

Formlabs Fuse 1 & Sift

The Fuse 1, a no-compromise low-cost SLS machine that makes additive manufacturing accessible to all.



Review

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Conducted at Formlabs UK Reseller - Solid Print3D

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I. Introduction - claims

The **Fuse 1** is an **SLS** 3D printer designed by **Formlabs**, a US (Somerville, Massachusetts-based) company founded in **2011**, the company provides a wide range of 3D printers. Formlabs is known as a leader in additive manufacturing in the world and its best-known model is the Form 2. For this new SLS setup, announced in 2017, the range is made up of one printer and one cleaning station, the printer is the **Fuse 1**, and the post-processing station, the **Sift**. Both of these machines complement each other in the SLS printing process. Formlabs develops 3D printers with ease of use and versatility in mind, to offer high-quality 3D printing to a variety of users. The company's flagship 'Form' range is suitable for prosumer and industrial users. However, the Fuse 1 SLS system can only print two different materials (Nylon 11 and Nylon 12), but Formlabs is working hard to extend the range of powder usable with this machine. Formlabs is now well-known in the 3D printing solutions market thanks to its high-quality systems.

The Fuse 1 is **one of the latest** additions and is made for professional use. It has a large build volume with **one laser diode** SLS. The workspace is a **165x165x300 mm³** cuboid. Other key features claimed by the 3D printer, to be discussed in this report, are as follows.

Features :

- An "industrial-grade" SLS 3D printer designed with the advanced users, designed for industrial
- Independent post-processing station
- Heated Build Chamber (up to 200°C), Fully enclosed, with a HEPA filter (active carbon)
- Ytterbium Fiber 10W laser diode
- 200 micron laser spot diameter
- Large build volume with professional high-quality printing
- Simple, sturdy all-metal frame design
- Powder Compatibility: Formlabs Nylon 11 and Nylon 12

Specifications

- **Printing**
 - Print Technology: SLS (Selective laser sintering)
 - Build Volume: 165mm x 165mm x 300mm (6.5" x 6.5" x 11.8")
 - Maximum Part Size (Nylon 12 Powder): 15.9 x 15.9 x 29.5 cm (6.3" x 6.3" x 11.6")
 - Layer Thickness: 0.110mm (0.004")
 - Laser spot diameter: 0.20mm (0.008")
 - Build Chamber Temperature: up to 200°C (392°F)
- **Mechanical & Dimensions**
 - Laser Quantity: One
 - Printer Dimensions: 64.5 x 68.5 x 107cm (165.5 cm with stand) (25.4"x27"x42" (65" in with stand))
 - Printer Weight: 114kg (251.3 lb)
- **Software & Electrical**
 - Software: PreForm
 - Connectivity: USB/Wi-Fi/Ethernet
 - File Type: Input: .stl, .obj, .form ; Output: .form
 - Supported (OS): Windows 7/8/10, Mac OS X 10.12

II. Packaging

1. Kit content

The Formlabs Fuse 1 printer and Sift post-processing station come with a pack of useful accessories.

