MANUAL FOR FABCONTROL™ OPTIMIZER

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Contents

1 Introduction

Lack of standards, feedstock material variability, batch-to-batch variations in composition and geometry make it impossible to rely on the once-determined 3D printing process parameters even for nominally the same feedstock materials. Each time 3D printing engineers have to arrive to the optimal 3D printing settings intuitively rather than purposefully. Moreover, it is a common practice to print the same G-code and to tweak the printer by changing extrusion temperature, printing speed, and flow rate while testing a new feedstock material. Such approach is inefficient and time-consuming; therefore, we felt that an urge existed to develop a consistent procedure to arrive to optimal printing settings.

Optimizer is one of the FabControl™ utilities to facilitate your 3D printing experience. Optimizer is a software tool which helps to optimize fused-filament fabrication (FFF) process parameters for a new feedstock material in a systematic and operator-independent way. Optimizer generates a series of G-codes with self-consistent test structures for a given 3D printing hardware configuration to determine the optimal 3D printing process parameters. The following 3D printing process parameters can be tested: (1) first-layer track height, and (2) first-layer track width, (3) first-layer printing speed, (4) track height, and (5) track width, (6) printing speed, (7) extrusion temperature, (8) extrusion multiplier, (9) retraction distance, (10) printing speed during bridging, and (11) extrusion multiplier during bridging.

Using Optimizer one can optimize the 3D printing process parameters for minimum printing time, or high-resolution printing, or good interlayer melt-together.

The following is the output of the Optimizer:

- optimal 3D printing process parameters for printing given feedstock material with a given hardware (3D printer, hotend, nozzle) which can be stored or even shared in FabControl™,
- downloadable PDF file with feedstock material test report for filing or sharing,
- downloadable configuration files for your slicing software (either FFF file for Simplify3D™ or INI file for Slic3r Prusa Edition, respectively),

- downloadable G-codes of common sample geometries listed in ISO 3167:2014 standard "Plastics – Multipurpose test specimens" sliced in FabControl™ environment using Slic3r Prusa Edition and the determined optimal 3D printing process parameters.

This document is a manual for using Optimizer. Here you can find all the information on preparations you need to take prior the tests, detailed descriptions of the available tests, and some hints on troubleshooting.

2 Selecting nozzle inner diameter

As mentioned above, Optimizer allows you to develop 3D printing process parameters optimized for three different targets:

- `Aesthetics` if you want to arrive to the 3D printing process parameters optimized for printing fine details,
- `Mechanical strength` if you want to arrive to the 3D printing process parameters optimized for printing parts for demanding applications, or
- `Short printing time` if you are ready to sacrifice high resolution and mechanical strength of the printed part for the short printing time.

Depending on what your preference is, select the suggested nozzle inner diameters from Table 2.1.

Target	Nozzle inner diameter
Aesthetics	0.10 – 0.40 mm
Mechanical strength	0.40 – 1.20 mm
Short printing time	0.60 – 1.20 mm

Table 2.1: Select the appropriate nozzle inner diameter, depending on what your target is.

Specifying 3D printing settings type in the `Target` dropdown menu of the `Test setup` tab, serves only for filing and information purposes only, and will not change the G-code generation algorithms. However, depending on what your target is, you will have to evaluate the running tests using slightly different criteria, e.g. validating the results with the higher printing speed values would result in the shorter printing time, whereas validating the results with smaller track height values would result in an enhanced part resolution. Such cases will be discussed below where appropriate.

3 Hardware preparations prior to testing

ONCE YOU HAVE SELECTED THE NOZZLE INNER DIAMETER, check that the nozzle is without defects (e.g. without rough edges, deep cuts, deformed surfaces).

NB! These tests rely very much on the right geometry of the nozzle, so if the capillary or the forming surface of the nozzle gets worn, the results of the tests will not be representative.

Use isopropyl alcohol to clean the inside and outside of the nozzle prior to installing it into the 3D printer. Mount the nozzle onto the effector according to the 3D printer manufacturer's guidelines, and make sure you reconnect the heating block tightly to the nozzle.

Prior to start with the Optimizer, be sure that:

- the pulleys are not loose,
- the belts are not loose,
- the bearings or rods are not worn or dirty.

Moreover, you have to:

- calibrate the feeder each time you replace the feedstock reel according to the procedure described below,
- calibrate the 3D printer according to the procedure described below,
- level the build platform each time you manipulate it (e. g. clean, reapply the coating etc.),
- decide whether you have to dry your feedstock material prior to printing or not.

NB! To ensure the reproducibility of the tests, we advice you to refresh the coating on the build platform prior to each print job by degreasing it with isopropyl alcohol, and reapplying the coating.

3.1 Feeder calibration

NB! This is just an exemplary calibration procedure, consult the manual for your respective 3D printer.

1. Disconnect the Teflon tube at the liquefier.
2. Using a sharp knife cut the feedstock material right to the length of the Teflon tube.
3. Go to `Manual Control` tab in Repetier-Host software and extrude 100 mm of the feedstock material.

4. If your firmware does not allow filament extrusion at low temperatures, run `M302 S1` command from `Manual Control` tab to enable cold extrusion.
5. Cut the feedstock material and repeat this procedure four more times.
6. Measure the average length of the cut pieces.
7. If the average length differs by more than $\pm$ 5 % from the set 100 mm you need to change the number of steps the step motor does to feed in one millimetre of feedstock material (`Steps per mm`) in the EEPROM settings. The new value for `Steps per mm` (s_{new}) should be calculated as follows:

$$s_{\text{new}}\,[\text{steps per mm}] = s_{\text{old}}\,[\text{steps per mm}]\frac{100\,\text{mm}}{l_{\text{average}}\,[\text{mm}]},$$

where s_{old} is the current value for `Steps per mm` and l_{average} is the average length of the cut feedstock material pieces. The EEPROM settings can be accessed directly from the main menu in the 3D printer, by pushing the context menu button in the `Settings` menu, or from the Repetier-Host software under `Config` $\rightarrow$ `Firmware EEPROM Configuration`.

4 Feedstock-material preparations prior to testing

4.1 Drying of feedstock material

Excess moisture contained in polymers can lead to hydrolysis of the polymer melt during fabrication. The moisture content in polymers differs from supplier to supplier, and also strongly depends on the filament storing conditions. Some commercially available polyamides can absorb moisture up to several weight percent under ambient conditions upon a prolonged exposure. Typical signs of moisture induced printing artefacts are splatter and spiting at the hotend due to water evaporating. This leads to 3D printing process instability, and results in poor surface quality of the prints and bad interlayer adhesion. You should use only well-dried feedstock to avoid any moisture related printing artefacts.

