PLA Comparison Part I: Underextrusion

Summary

As part of an exploratory research into under-extrusion, twelve different materials from three suppliers are compared. The materials are tested on two Ultimaker 2 machines at ten extrusion speeds and two temperatures. The results show influence of the printer's build quality is most significant for the results across all materials tested. In the best situation, all materials seem to extrude at the maximum tested speed in the best adjusted printer at the highest tested temperature. Materials by Supplier 3 seem most unaffected by low temperature or worse build quality, while Supplier 1 material seems most affected.

Introduction

This report covers the first group of tests that aim to compare the behavior of PLA in Ultimaker 2 printers. As there are many different variables that amount to succesful printing, these tests are limited to a qualitative approach to serve as a first step in improving understanding of material-machine interaction.

The first experiment, as covered by this report, is designed to compare underextrusion symptoms for different materials. Under-extrusion is a situation which a printer extrudes less material than the instructions given to it. The resulting print loses build quality at layers where underextrusion occurs, or might display gaps or fail completely in more severe cases.

The causes of underextrusion are complex. Insufficient heating of the thermoplast inside the nozzle, blockages preventing molten material to pass either partially or totally, friction along machine parts and feeder failure all contribute. In each of these problems, some material property is a factor in the problem.

This experiment does not allow for discrimination as to which of these problems occurred. It is solely aimed at identifying which materials generate the most underextrusion problems in total.

Method

Material

Twelve PLA filaments from three suppliers, Supplier 1, Supplier 2 and Supplier 3 were selected for this test (Table 1). The newest materials available were used, with the oldest materials being around 3 months old. Because users report problems with certain colours of filament, the four most used filament colours were chosen as reported in [1].

Table 1: Specification of filaments used.

	Supplier 1	Production Date (DDMMYY)	Supplier 2	Production Date (DDMMYY)	Supplier 3	Production Date (DDMMYY)
White	'White'	16-04-14	'White'	12-05-14	'White'	12-05-14
Black	'Black'	29-04-14	'Black'	08-05-14	'Black'	09-04-14
Red	'Red'	22-04-14	'Red'	06-05-14	'Red'	20-05-14
Blue	'Ultimate Blue'	25-03-14	'Ultimate Blue'	16-05-14	'Ultimate Blue'	09-04-14

Print instructions

For the test, a G-code was based upon work by illuminarti, a community member [2].
The modified G-code builds single-line thick cylinders at ten different commanded volumetric flows, ranging from an estimated 1-10 cubic mm per second[1].

Two temperatures were tested: 210 and 230 degrees Celcius.
210 degrees Celcius was chosen because it is the standard Ultimaker setting for PLA, and 230 because research has indicated that higher head temperatures are needed at higher extrusion rates [3]

Printers

Two recently refurbished UM2 machines were set up and adjusted(Fig.1). To test whether they were fit for the experiment, some test prints were done on both printers using old UM stock filament, and any obvious problems were fixed.

To eliminate ordering effects as much as feasible, as well as to minimize machine influence on test results, each material was tested on both machines. Since three different suppliers were compared and 2 machines were available for testing, the testing order was shifted as detailed Table 2.

Table 2: Order effect compensation

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Etc.
Printer 1	Supplier 1	Supplier 2	Supplier 3	Supplier 3	Supplier 2	Supplier 1	**Etc.**
Printer 2	Supplier 2	Supplier 1	Supplier 3	Supplier 2	Supplier 3	Supplier 1	**Etc.**

[1] The reliability of calculating a commanded volumetric flow based upon gcode instructions is unknown due the complexity in the dynamics of the filament transport system.