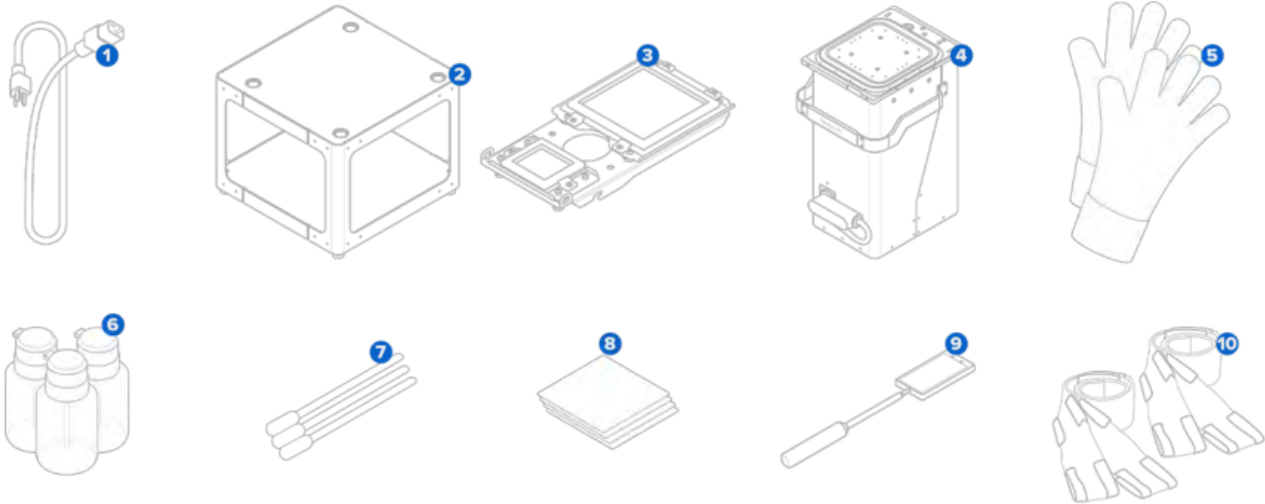


Fig.1: Fuse 1 kit content

1. Power cable	2. Stand	3. Optical cassette	4. Build chamber	5. Thermal gloves
6. Push-top dispensers	7. Swabs	8. PEC*PADs	9. Telescoping mirror	10. Lifting straps

Tab.1: Fuse 1 kit content

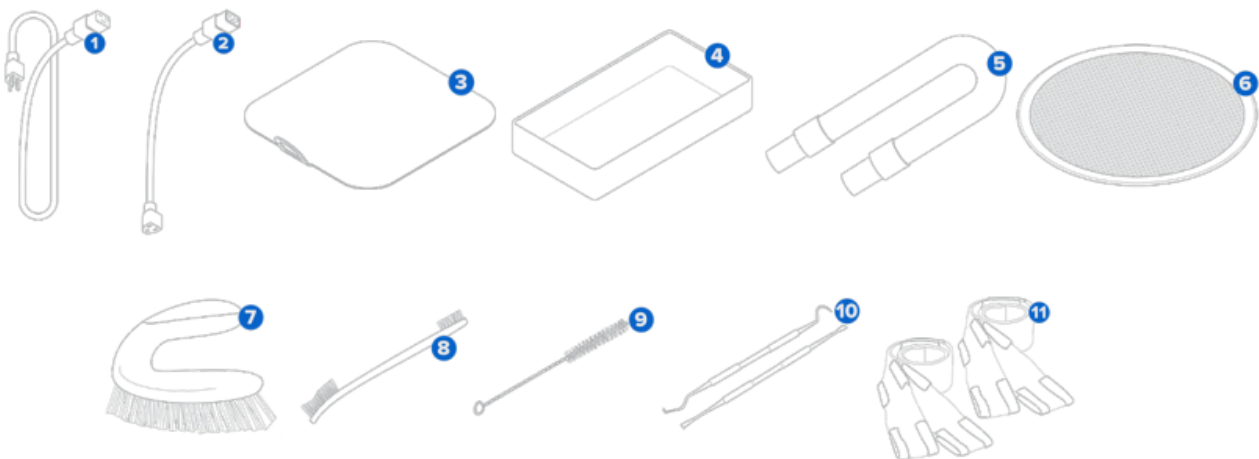


Fig.2: Sift kit content

1. Power cable	2. Vacuum adapt. cable	3. Build chamber cover	4. Parts basket
5. Vacuum hose	6. Surface grate	7. Large brush	8. Double-sided brushes
9. Wire brushes	10. Picks	11. Lifting straps	