4.2 Feedstock-material impurities and process stability

Impurities on the surface or in the bulk of 3D printing filament can form debris, that can clog the nozzle or even the liquefier. We advise you to use powder-free gloves when loading the filament into the 3D printer to avoid its contamination with fat and sweat products from the hands, this is especially important when working with the nozzles having small inner diameters (< 0.4 mm). It is also a good idea to fix a piece of soft tissue or paper towel around the filament to wipe off the dust particles or other contaminants around the filament during feeding. Store filaments in a sealed plastic bag to avoid contamination.

5 Calibration procedure for Mass Portal delta 3D printers

THIS DELTA 3D PRINTER CALIBRATION PROCEDURE consists of two routines: the zero level of the build platform (i.e. the points where `Z = 0.0 mm`) is defined in the first stage using the `G36` build-platform levelling routine, and in the second stage the new build-platform level is verified and probed again with the `G37` tool compensation routine. This ensures that the same Z-height is maintained between the towers. If the `G37` routine fails to verify the newly defined Z-heights, you have to adjust the EEPROM parameters.

5.1 `G36` bed levelling routine

Make sure the `Printbed coating` value is set to 0.0 mm before performing this calibration procedure.

1. Run the `G36 S` command from the G-code command line under `Manual Control` tab in the Repetier-host software.
2. Place a piece of paper below the toolhead. Use toolhead controls under `Manual Control` to incrementally lower the toolhead to the build platform, so it barely touches the paper sheet. Move it down further by 0.1 mm. Moving the paper sheet back and forth, as the toolhead is lowered, may help detecting when the toolhead touches the paper sheet.
3. Run the `G36 X` command.
4. Repeat Step 2.
5. Run the `G36 Y` command.
6. Repeat Step 2.
7. Run the `G36 Z` command.
8. Run the `G32 S2` command. The printer will perform the automatic bed levelling procedure.

5.2 `G37` validation routine

1. Enter `G37` command. The print head should move to the centre of the build plate `X = 0 mm`, `Y = 0 mm`.

2. Verify the Z-height value by placing a paper sheet below the toolhead and lowering the toolhead to its lowest position, i.e. `Z = 0.00 mm`. The toolhead should firmly hold down the paper sheet, but it should still be moveable. Note down the Z-height value.
3. Enter `G37` command. The printhead should move to the X tower.
4. Repeat Step 2.
5. Enter `G37` command. The printhead should move to the Y tower.
6. Repeat Step 2.
7. Enter `G37` command. The printhead should move to the Z tower.
8. Repeat Step 2.
9. Enter `G37` command. The printhead should move in between the X-Y towers.
10. Repeat Step 2.
11. Enter `G37` command. The printhead should move in between the Y-Z towers.
12. Repeat Step 2.
13. Enter `G37` command. The printhead should move in between the X-Z towers.
14. Repeat Step 2.

5.3 Adjustments

If the toolhead height between the centre, points at the towers, and points between the towers varies within ± 0.05 mm, further adjustments need to be made.

If the Z-height value in the centre point (`X = 0.0 mm`, `Y = 0.0 mm`) is higher than the Z-height value of the points next to the X, Y, Z towers, reduce the `Horizontal rod radius at 0,0` value in the EEPROM settings. Increase it, if the Z value in the centre point is lower than the Z-height value of the points next to the X, Y, Z towers. Reduce or increase the `Horizontal rod radius at 0,0` value in `0.05 mm` steps. Run `G36` and `G37` routines once again. If the Z-heights values next to the X, Y, Z towers are not equal within 0.02-0.03 mm, run `G36` and `G37` routines again.

The EEPROM settings may be found in Repetier Host software under `Config` → `Firmware EEPROM Configuration`.

If any of the Z-heights between the towers X-Y or Y-Z or X-Z is lower than the other two increase the `Tower endstop Z offset` or `Tower endstop X offset` or `Tower endstop Y offset` in the EEPROM settings, respectively. Reduce or increase the `Tower endstop offset` values in 50 or 100 steps. One tower endstop offset always should be 0. Run `G36` and `G37` routines again.

6 Setting up Profiler

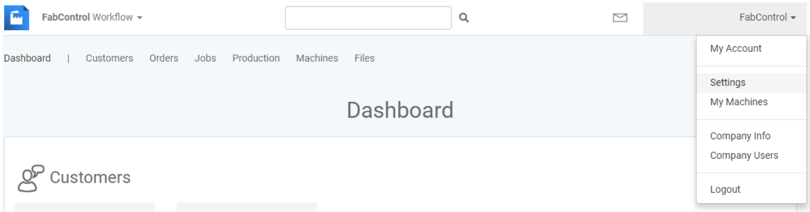
To use Optimizer you need to have Internet access and a valid FabControl™ account.

You also need to enable Profiler and Optimizer, and your 3D printer and material should be registered in FabControl™. This chapter briefly describes how to enable Profiler and Optimizer tools in FabControl™, and to add your 3D printer and material to FabControl™.

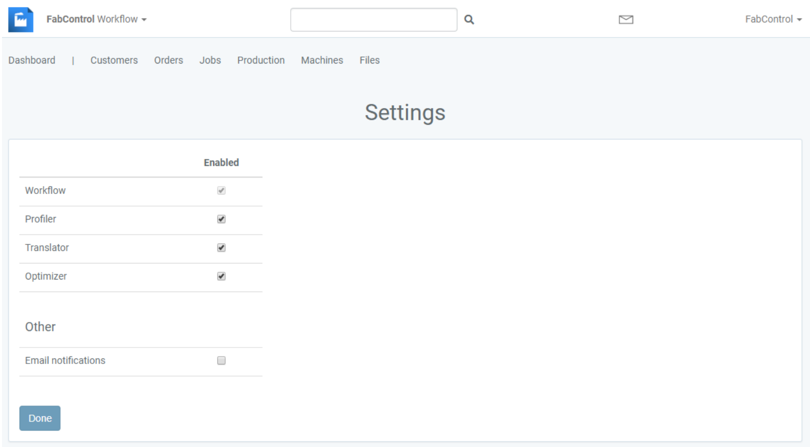
6.1 Enabling Profiler and Optimizer

1. Go to `www.fabcontrol.app` and login to the account with your credentials:

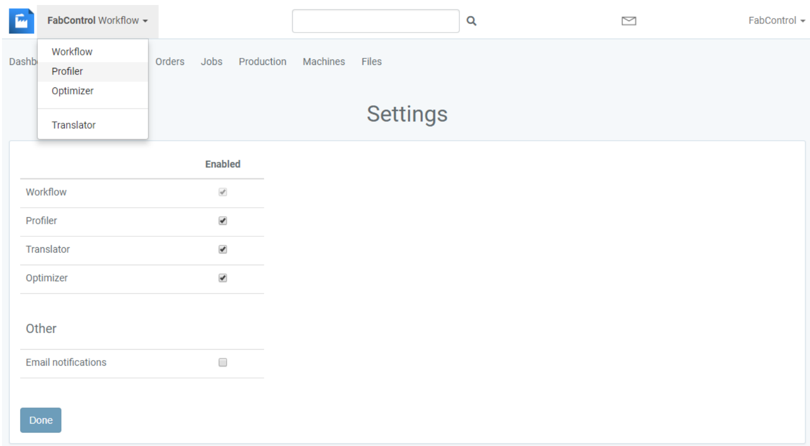
2. You will be redirected to the main window of FabControl™: Dashboard. In the top right corner of the screen you will see an icon with your company's name, click there, and select `Settings` from the dropdown menu:



3. Enable Profiler and Optimizer under `Settings` menu and click `Done` to save the changes:

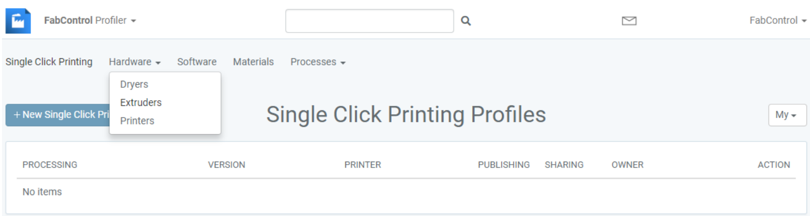


4. You will be able to see Profiler and Optimizer in the top left dropdown menu. Click on Profiler:



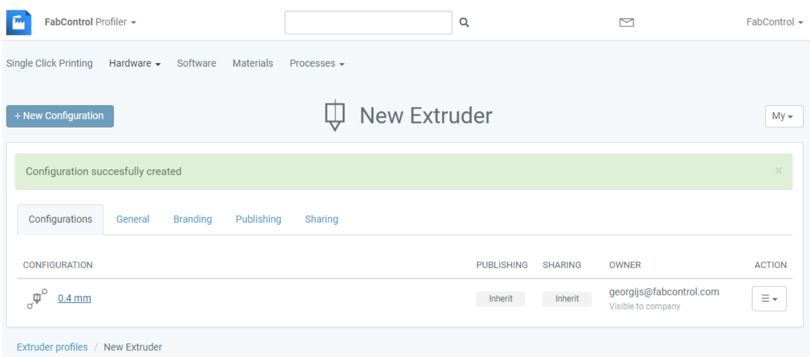
6.2 Creating Extruder Profile

1. Select `Extruders` from the `Hardware` dropdown menu in the main navigation bar and click on the button `+ New Extruder Profile` to create a new extruder profile:



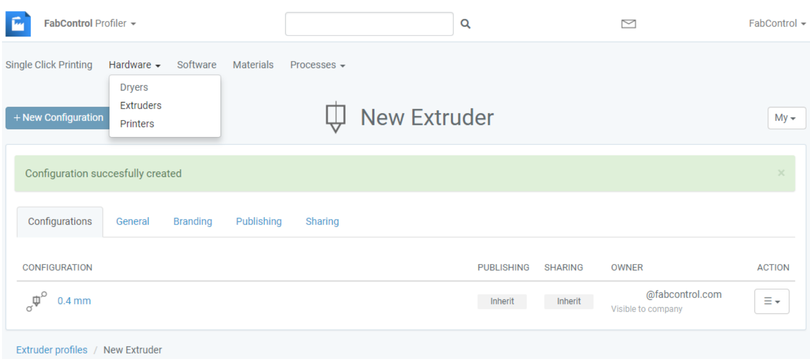
2. Give a name to the new extruder profile (required field) and fill in other optional fields. Click `Done` to save the changes.
3. Click on the `+ New Extruder Configuration` button in the new window where you can configure the new extruder. Fill in all the required fields and click `Done` to save the changes. You will see a new extruder profile appear:

If you do not enable the "Hide from others in my company" option, your colleagues will be able to see and use (but will not be able to edit) this configuration.



6.3 Creating 3D printer profile

1. Select `Printers` from the `Hardware` dropdown menu in the main navigation bar to create a new printer profile and click on the button `+ New Printer Profile`:



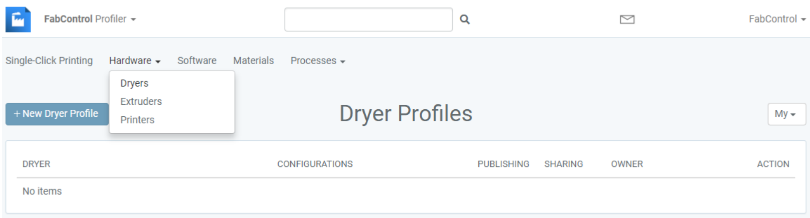
2. Give a name to the new printer profile (required field) and fill in other optional fields. Click `Done` to save the changes.

3. Click on the `+ New Printer Configuration` button in the new window where you can configure the new printer. Fill in all the required fields, in the Tools section select the right configuration of the extruder and click `Done` to save the changes. You will see a new printer profile appear.

If you do not enable the "Hide from others in my company" option, your colleagues will be able to see and use (but will not be able to edit) this configuration.

6.4 Creating a dryer profile

1. Select `Dryers` from `Hardware` dropdown menu in the main navigation bar to create a new dryer profile and click on the button `+ New Dryer Profile`:

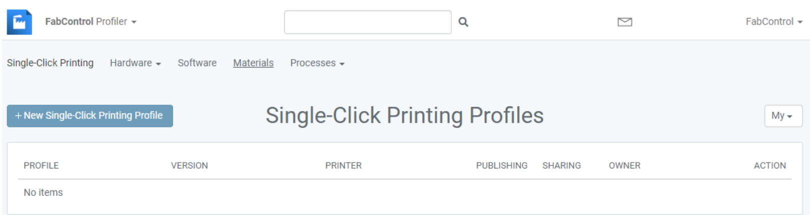


2. Give a name to the new dryer profile (required field) and fill in other optional fields. Click `Done` to save the changes.
3. Click on the `+ New Dryer configuration` button in the new window where you can configure the new dryer. Fill in all the required fields and click `Done` to save the changes. You will see a new dryer configuration appear.

If you do not enable the "Hide from others in my company" option, your colleagues will be able to see and use (but will not be able to edit) this configuration.