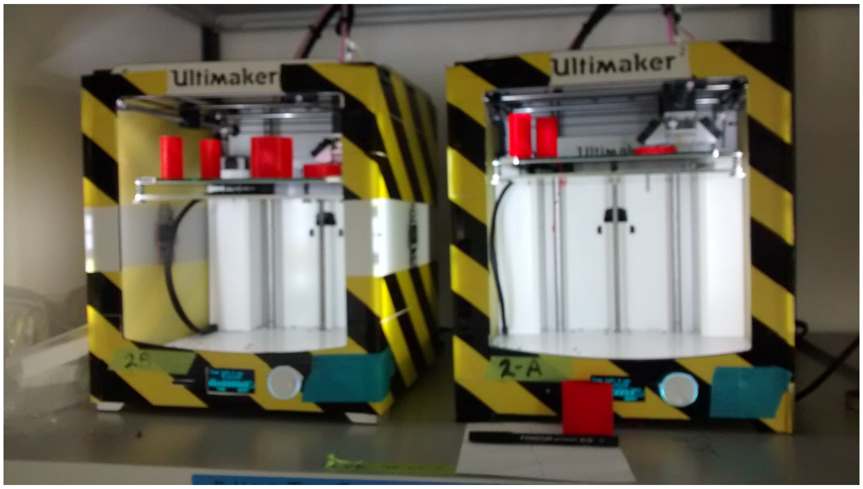


Fig. 1: Test Printers

Under-extrusion was rated by examination of the printed samples in direct sunlight and was reported when a discernible shortage of material was observe (Fig. 2.). Other defects observed were assumed to be either caused by movements of the print head or insufficient cooling due to the high print speeds. The geometry contains numbers and inset lines to delineate different volumetric flow rates. (Layer demarcation in Fig. 2.)

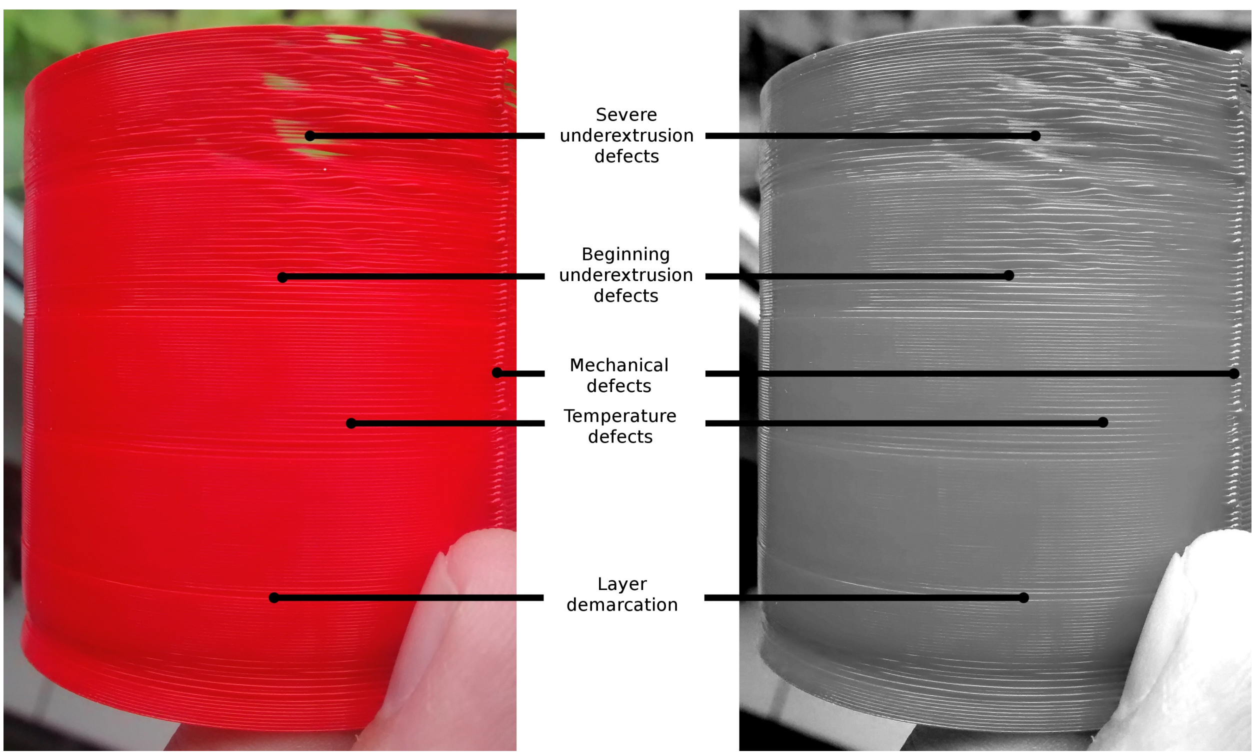


Fig. 2: Defect identification

Results

No under-extrusion defects were found in parts printed with commanded flow lower than 5 cmm/s.