Tab.2: Sift kit content

2. Nomenclature

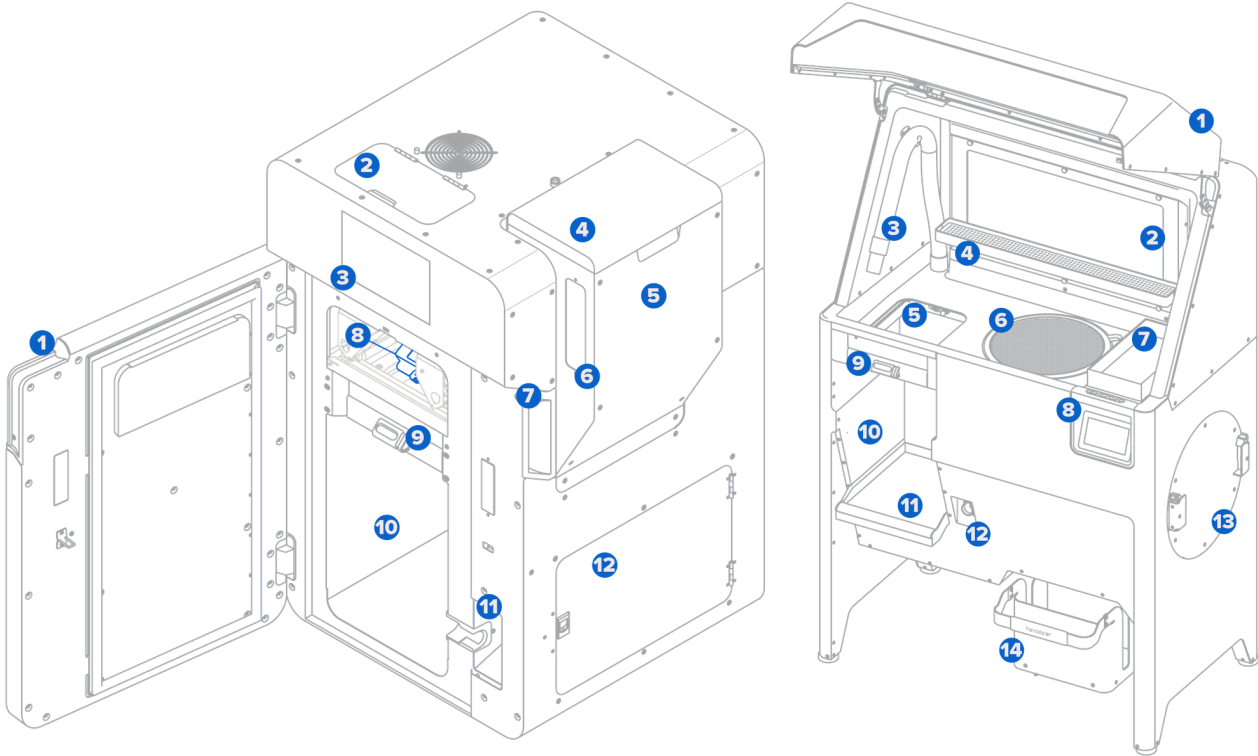


Fig.3: Nomenclature

Fuse 1 nomenclature:

1. Print enclosure door	5. Hopper	9. Build chamber latch
2. IR sensor door	6. Hopper window	10. Print enclosure
3. Touchscreen	7. Door handle	11. Build chamber socket
4. Hopper lid	8. Cassette tray	12. Filter cabinet door

Tab.3: Fuse 1 nomenclature

Sift nomenclature:

1. Hood	6. Surface grate	11. Powder catch
2. Vent	7. Fresh powder hopper lid	12. Build chamber socket
3. Vacuum	8. Control panel	13. Mixer
4. Tool shelf	9. Build chamber latch	14. Cartridge drawer
5. Build chamber port	10. Build chamber enclosure	

Tab.4: Sift nomenclature

III. Fuse 1 hardware

1. Architecture

The **Formlabs Fuse 1** is an SLS 3D printer with a **full metal chassis**. A metal protective casing borders the workspace with one opening at the front for access to the build area. The **laser moves on the X and Y axis**, whereas the **bed moves on the Z axis**.

The workplace is an **8.17-liter cuboid** which is around average for SLS printers (typically 5-8 liters). The print chamber is well optimized compared to the overall size of the machine knowing that it is a high-temperature machine, capable of heating the print chamber up to 200°C. The machine size is decent with a volume of **645x685x1070 mm**. It will be perfect for any prototyping or production operation requiring the precision and strength of SLS technology.

2. Components

3. Laser diode

The Fuse 1 is a **single laser diode** 3D printer. It is able to print one material per print. Customers can choose between two different materials: Nylon 11 and Nylon 12. But Formlabs is working on increasing the variety of materials usable with this system. The powder is deposited on the bed with each layer being evenly laid with a roller. The roller deposits a uniform and very precise layer to ensure perfect print quality.

There is one **laser diode**. A system with two lasers allows for faster printing, but this is relatively rare, especially at the price point. For this machine, one laser is more than sufficient and allows for relatively fast printing. The diode used is **10W**, with an infrared beam with a wavelength of **1065nm**, with a beam divergence of **4.01mrad**.