6.5 Creating a material profile

1. Click on `Materials` from the main navigation bar:

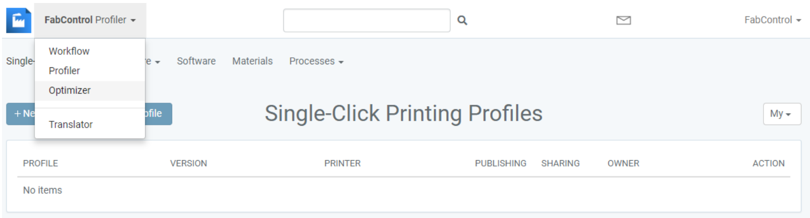


2. By clicking on the `+ New Material Profile` button you can configure a new material. Give a name to the new material (required field) and fill in other optional fields. Click `Done` to save the changes. By clicking on the `+ New Product Profile` button you can configure a new product profile. Fill in all the required fields and click `Done` to save the changes. You will see a new product profile appear under your materials list.

If you do not enable the "Hide from others in my company" option, your colleagues will be able to see and use (but will not be able to edit) this configuration.

6.6 Initializing a new Optimizer testing session

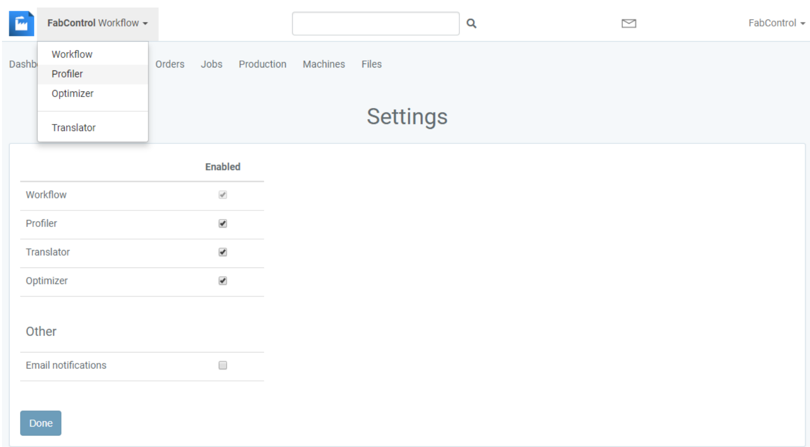
1. Go to the Optimizer tab by clicking on the top left dropdown menu from the main Profiler window:



2. Click on the button `New Testing Session`.
3. In `Printer` dropdown menu you will see all your 3D printers registered in FabControl™. Select the 3D printer and its configuration you want to use for your tests. Make sure the nozzle geometry parameter values stored in the software correspond to those of the currently installed nozzle.
4. In `Material` dropdown menu you will see all your materials registered in FabControl™. Select the material you want to run through the tests.
5. Depending on your preference, select one of the targets from `Target` dropdown menu.

6.7 Configuring a new drying process

1. Click the top left dropdown menu, select Profiler:



2. In the `Processes` dropdown menu from the navigation bar select `Drying`.

3. By clicking on the `+ New Drying Process` button you can configure a new drying process for a certain material. Give a name to the new drying process (required field), select the right material and dryer. Under `Drying Steps` add drying steps which can be of two types: Drying or Conditioning. In the drying step the material will be intensively dried under the conditions you specify. The conditioning step follows the drying step and is meant to condition the dried material during the printing process (usually at a lower temperature compared to the drying step). Click `Done` to save the changes.

If you do not enable the "Hide from others in my company" option, your colleagues will be able to see and use (but will not be able to edit) this configuration.

7 General description of test structures

7.1 Test structures and test design

Figure 7.1 shows how a typical test structure looks like. Most test structures look the same and consist of the same parts: (1) a wipe strip to prime the nozzle, (2) a square raft structure to support (3) seven double-layered test structures with four segments printed with four different printing speed values.

The test structure size scales with the nozzle inner diameter.

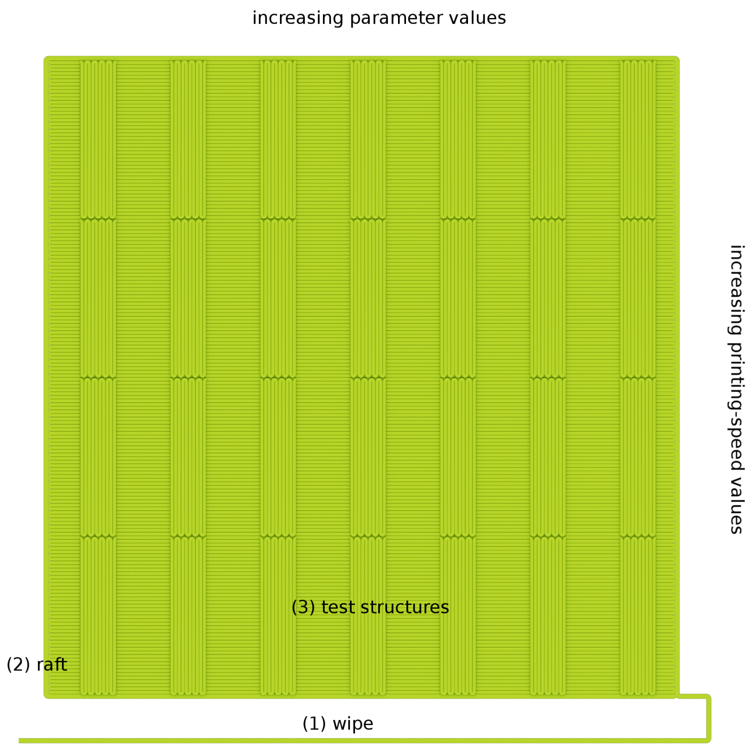


Figure 7.1: The test structure consists of the following parts: (1) a wipe strip to prime the nozzle, (2) a square raft structure to support (3) seven test structures on top. Note that seven parameter values to be tested increase in row from right to left, the printing speed increases from top to bottom. One can test up to $7 \times 4 = 28$ different combinations of 3D printing parameters in a single print.

The tests for the `First-layer track height` and `First-layer track width` do not have the raft structure, and consist of a wipe strip and seven single-layered test structures. The tests for the

`First-layer track width`, `Printing speed` and `Retraction speed` are printed at a constant printing-speed value.

In the beginning of the generated G-code you will see comments summarizing the testing conditions and values to be tested; along the further G-code text you will see comments describing the actual commands being executed (see Figure 7.2).

