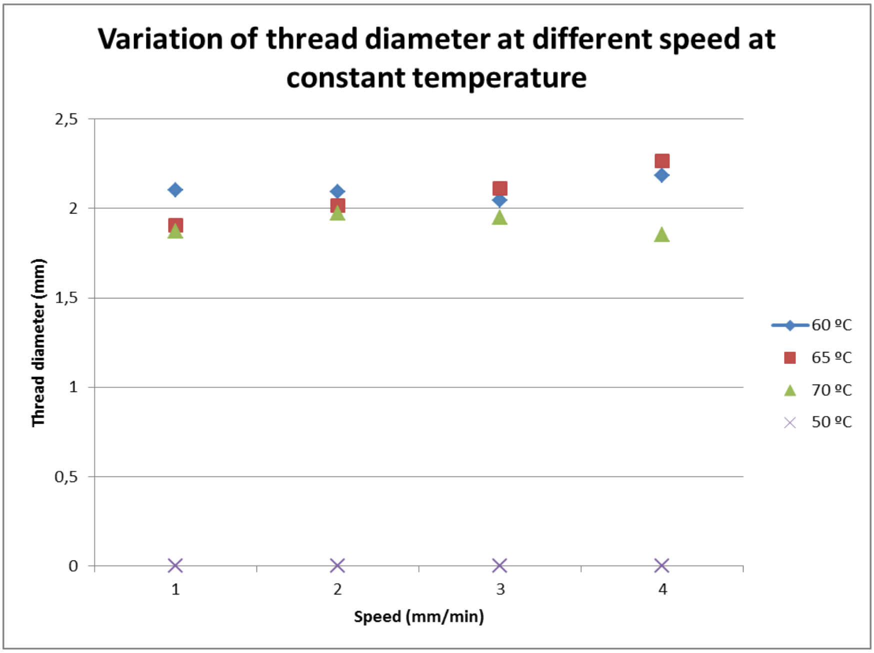


Figure 7 Variation of thread diameter at different speed at constant temperature

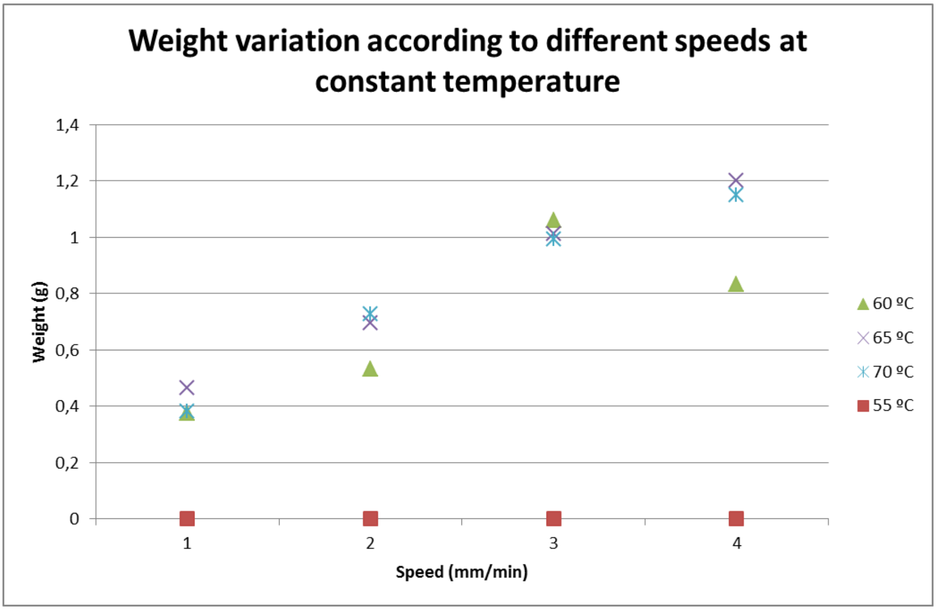


Figure 8 Weight variation according to different speed at constant temperatures. Standard deviation of the order of ±0,712 mm were observed.

5. DISCUSSION

The experiments confirm the first assumption, on the possibility to print paraffin wax on FDM by using a spur gear based extrusion system, resembling the one conventionally used for polymer extrusion in FDM. Figure 5 shows a series of extruded threads at different parameters.

Figure 6, Figure 7, Figure 8 and Figure 9 show the dependency of the process from speed and temperature. Figure 6 shows how the amount of material extruded increases with the increasing of the temperature. This is verified at constant speed and regardless of the speed used. However for Speed 1, Speed 2 and Speed 3 the amount of material extruded is rather constant, whereas if Speed 4 is considered there is a larger difference for the material extruded between 60ºC and 65ºC. This means that if the speed of deposition is increased, also the temperature of the nozzle has to be necessarily increased as well in order to shorten the time used by the paraffin wax to reach the transition temperature. For lower speeds, a lower temperature can be used instead.

