PROJECT ACTIVITY SUMMARY

Process optimization and equipment upgrades for extrusion of 3D printer filament

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Contents

Introduction

Extrusion of a 3D printer filament is quite straightforward a process. Molten plastic is pushed through a round die exit and pulled through a cooling system at a set speed to manipulate the diameter of the round filament. The solidifying of the molten filament is often manipulated by running it through a water bath with a pre-determined temperature, or two in some cases. This ensures uniform cooling at an optimal pace.

Theoretically any thermoplastic can be turned into a filament with relatively simple process. In the market various kinds of desktop filament extruders have emerged. [1] [2] [3] There is a high level of interest among hobbyists of making filament with recycled materials at home, as the price of a good quality filament is relatively high for plastic assessed by mass unit [kg], when even the cheapest ones are in tens of euros per kilogram, ranging up to over 100 €. [4]

This document is a summary of the process optimization actions as well as equipment upgrades performed during the project funded by Tekes EAKR.

Extrusion process and equipment used in making 3D printer filament

The desktop filament extruders are slow and uncontrollable in terms of filament tolerances. Optimally the deviation for the diameter is less than 3%. [5] Getting a filament of such demanding tolerance is challenging on an industrial scale, and even more so with a small machine with no means of quality control. The equipment at Arcada falls somewhere between the two; the industrial scale fast processes and home, desktop filament production.

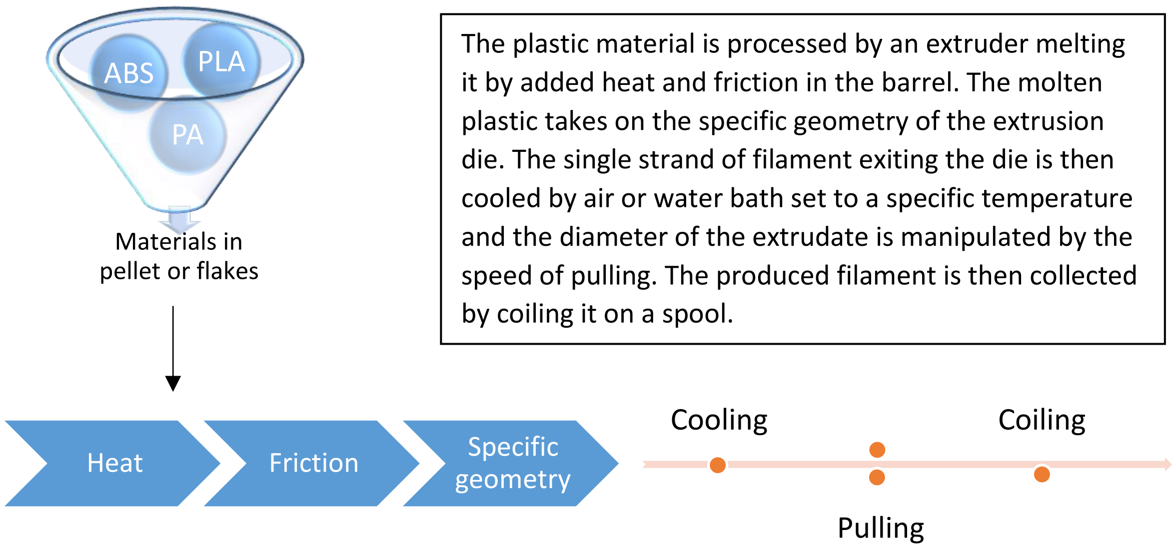

Figure 1: The schematic process of extrusion

The Figure 1 above shows a schematic of the extrusion process, the blue section in the left representing the actual extrusion process and the pink section on the right the processes that come after the plastic exits the die. The most important process parameters affecting the diameter and shape of the extrudate that can be adjusted in the process are temperature of both, the molten plastic within the extruder and the cooling measures after, and the speed of pull.

In addition to the process parameters, the shape of the die has a dramatic effect on the quality of the extrudate, as well as the angle it is introduced to its cooling method. Most monofilament dies output to the direction of gravitational pull to ensure a 90 degree angle of submerging in the cooling water. [6]

Extrusion die

During this work period, a new die was designed. The die previously in use was worn out as can be seen in Figure 2 below. This was due to it being made of material too soft to maintain its geometry under the high processing temperatures and pressures typical to the extrusion process. The aluminium die plates had clearly deformed in use, including the surfaces that require a very specific shape and a tight fit to their counterparts. In Figure 2 the heavy deformation of the surface to be attached to the breaker plate and sealed around it can be seen.