Such test design allows to systematically test up to $7 \times 4 = 28$ different combinations of 3D printing parameters in a single print, and allows to a certain degree to separate the mutual influence of the 3D printing parameters.

```
1 ;FabControl Material Testing G-code
2 ;--- start header ---
3 G28; move to the home position
4 G21; unit in mm
5 G92 E0; reset extruder
6 M83; set extruder to relative mode
7 M302 S1; allow cold extrusion
8 ;--- end header ---
9
10
11 G91
12 ; --- 2D test for first-layer track height of Optimizer Material Product from  (batch: 40) using  model (SN: 12345) and 0.4 mm brass nozzle---
13 ; --- testing the following first-layer-track-height values: 0.119 mm, 0.136 mm, 0.153 mm, 0.169 mm, 0.186 mm, 0.203 mm, 0.220 mm ---
14 G90
15 G1 X0.000000 Y0.000000 E0.000000
16 G91
17 G1 F8400
18 G90
19 G1 X-60.000000 Y-60.000000 Z0.400000 E0.000000
20 G91
21 ; --- start to clean the nozzle ---
22 M109 S220 T0; set the extruder temperature and wait till it has been reached
23 G4 P5000 T0; set the waiting time in ms
```

Figure 7.2: An example of a G-code for the First-layer-track-height test. In line 12 one can see a summary of the test: tested material, its ID, used 3D printer and nozzle. In line 13 one can see the first-layer-track-height values to be tested.

Table 7.1: Overview of the main test parameters and their values in different tests.

	(1)	(2)*	(3)	(4)*	(5)*	(6)	(7)	(8)	(9)
First-layer extrusion temperature	determined before the tests								
First-layer track height	from (1)								
First-layer track width	d	from (2)							
First-layer extrusion multiplier	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
First-layer printing speed	from (1)								
Extrusion temperature	–	–	from (3)						
Track height	–	–	**	from (4)					
Track width	–	–	d	d	from (5)				
Extrusion multiplier	–	–	1.00	1.00	1.00	from (6)			
Printing speed	–	–	from (3)(4)(5)(6)(7)						
Retraction distance	–	–	–	–	–	–	–	from (8)	
Retraction speed	–	–	–	–	–	–	–	from (8)	
Bridging printing speed	–	–	–	–	–	–	–	–	from (9)
Bridging extrusion multiplier	–	–	–	–	–	–	–	–	from (9)
Travel speed	defined before the tests								

Legend:
(1) First-layer track-height test
(2) First-layer track-width test
(3) Extrusion temperature test
(4) Track-height test
(5) Track-width test
(6) Extrusion-multiplier test
(7) Printing-speed test
(8) Retraction-distance test
(9) Bridging test
* these tests are optional
** depends on the selected target
d stands for nozzle inner diameter
– means that this value is irrelevant for the given test

7.2 Criteria for selecting test structures

This section summarizes up some qualitative criteria for selecting the best process parameters from the printed test structures.

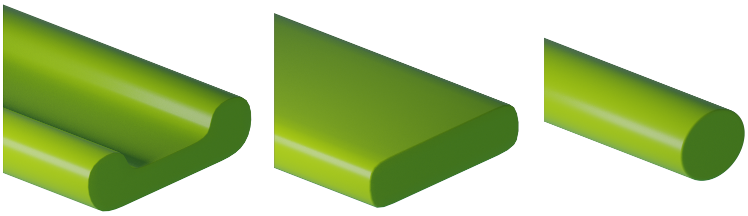


Figure 7.3: Typical shapes of separate tracks: *(left)* the extruded amount is too high (overextrusion) for the actual or set track height; *(middle)* the printing height, the printing speed, and the extruded amount are well-balanced; *(right)* the extruded amount is too low (underextrusion) for the actual or set track height, and the melt is not spread between the base layer and the nozzle.

The printing of the test structure begins with the wipe strip to clean the nozzle. Inspect whether the wipe strip reaches the zero Z-level. If it does not, it is an indication that your 3D printer is not properly levelled or calibrated. Repeat the calibration and/levelling procedure as described in the calibration procedure (if you have a Mass Portal 3D printer, see Calibration procedure for Mass Portal delta 3D printers).

Inspect the printed test structures. If the interval of the tested parameter and/or printing-speed values is too narrow, you will see that some of the 3D printing parameter combinations result in a better quality of the test structures. The separate tracks should be smooth and flat (with a rectangle-like cross section; see the middle image in Figure 7.3 for an example), consisting of continuous tracks; they also should have uniform track heights and widths, and with no bubbles or colour changes.

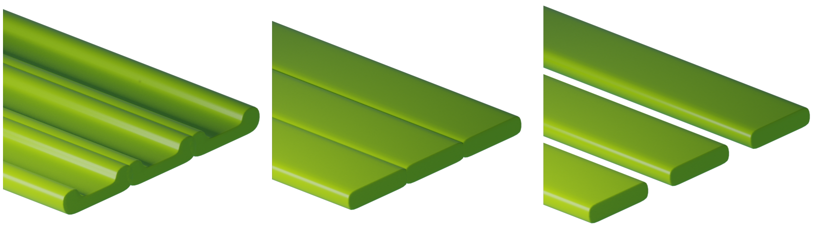


Figure 7.4: Typical shapes of several tracks building up a closed layer (from left to right): *(left)* the extruded amount is too high (overextrusion); *(middle)* the track height, the printing speed, and the extruded amount are well-balanced; *(right)* the extruded amount is too low (underextrusion) to create a closed layer.

When the separate tracks are printed next to each other and form a solid layer, it should be smooth and flat (with a rectangle-like cross section; see the middle image in Figure 7.4 for an example), consisting of continuous tracks with no gaps in between the tracks; they also should have uniform track heights and widths, with good melt-together, and with no bubbles or colour changes.

8 Available 3D-printing process-parameter tests

After having selected 3D printer and material, you can start the testing session by clicking the `Next` button. A new testing session will start with the `First-layer track-height test`. You also have to set `First-layer extrusion temperature`, `Part-cooling fan power`, `Travel speed` and `Printbed temperature` to generate any of the G-codes. These values will be used throughout the entire testing session.

8.1 First-layer track-height test

Often a determining factor in whether or not you will get a successful print is the quality of the first layer (i.e. whether it is well-adhering, solid and smooth). That is why the first test is the First-layer track-height test.

The first-layer track height can be smaller or larger than the regular track height. In order to be sure your first layer has a good hold on the build platform, you should print the first layer at a slower printing speed – usually 30-50 % of regular printing speed. This gives the melt enough time to spread and stick to the build platform.