Fig.4: Laser diode

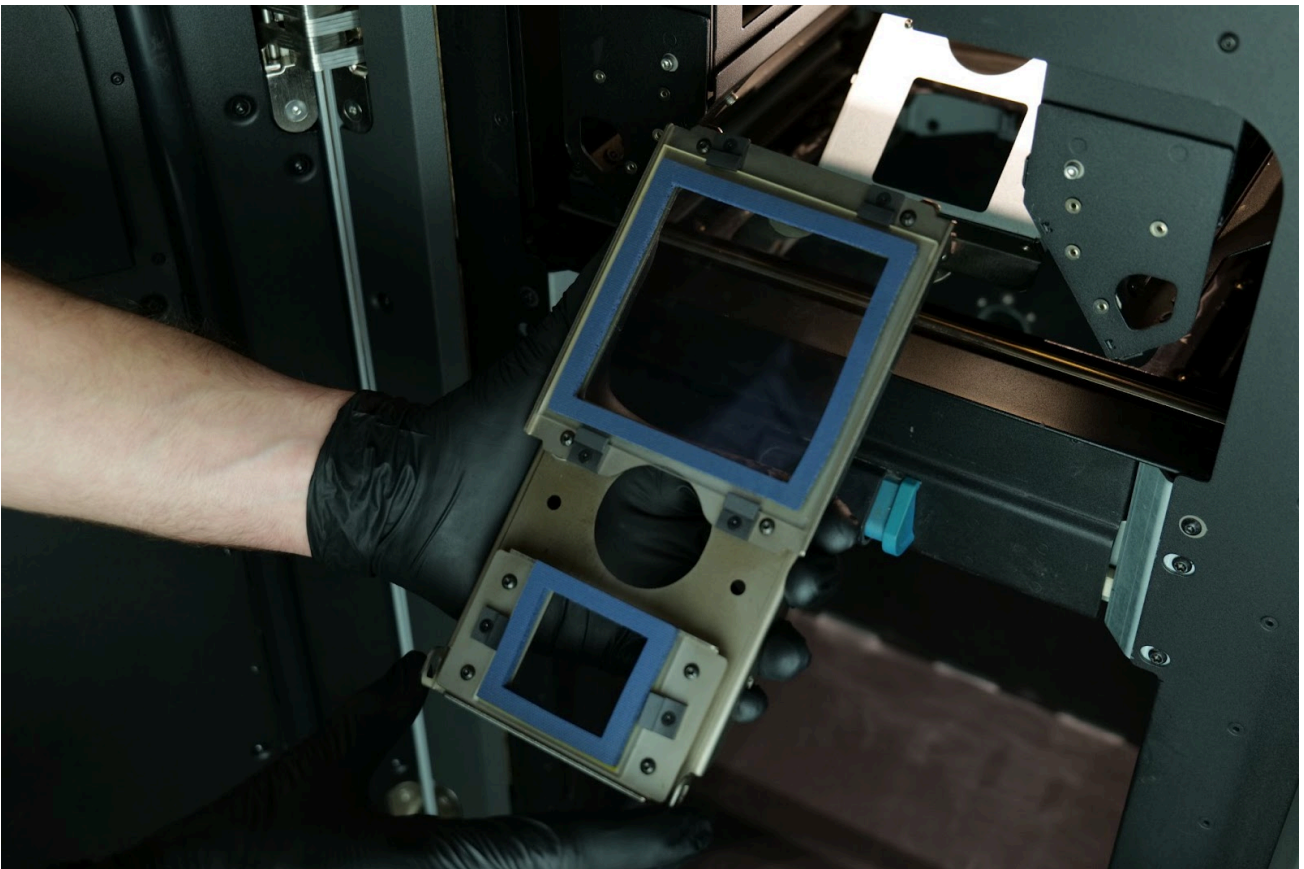
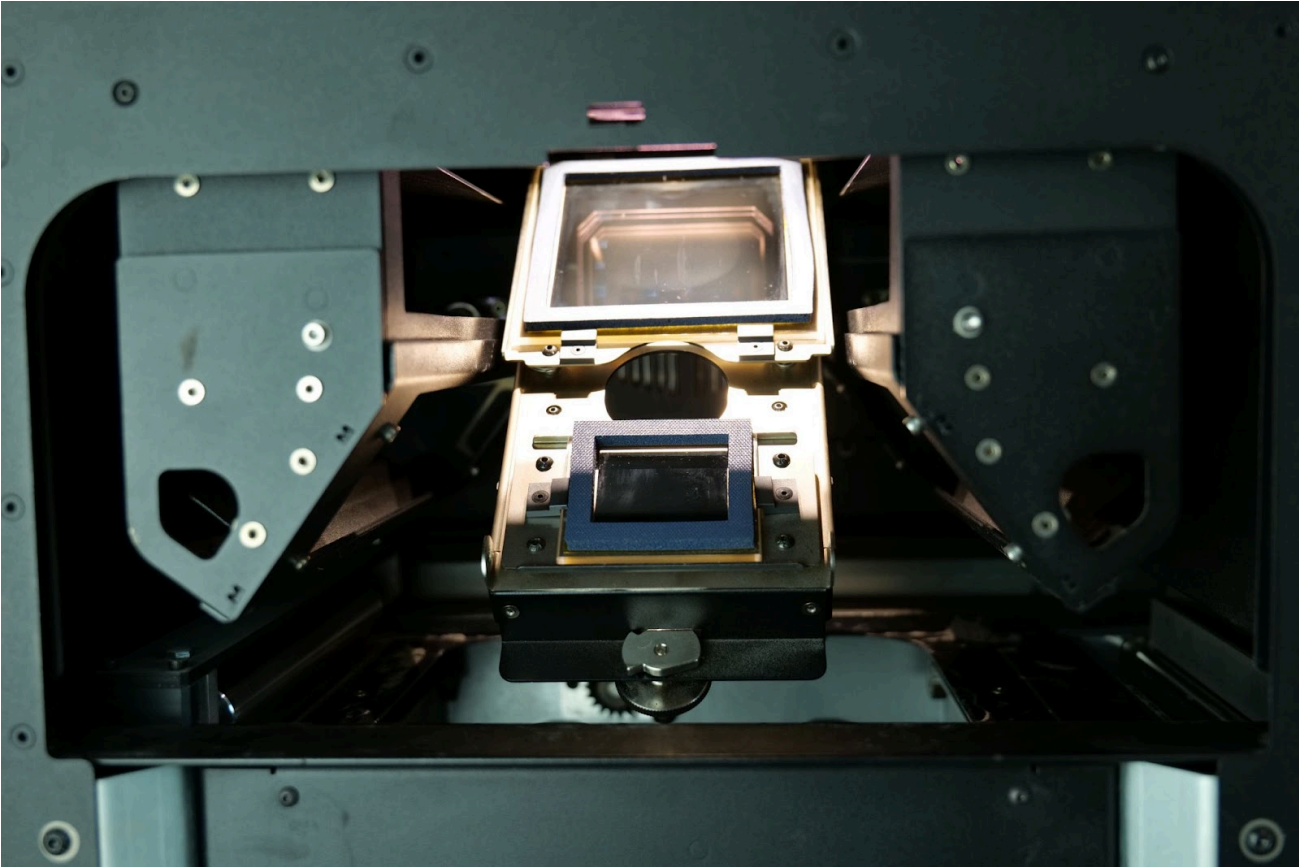