Figure 2: The damage in the old die adapter plate

There were some additional issues to consider in designing the new die. There were issues with build-up of material with the previous design, due to the exit hole being on the outer surface. [7] There were issues with oval cross sections in the filaments as well that were possibly due to land length of the die being less than optimal. [8] For most monofilament extrusion processes the land length/die exit diameter ratio is often within the range 2-5. [6]

Also the diameter of the die exit being only 2 mm it left very little room for adjusting the extrudate by pulling, and with some unconventional experimental materials the diameter of the obtained filament was too thin.

There were some additional requirements for the new die design to be met to ensure making the most of the purchase. All the design requirements are as listed below

1. Larger exit diameter to ensure better quality filament
2. Longer land length to ensure less fluctuation from the round shape [9]
3. Modularity
    a. to make a separate adaptor plate that can be used with other, previously made die plates (the adaptor is to reduce from the 18 mm breaker plate outlet to 10 mm die inlet)
    b. to make also possible to change the diameter of the filament die exit to experiment making 3 mm diameter filament as well, or higher drawing speeds
4. The die exit to have an outward step design to reduce the chance of build-up
5. Sustainable material selection

As the die in Arcada production laboratory will be used with a wide range of materials, from the conventional filament extrusion grade plastics (PLA, ABS) to more unconventional recycled plastics and composite materials, an approximately 3.2 ratio of die land length/diameter was chosen. A higher ratio allows the plastic to solidify/cool more inside the die land making it more likely for the extrudate to keep its desired shape, whereas a too long land length for any material can cause the pressure within the die to accumulate too high. There is extensive theory on how an optimal land length for each extrudate geometry and material is to be derived, but as the material is unknown, an aluminium prototype was first produced to test the design with the longer die land. [10]

Figure 3: The aluminium prototype. An additional disc was designed to cover the bolts from getting contamminated with molten plastic while in use to ensure easy dis-assembly.

The prototype seen in Figure 3 above has a 4 mm die exit. The prototype was successful, only minor tweaks were needed to the final design with a more expensive, sustainable material. In addition to the 4 mm diameter die exit, an additional die plate with a 6 mm diameter was designed with the same land length.

The 3D model of the first prototype can be observed online. [11]

The final die design is implemented in tool steel by a subcontractor, Py-Tas Oy. [12]

Additional equipment upgrades

The additional equipment include all the processing equipment used in the process after the extrudate has exited the die. The puller and the heating bath were upgraded, and plans for a diameter measurer and a pull speed monitor are explained.

The Filament Pulling Device

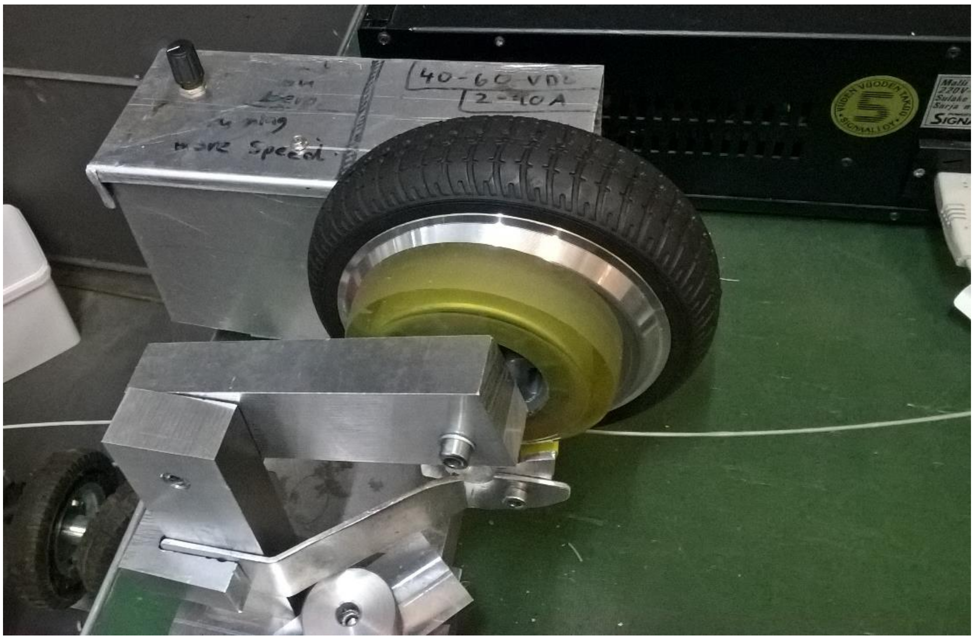

Figure 4: The new puller with filament

The puller was upgraded in order to obtain more constant pull and to reach higher speeds. Both these objectives were reached. However, the new puller does not have any means of observing the difference an adjustment in the speed makes.