1. In this test two parameters will be determined: the `First-layer track height` and the `First-layer printing speed`; these values will be used later through all the tests (see Table 7.1). For this test the `First-layer track-width` value is set equal to the nozzle inner diameter, but, if needed, it can be tested in a separate test (see First-layer track-width test for details). We do not define a separate value for the first-layer extrusion-multiplier, but effectively the `First-layer extrusion-multiplier` value is equal to the `Extrusion multiplier` and per default is set to 1.00 in this test.
2. In the field `First-layer track-height test values to be tested` you can see automatically generated seven default `First-layer track-height` values linearly spaced between the

minimum and maximum values. You can change these limiting values manually if you want to; by doing so all seven values of the first-layer track height will be automatically recalculated. The minimum value of the first-layer track height is limited to the one tenth of the nozzle inner diameter, the maximum value of the first-layer track height is limited to the nozzle inner diameter.

3. Enter the minimum and maximum first-layer printing-speed values into the fields `Minimum first-layer printing speed` and `Maximum first-layer printing speed`, respectively. Typically, first-layer printing speeds in the range of 5-15 mm/s are adequate for printing flexible materials. For harder materials, you can go up to 10-25 mm/s. If you set the printing speed too high, the melt will not have time to spread over the build platform, and it will result in the voids in between the tracks and bad adhesion to the build platform.

4. To determine the `First-layer extrusion temperature` you can do the following: Ramp the extruder temperature up starting from 180 °C. Monitor the temperature when the extrudate starts to exit the nozzle at a steady speed or if the diameter of the strand is too thin, try increasing the hotend temperature. Set the `First-layer extrusion temperature` to 20 °C higher. If a characteristic popping or hissing noise occurs while extruding, dry the filament. Consider using a filament dryer for longer prints and if the environment is humid.

If the firmware of your 3D printer does not allow that low extrusion temperatures, run the `M302 S1` command to enable cold extrusion.

5. Set the `Part cooling` based on your experience or the following considerations: Generally, active part cooling is needed when printing using high deposition rates and when printing fine details (i.e. when your `Target` is either `Short printing time` or `Aesthetics`, respectively).

`Target`	Part cooling fan power
`Aesthetics`	100 %
`Mechanical strength`	50 %
`Short printing time`	100 %

Table 8.1: Suggested part cooling fan setting depending on the target.

We strongly recommend you to perform the tests in a closed printing environment, as it keeps uncontrollable draughts low, gives you more control over the process and leads to more reproducible results. If you need a more efficient way to cool down your 3D printed part, use the built-in air exchange fans.

6. By pressing the `Next` button, you will generate the G-code. You can either download it to your hard drive it or send for printing. Run the First-layer track-height test.

7. Inspect the printed test structure. By clicking on the values, select one combination of the printing-speed and one first-layer-track-height values which results in the best test structure. A good test structure has flat, continuous tracks with no gaps between the tracks, and no grooves, it has uniform track heights

If the track does not adhere to the build platform, increase the `First-layer extrusion temperature` and run the test once again. If this does not help, try either to decrease the `First-layer printing speed` or to increase the `Printbed temperature` and/or try to apply another coating on the build platform.

and widths, with good melt together, and no bubbles or colour changes in the material. Inspect the bottom side of the printed structure as well. If you cannot find acceptable combination of the first-layer track height and first-layer printing speed, run the test again with different `First-layer extrusion-temperature` value and/or using different `Printing-speed` range.

8. Press `Next` to proceed.

8.2 First-layer track-width test

The next optional test is the First-layer track-width test. Run it only if you see voids in between the tracks in the First-layer track-height test.

Our experience shows that often it is not really necessary to run through all the tests, it will suffice to perform four tests in the following order: First-layer track-height test, Extrusion-temperature test, Printing-speed test, and Retraction-distance test. Other tests can be skipped by pressing on the `Skipt this test` button, but be aware that you cannot run the preceding tests.

1. In this test only one parameter will be determined: `First-layer track width`. To generate this test structure the `First-layer track-height` and `First-layer printing-speed` values determined in the First-layer track-height test will be used (see Table 7.1). Similarly, as in the previous test, the `First-layer extrusion-multiplier` value is set to 1.00 in this test, and cannot be changed.

2. In the field `First-layer track-width values to be tested` you can see automatically generated seven default `First-layer track-width` values linearly spaced between the minimum and maximum values. You can change these limiting values manually if you want to. The minimum value of the `First-layer track width` is limited to one half of the `Nozzle inner diameter`, the maximum value of the `First-layer track width` is limited to the double of the `Nozzle inner diameter`.

3. As the `First-layer printing-speed` value has already been determined in the First-layer track-height test, this value will be automatically used to generate the G-code for this test.

4. By pressing the `Next` button, you will generate the G-code. You can either download it to your hard drive it or send for printing. Run the First-layer track-width test.

5. Inspect the printed test structure. By clicking on the value, select one first-layer-track-width value which results in the best test structure. A good test structure has flat, continuous tracks with no gaps between the tracks, and no grooves, it has uniform track heights and widths, with good melt together, and no bubbles or colour changes in the material. Inspect the bottom side of the printed structure as well.

6. Press `Next` to proceed.

8.3 Extrusion-temperature test

After you have run through the First-layer track-height test (and, if needed, First-layer track-width test), you should know the printing parameters of the first layer (`First-layer extrusion temperature`, `First-layer track height`, `First-layer track width`, and `First-layer printing speed`), and you can proceed to the Extrusion-temperature test.

1. In this test two parameters will be determined: the `Extrusion temperature` and the `Printing speed`. To generate the raft for this test the `First-layer track-height` and `First-layer track-width`, as well as `First-layer printing-speed` values determined in the First-layer track-height test and First-layer track-width test will be used (see Table 7.1). The `Extrusion-multiplier` value is set to 1.00 in this test, but, if needed, it can be tested later in a separate test (see Extrusion-multiplier test for details).
2. In the field `Extrusion-temperature values to be tested` you can see automatically generated seven default `Extrusion-temperature` values linearly spaced between the minimum and maximum values. You can change these limiting values manually if you want to. The minimum value of the extrusion temperature is equal to the `First-layer extrusion temperature`, the maximum value of the extrusion temperature is limited to the `Maximum extrusion temperature` of the hotend.
3. Enter the `Minimum printing-speed` and `Maximum printing-speed` values. The `Minimum printing-speed` value can be approximately double the `First-layer printing-speed` value you determined in First-layer track-height test.
4. To generate a G-code one has also to specify the `Track width` and `Track height`. Set the `Track-width` value equal to the `Nozzle-inner- diameter` value. The value of the `Track height` depends on what your `Target` is. See Table 8.2 to select the right value.
5. By pressing the `Next` button, you will generate the G-code. You can either download it to your hard drive it or send for printing. Run the Extrusion-temperature test.

Table 8.2: Depending on what your `Target` is, select appropriate `Track-height` value. When selecting succeeded test structures, give preference to the `Extrusion-temperature` and `Printing-speed` values listed in the last columns.