Figures 3 and 4 show the measured commanded volumetric flow at which under-extrusion occurs, averaged over the two printers used, for 210C and 230C, respectively.

Figures 5 and 6 shows the same data separated for both printers.

Fig. 3: Underextrusion occurrence

Per supplier, averaged, 210C

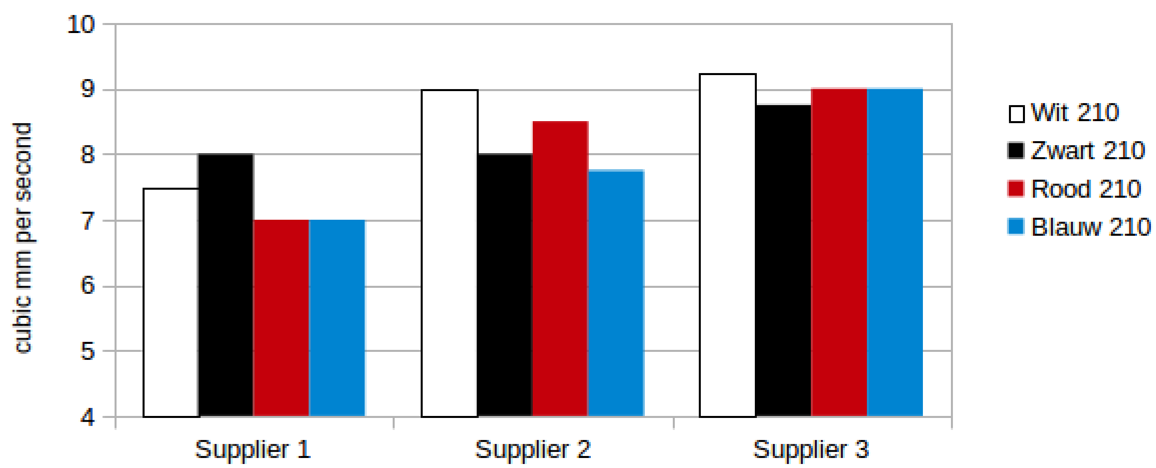
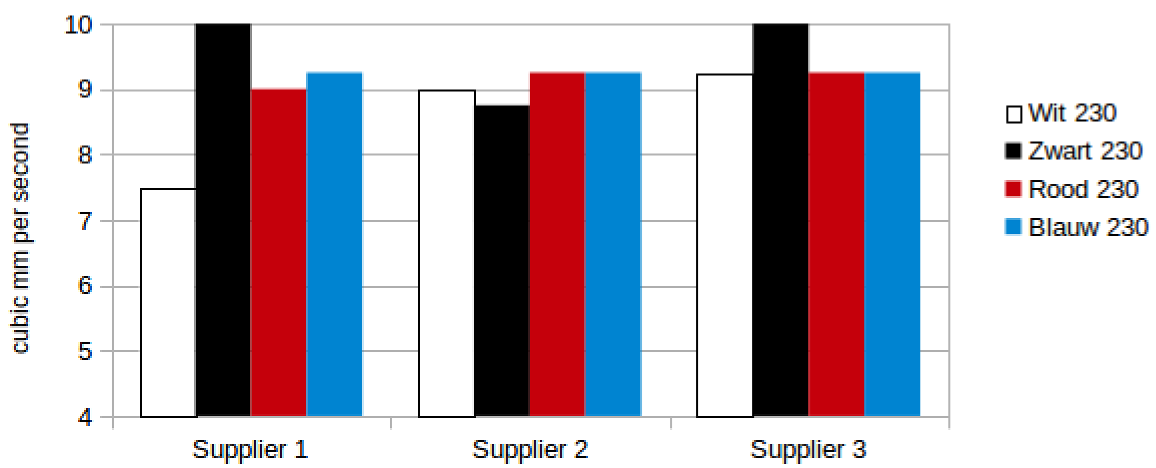