As for the speed, can be seen that for constant temperatures of extrusion, this does not affect the thickness of the thread (Figure 8) but very much the amount of material extruded (Figure 9) which has a linear behavior.

During the experiments it is observed that for temperatures between 60ºC and 65ºC the thread maintains a cylindrical shape during extrusion and the consistency of the wax is more compact. For higher temperatures the wax would sink on the build plate, expanding on the sides and obtaining a flat bottom. This is due to the lowering of the viscosity with the increasing of the temperature. The wax is therefore more liquid and more difficult to control in its deposition.

After the tests and visual observations can therefore be estimated that optimal parameters can be found between the following ranges:

- 60ºC and 65ºC
- 24mm@48mm/min and 36mm@72mm/min.

The process window is visualized and shown in Figure 9.

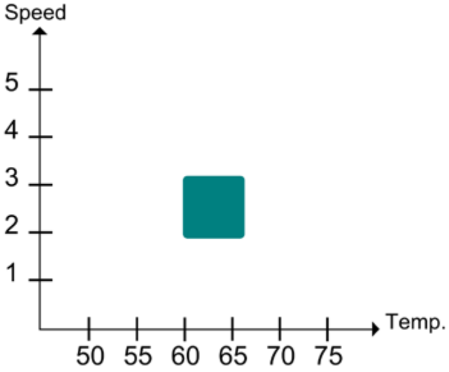


Figure 9 Estimation of the process window of the presented system, for the extrusion of paraffin wax

6. CONCLUSIONS AND FUTURE WORK

To conclude:

- The experiments were successful and it was proven that it is possible to extrude the paraffin wax with a geared extruder controlled by a stepper motor
- By changing the parameters of the system it is possible to influence the feed ratio, the viscosity of the wax and therefore control the extrusion process
- Temperature and speed are key factor during the extrusion of wax.
- Future work will aim to install the set up on a Cartesian platform, and perform some prints in simple geometries to test the behavior when creating layers as well as perform more tests among shorter intervals of temperatures and speeds.

REFERENCES

Carlen, E. T., & Mastrangelo, C. H. (2002). Electrothermally activated paraffin microactuators. *Journal of Microelectromechanical Systems, 11*(3), 165–174. doi:10.1109/JMEMS.2002.1007394

D'Angelo, G. (2012). *System Design for a Wax Material Addition Unit for Fused Deposition Modelling in Additive Manufacturing*.

David Bue Pedersen. (2013). *Additive Manufacturing. Multi Material Processing and Part Quality Control*. Technical University of Denmark.

Freund, M., Csikos, R., Keszthelyi, S., & Mozes, G. Y. (1982). *Paraffin products, properties, technologies, applications*. Elsevier.

Ian Gibson, David W. Rosen, B. S. (2010). *Additive Manufacturing, Rapid Prototyping to Direct Digital Manufacturing*. (Springer, Ed.).

Jhon Excell, S. N. (2010). The rise of Additive Manufacturing. *The Engineer*. Retrieved from http://www.theengineer.co.uk/in-depth/the-big-story/the-rise-of-additive-manufacturing/1002560.article

Jones, R. O., Irvani, P., Bowyer, A. (2012). *Rapid Manufacturing of Functional Engineering Components. Other*. Bath, UK.

Liu, R. (2004). Single-use, thermally actuated paraffin valves for microfluidic applications. *Sensors and Actuators B: Chemical, 98*(2-3), 328–336. doi:10.1016/j.snb.2003.09.037

Malone, E., & Lipson, H. (2007). Fab@Home: the personal desktop fabricator kit. *Rapid Prototyping Journal, 13*(4), 245–255. doi:10.1108/13552540710776197

Mills, N. (2005). *Plastics microstructure and engineering applications* (Thrid.). Elsevier.

Olfmeier, U. W. E. W., Aktiengesellschaft, H., & Gersthofen, W. (2012). Republic of Germany Federal Republic of Germany. doi:10.1002/14356007.a28

Serope Kalpakjian, S. R. S. (2010). *Manufacturing Engineering and Technology* (Sixth edit.). Prentice Hall.

Templin, P. R. (n.d.). Coefficient of Volume Expansion for Petroleum axes and Pure n- araffins, 154–161.

Wolers, T. (2012). *Wholers Report 2012*.