`Target`	`Track height`	`Extrusion temperature`	`Printing speed`
`Aesthetics`	0.05 – 0.10 mm	lower	lower
`Mechanical strength`	0.20 – 0.25 mm	higher	higher
`Short printing time`	0.10 – 0.35 mm	much higher	much higher

6. Inspect the printed test structure. By clicking on the value, select one combination of the `Printing-speed` and one `Extrusion-temperature` values which results in the best test structure. A

good test structure has flat, continuous tracks with no gaps between the tracks, and no grooves, it has uniform track heights and widths, with good melt together, and no bubbles or colour changes in the material. If you cannot find acceptable values, re-run the test with the `Extrusion-temperature` range and/or `Printing-speed` range.

7. Press `Next` to proceed.

8.4 Track-height test

The next optional test is the Track-height test. This test is optional because the Track height is defined by your `Target`, i.e. desired printing resolution.

1. In this test two parameters will be determined: the `Track height` and the `Printing speed`. To generate the raft for this test the values determined in the First-layer track-height test and First-layer track-width test will be used (see Table 7.1). The `Extrusion-multiplier` value is set to 1.0 in this test, but, if needed, it can be tested later in a separate test (see Extrusion-multiplier test for details).
2. In the field `Track-height values to be tested` you can see automatically generated seven default `Track-height` values linearly spaced between the minimum and maximum values. You can change these limiting values manually if you want to. The minimum value of the track height is limited to the one tenth of the nozzle inner diameter, the maximum value of the first-layer track height is limited to nozzle inner diameter.
3. Although the `Printing-speed` value has already been found in the Extrusion-temperature test, enter the same `Minimum printing-speed` and `Maximum printing-speed` values you used in the Extrusion-temperature test.
4. By pressing the `Next` button, you will generate the G-code. You can either download it to your hard drive it or send for printing. Run the Track-height test.
5. Inspect the printed test structure. By clicking on the value, select one combination of the `Printing-speed` and one `Track-height` values which results in the best test structure. A good test structure has flat, continuous tracks with no gaps in between the tracks, and with no grooves, it has uniform track heights and widths, with good melt together, and with no bubbles or colour changes in the material. If you cannot find acceptable values, try to re-run the Extrusion-temperature test with another `Extrusion-temperature` range and/or `Printing-speed` range.
6. Press `Next` to proceed.

8.5 Track-width test

The next optional test is the Track-width test. Run it only if you see voids in between the tracks in the Track-height test.

1. In this test only one parameter will be determined: `Track width`. To generate this test structure the `Track-height` value either defined in the Extrusion-temperature test or determined in the Track-height test will be used (see Table 7.1). The `Extrusion-multiplier` value is set to 1.0 in this test, but, if needed, it can be tested later in a separate test (see Extrusion-multiplier test for details).
2. In the field `Track-width values to be tested` you can see automatically generated seven default `Track-width` values linearly spaced between the minimum and maximum values. You can change these limiting values manually if you want to. The minimum value of the track width is limited to the one half of the nozzle inner diameter, the maximum value of the first-layer track height is limited to the double nozzle inner diameter.
3. Although the `Printing-speed` value has already been found in the Extrusion-temperature test and validated in Track-height test, enter the same `Minimum printing-speed` and `Maximum printing-speed` values you used in the Extrusion-temperature test or Track-height test.
4. By pressing the `Next` button, you will generate the G-code. You can either download it to your hard drive it or send for printing. Run the Track-width test.
5. Inspect the printed test structure. By clicking on the value, select one combination of the `Printing-speed` and one `Track-width` values which results in the best test structure. A good test structure has flat, continuous tracks with no gaps in between the tracks, and with no grooves, it has uniform track heights and widths, with good melt together, and with no bubbles or colour changes in the material. If you cannot find acceptable values, try to re-run the test with another `Track-width` range.
6. Press `Next` to proceed.

8.6 Extrusion-multiplier test

The next optional test is the Extrusion-multiplier test. Run it only if you see voids in between the tracks in the previous tests.

1. In this test only one parameter will be determined: `Extrusion multiplier`. To generate this test structure you should know the `Extrusion-temperature`, `Track-height`, `Track-width` values, which either were defined or determined in the previous tests (see Table 7.1).

2. In the field `Extrusion-multiplier values to be tested` you can see automatically generated seven default `Extrusion-multiplier` values linearly spaced between the minimum and maximum values. You can change these limiting values manually if you want to. The minimum value of the extrusion multiplier is limited to 0.25, the maximum value of the extrusion multiplier is limited to 2.00.
3. Although the `Printing-speed` value has already been found in the previous tests, enter the same `Minimum printing-speed` and `Maximum printing-speed` values you used in the Extrusion-temperature test or Track-height test.
4. By pressing the `Next` button, you will generate the G-code. You can either download it to your hard drive it or send for printing. Run the Extrusion-multiplier test.
5. Inspect the printed test structure. By clicking on the value, select one combination of the `Printing-speed` and one `Track-width` values which results in the best test structure. A good test structure has flat, continuous tracks with no gaps in between the tracks, and with no grooves, it has uniform track heights and widths, with good melt together, and with no bubbles or colour changes in the material. If you cannot find acceptable values, try to re-run the test with another `Track-width` range.
6. Press `Next` to proceed.

8.7 Printing-speed test

The next test is the Printing-speed test. Running this test allows you to squeeze out the maximum printing speed from your current settings.

1. In this test only one parameter will be determined: `Printing speed`. To generate this test structure the `Track-height` value either defined in the Extrusion-temperature test or determined in the Track-height test, and the `Extrusion-temperature` value either determined in the Extrusion-temperature test will be used (see Table 7.1).
2. In the field `Printing-speed values to be tested` you should manually set the minimum and maximum values. While the minimum value of the printing speed is not limited, we recommend to set it to 90 % of the `Printing-speed` value determined in the previous tests. The maximum value of the printing speed is limited to the maximum printhead moving speed (250 mm/s). Note that printing at very high printing speeds can lead to hardware-related artefacts such as vibration or ringing/ghosting.
3. By pressing the `Next` button, you will generate the G-code. You can either download it to your hard drive it or send for printing. Run the Printing-speed test.

4. Inspect the printed test structure. By clicking on the value, select one `Printing-speed` value which results in the best test structure. A good test structure has flat, continuous tracks with no gaps in between the tracks, and with no grooves, it has uniform track heights and widths, with good melt together, and with no bubbles or colour changes in the material. If you cannot find acceptable values, try to re-run the test with another `Printing-speed` range.
5. Press `Next` to proceed.