Fig. 4: Underextrusion occurrence

Per supplier, averaged, 230C



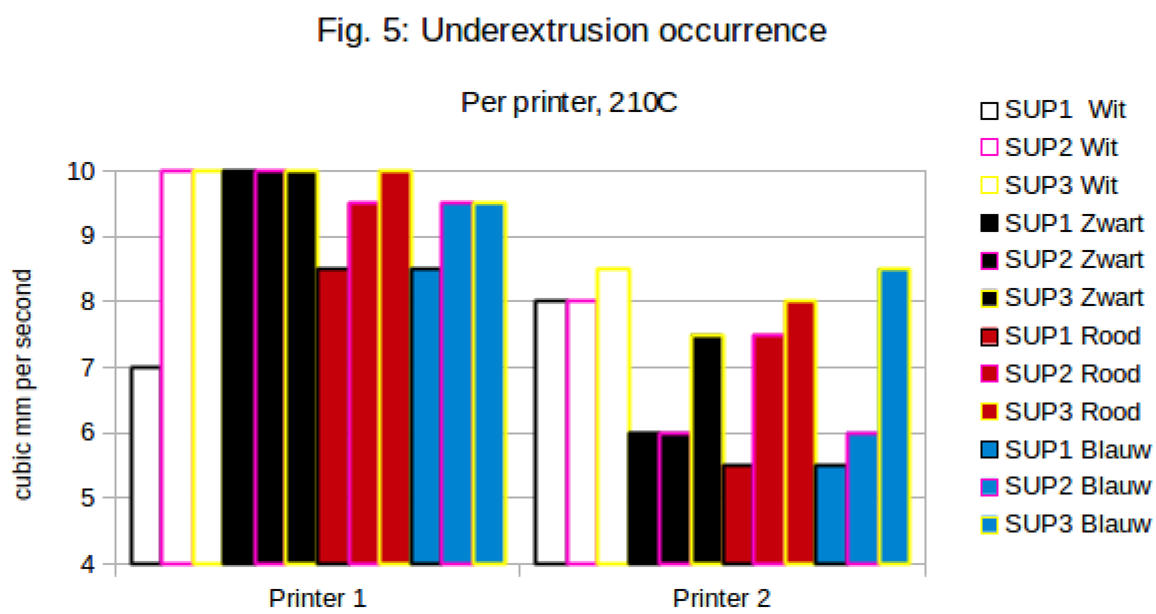


Fig. 5: Underextrusion occurrence
Per printer, 210C
cubic mm per second
10
9
8
7
6
5
4
Printer 1
Printer 2
SUP1 Wit
SUP2 Wit
SUP3 Wit
SUP1 Zwart
SUP2 Zwart
SUP3 Zwart
SUP1 Rood
SUP2 Rood
SUP3 Rood
SUP1 Blauw
SUP2 Blauw
SUP3 Blauw