In the future the puller is suggested to be updated so that the pull speed could be monitored and controlled better. Currently one can only blindly control it turning the knob at the top of the box without any shown value for the pull, making it impossible to actually repeat an experiment.

Cooling bath heating element

It is important for the cooling bath to have a set temperature with minimal fluctuation. This is important to ensure uniform extrudate quality for the entire length of production.

Previously the cooling water was heated by adding boiling water to the room temperature cooling water, but the water temperature fluctuated a lot causing a lot of instability. It was difficult to maintain high temperatures in the bath, making it impossible to focus on the entire experiment completely.

Figure 5: The new healing element in the cooling bath, resting on supports on the bottom of the bath

The heating element was shaped in a curvy fashion to cover the entire bottom level of the cooling bath to ensure uniform heating. The distance between the strands of the elements is approximately 5 cm. Because the element had to suit the cooling bath, it was designed in house and ordered from a subcontracting company. Note the shape of the element also taking into account the tubing in the cooling bath.

The heating is controlled by a digital thermostat next to the controls of the extruder, making it notably easier to use the heating in the cooling bath. No future improvements to suggest, performs as intended.

Future suggestions

Diameter measurer

The necessary materials to set up a bi-axial non-contact diameter measurer of the extrudate were obtained, but the actual setting up of the equipment will be done at a later time. At the end phase of the project, a novel and relatively very cheap solution was found. [13] It remains to be seen how well the equipment works. Optimally it will be attempted to be set so that it automatically controls the pull speed of the puller to obtain as uniform a diameter for the entire length of the extrudate as possible. The attempt will be made to set two of the simple diameter measurers in a bi-axial manner to assess the roundness of the extrudate as well.

Pull speed measuring equipment

It would be good to find an easy way to measure and monitor the pull speed. In the future, options for this should be assessed to increase the repeatability of experiments. The current method of adjusting the pull speed makes it impossible to even recognize the effect an adjustment might have on the production as there is no numerical value. For the sake of external reporting, the data unit would optimally be m/min or m/s (not RPM).

References

[1] 3devo, “3devo start page,” 3devo, [Online]. Available: https://3devo.com/. [Accessed 24 09 2017].

[2] Filastruder, “Products: Filastruder kit,” Filastruder, [Online]. Available: https://www.filastruder.com/products/filastruder-kit. [Accessed 24 09 2017].

[3] M. Lansard, “The best filament extruders for 3D printers,” Aniwaa, 19 05 2016. [Online]. Available: http://www.aniwaa.com/blog/the-best-filament-extruders-for-3d-printers/. [Accessed 24 09 2017].

[4] 3D Prima, “All Filaments,” Prima Printer Nordic AB, [Online]. Available: https://www.3dprima.com/filaments/all-filaments/. [Accessed 25 09 2017].

[5] NatureWorks LLC, “3D Printing Monofilament Guide for Ingeo Biopolymer,” [Online]. Available: http://www.natureworksllc.com/~/media/Files/NatureWorks/Technical-Documents/Processing-Guides/ProcessingGuide_Monofilament-for-3D-Printing_pdf.pdf. [Accessed 25 09 2017].

[6] J. R. Wagner, E. M. Mount and H. F. J. Giles, Extrusion: The Definitive Processing Guide and Handbook, New York: William Andrew, Inc., 2005.

[7] J. Perdikoulias and T. Cunningham, “Stop Die Buildup,” 1 1 2009. [Online]. Available: http://www.ptonline.com/articles/stop-die-buildup. [Accessed 22 09 2017].

[8] M. Lipponen, “Designing extrusion die for 3D filament manufacturing,” 09 06 2015. [Online]. Available: https://www.theseus.fi/handle/10024/96364.

[9] D. Cykana, “Tooling Know-How: Five Tips on Profile Die Design,” 01 01 2010. [Online]. Available: http://www.ptonline.com/columns/tooling-know-how-five-tips-on-profile-die-design. [Accessed 25 09 2017].

[10] W. Michaeli, Extrusion Dies for Plastics and Rubber; Design and Engineering Computations -3rd ed., Hanser Gardner Publications, Inc., 2003.

[11] AutodeskFiles, 2016. [Online]. Available: http://a360.co/29WXzaz.

[12] Py-Tas Oy, “Etusivu,” [Online]. Available: http://www.kolumbus.fi/py-tas.oy/index.html. [Accessed 25 09 2017].

[13] Objects with Intelligence LLC, “Filament Sensor Kit,” [Online]. Available: http://owi.storenvy.com/products/10451151-filament-sensor-kit. [Accessed 1 9 2017].