If you suspect that the actual printing speed is not increasing anymore while printing the G-code, it could also be an indication that your acceleration and jerk settings are too high. Consult your 3D printer manual to change the jerk value.

8.8 Retraction-distance test

The next test is the Retraction-distance test.

1. In this test only one parameter will be determined: `Retraction distance`. To generate this test structure the `Track-height` value either defined in the Extrusion-temperature test or determined in the Track-height test, the `Extrusion-temperature` value either determined in the Extrusion-temperature test, and the `Printing-speed` value determined in the Printing-speed test will be used (see Table 7.1).
2. In the field `Retraction-distance values to be tested` you should manually set the minimum and maximum values. The minimum value of the retraction distance is limited to 0.00 mm. The maximum value of the retraction distance is limited to 10.00 mm.
3. Set the desired retraction speed. Do not use values greater than 120 mm/s.
4. By pressing the `Next` button, you will generate the G-code. You can either download it to your hard drive it or send for printing. Run the Retraction-distance test.
5. Inspect the printed test structure. By clicking on the value, select one `Retraction-distance` value which results in the best test structure. A good test structure should have minimum amount of strings in between the supporting columns. If you cannot find acceptable values, try to re-run the test with lower or higher `Retraction speed`, or `Retraction-distance` range.
6. Press `Next` to proceed.

8.9 Bridging test

The next test is the Bridging test.

1. In this test two parameters will be determined: `Bridging extrusion multiplier` and `Bridging printing speed`. To generate this test structure all the previously determined or defined values will be used (see Table 7.1).

2. In the field `Bridging extrusion-multiplier values to be tested` you should manually set the minimum and maximum values. The minimum value of the extrusion multiplier is 1.00. The maximum value of the extrusion multiplier is limited to 2.00.
3. The support structures will be printed using the `Printing-speed` values determined in the previous tests. Enter the `Minimum printing-speed` and `Maximum printing-speed` values for printing the bridging structures. A good starting value could be a half of the `Printing-speed` value for the `Minimum printing speed` and double the `Printing-speed` value for the `Maximum printing speed`, respectively.
4. By pressing the `Next` button, you will generate the G-code. You can either download it to your hard drive it or send for printing. Run the Bridging test.
5. Inspect the printed test structure. By clicking on the value, select one `Bridging extrusion-multiplier` and `Bridging printing-speed` value combination which results in the best bridging structure. A good test structure should have continuous bridges parallel to the build platform. If you cannot find acceptable values, try to re-run the test with another `Bridging extrusion-multiplier` or `Bridging printing-speed` range.
6. Press `Next` to proceed.

9 Generating PDF test report

When you are done with the tests you can generate a PDF test report summarizing: hardware configuration, used material, main printing settings, conducted tests, tested values, selected values, selected flow rates, and comments.

FabControl Optimizer

Test report for Test Material Ø1.75 mm

Report generated on: 2018-10-22 10:43:31
Target: mechanical strength
Material: Test Material (batch: 55)
3D Printer: Mass Portal Pharaoh XD20 (SN: 150633)
Nozzle: 0.80 mm, brass
Part cooling: 100 %
Retraction distance: 4.33 mm
Retraction speed: 80.0 mm/s
Critical overhang angle: 32.0 deg
Extruder temperature (first layer): 220 degC
Printbed temperature: 30 degC
Track width (first layer): 0.80 mm
Track height: 0.25 mm
Track width: 0.80 mm
Extrusion multiplier: 1.00
Consumed filament: 13464.2 mm

	Test name	Units	Tested values							Selected parameter value	Selected printing-speed value (mm/s)	Selected volumetric flow-rate value (mm3/s)
1	first-layer track height	mm	0.216	0.253	0.291	0.328	0.365	0.403	0.440	0.291	26.7	5.717
2	extrusion temperature	degC	220	232	243	255	267	278	290	278	66.7	12.439
3	printing speed	mm/s	55.0	58.7	62.3	66.0	69.7	73.3	77.0	58.7	58.7	10.946
4	retraction distance	mm	1.000	1.667	2.333	3.000	3.667	4.333	5.000	4.333	58.7	10.953

Figure 9.1: An example of a test report with a summary and results of the tests: tested material, its ID, used 3D printer and nozzle. One can also see the conducted tests, as well as the tested and selected values.

10 Generating configuration file for your slicing software

When you are done with the tests you can generate a configuration file for your slicing software using the slicer setting found in the tests. At the moment you can generate either an INI configuration file for Slic3r Prusa Edition or an FFF configuration file for Simplify3D™.

To generate a slicing configuration file one needs to define much more parameters than can be tested in the Optimizer; the default values for the missing parameters based on literature data and our experience as well as suggestions on how to orient the part are listed in Table 10.1.

Table 10.1: Selected default slicing settings depending on the selected `Target`.

Parameter	`Aesthetics`	`Strength`	`Short printing time`
Target	to look good	to resist some load	to print fast
Nozzle diameter	0.1 – 0.4 mm	0.4 – 1.2 mm	0.6 – 1.2 mm
Cooling fans	full power on		full power on
Perimeters	3 (or less to hide infill)	maximal	3
Perimeter-to-perimeter	0	4	0
Number of bottom layers	4	8	3
Number of top layers	4	8	3
Infill	as little as needed to support the top solid layer	100 % (only perimeters)	as little as needed to support the top solid layer
Track height	0.05 – 0.10 mm	0.25 mm	> 0.30 mm
Top layer infill pattern	rectilinear	concentric	
Bottom layer infill pattern	rectilinear	concentric	
Part orientation	curved or angled surfaces are parallel to the Z axis	functional features are perpendicular to the Z axis or in orientation that maximizes the surface area of these features	to minimize Z height

11 STL file library

Optimizer comes with a library of STL files, comprised of the common sample geometries listed in ISO 3167:2014 standard "Plastics – Multipurpose test specimens" (see Table 11.1 for the overview of the available sample geometries). You can also add your own custom STL file (which will be accessible only to you) for slicing it in the FabControl™.

From `Available standard geometries` dropdown menu select the object you want to slice using Slic3r software. The software will automatically slice the selected object (in the background it will generate an INI file for the given session, and use it to slice the object). You can either download the generated G-code or generate a print job, and send the generated G-code directly to your 3D printer.

Standard	Sample type
ISO 178	
ISO 179	1-1e, 1-1fU
ISO 306	
ISO 527	1A, 1B, 1BA, 1BB, 5A, 5B
ISO 604	
ISO 1183	
ISO 2039	
ASTM D412	
ASTM D638	I, II, III, IV, V

Table 11.1: Overview of the available standard sample geometries.