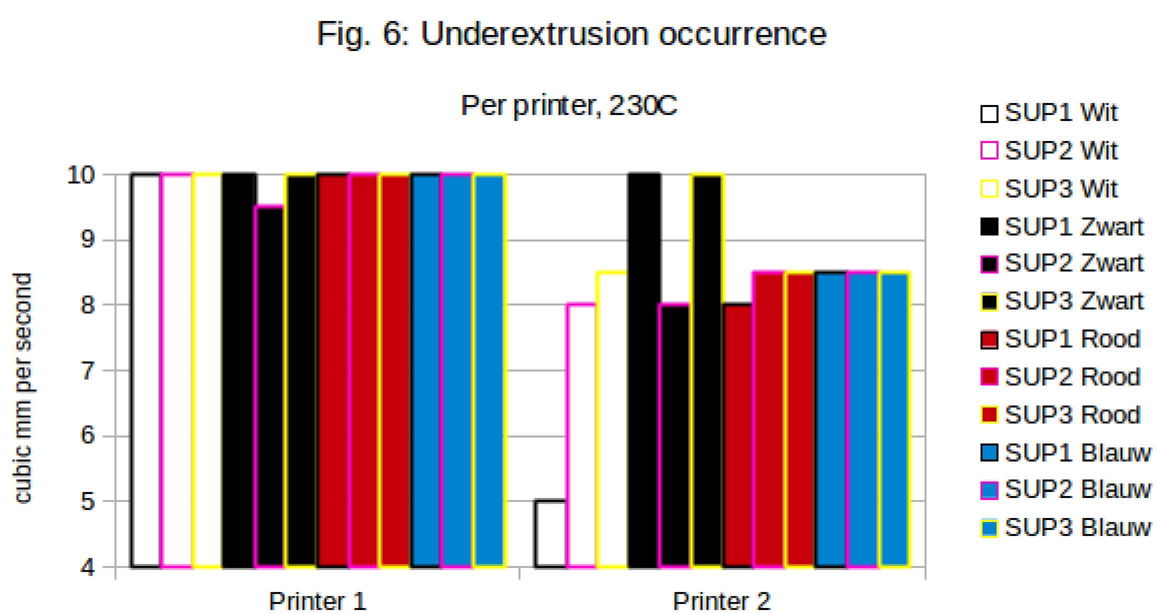


Fig. 6: Underextrusion occurrence
Per printer, 230C
cubic mm per second
10
9
8
7
6
5
4
Printer 1
Printer 2
SUP1 Wit
SUP2 Wit
SUP3 Wit
SUP1 Zwart
SUP2 Zwart
SUP3 Zwart
SUP1 Rood
SUP2 Rood
SUP3 Rood
SUP1 Blauw
SUP2 Blauw
SUP3 Blauw

Discussion

The results show a clear difference between the two printers used, regardless of the filament used. Especially worth noting is that on one of the printers, at a setting of 230C, eleven out of the twelve materials tested showed no clear under-extrusion signs at volumetric flows lower than 10 cmm/s. This seems to suggest that when avoiding under-extrusion is concerned, a well adjusted machine is more important than the choice of of materials.

The results of printer 2 (the one performing worst) more clearly discriminate between different filaments. Most likely printer 1 will show a similar discrimination at either lower temperatures, or at higher prints speeds. From this it can be concluded that when a qualitative comparison between materials needs to be made, it is best to test with badly performing printers or low temperature settings.

Materials by Supplier 3 show the least under-extrusion across the three suppliers, scoring higher or equal to both other suppliers in both printers at both temperatures. Supplier 1 materials seem to be most affected by printing and the badly performing second printer.

The difference in results between suppliers seems fairly consistent regardless of color. This suggests that the factor determining sensitivity to under-extrusion stems either from properties of the base material used, some additive included in all colors, or a difference in process. Consequently, further comparative research using natural PLA from different suppliers is warranted.

It should be duly noted that the validity of this research is very limited due to its scope and available resources. The score assigned to each material is subjective, and the color as well as amount of pigment used certainly influences the observation of under-extrusion. Lighter filaments allow for better judgment of changes in transparency and are easier to judge than darker filaments, for example. Furthermore, each unique set of variables was only tested once, which gives the result a low statistical significance. Lastly, environmental factors such as humidity, temperature, draft and many other factors could not be controlled, and their effects on these results are unknown.

Regarding the test itself, it is clear that temperature defects dominate at higher extrusion speeds due to there being insufficient time for the material to cool. Also, layer changes seem to create material buildup which aggregates and causes delamination in future layers. A fully spiralized approach with continuous would alleviate such defects. For the development of future under-extrusion tests these types of defects need to be avoided, especially for testing very high extrusion speeds.

Acknowledgement

Free samples for testing were provided by suppliers.
Development of testing G-Code was largely based upon work by Simon J. Oliver.

Citations

[1] 3D Hubs Trend Report, http://www.3dhubs.com/trends/2014-april, retreived at 20-05-2014
[2] A tougher underextrusion Test, http://umforum.ultimaker.com/index.php?/topic/5436-a-tougher-extrusion-test-o/, retreived at 05-06-2014
[3] Internal research by Jan Oosting