Fig.5: Cassette

In the pictures above we can see the **cassette**. This element is very important, it protects the laser diode as well as the camera. It is one of the elements that must be well maintained because if it is dirty, the laser beam can be deflected or the image captured by the camera can be clouded. These elements are the main causes of failures.

4. Bed and chamber

The build chamber is heated. Heating the chamber is necessary to prevent part warping. Keeping the temperature of the chamber higher than ambient temperatures allows users to keep the print hot and to avoid retraction of the material if the temperature drops. The build chamber heats up to **200C°**. The heat up and cool down cycles are relatively quick which aids users with higher output from the Fuse. The build area is removable for ease of cleaning and to reduce print turnaround time. After removing the build volume, it can be placed in the Sift post-processing station. The build surface is **165x165mm**.



Fig.6: Fuse 1 chamber



Fig.7: Fuse 1 chamber

5. The casing

The Fuse 1 is a **fully enclosed** machine. This is necessary with SLS printers in order to keep the temperature of the workspace higher than the ambient temperature outside. Doing so helps avoid delamination and warping issues on prints due to shrinkage of the material as it cools. Moreover, the enclosure adds to Fuse 1's user-friendliness claims, preventing accidental contact with the laser beam or the heated components, making this a safe system to have in the workplace. But an enclosed machine will logically have a bigger overall footprint. The user has to plan enough space in the area. In addition, the user should consider where to place the machine system, the powder being fine, it must not be contaminated by external elements such as dust or waste from other machines, and should not come into contact with users without proper PPE. For example, the Fuse 1 and Sift should not be placed next to a sandblasting machine, as the sand could contaminate the powder during recycling. A display is located on the front panel which allows you to see inside the printer during printing, the machine body is entirely built from metal.



Fig.8: The casing

6. Electronic components

The 3D printer is equipped with:

- A 10.1" full-color touchscreen multilingual user interface with a 1280x800 resolution. It allows us to calibrate the printer, manage files, and begin prints. The interface is very intuitive and easy to use. The position of the screen on the top front of the printer is very convenient for industrial configurations;
- Some lights to illuminate the interior of the printer;
- Communicates on your terms via USB, WiFi, or RJ45 cable

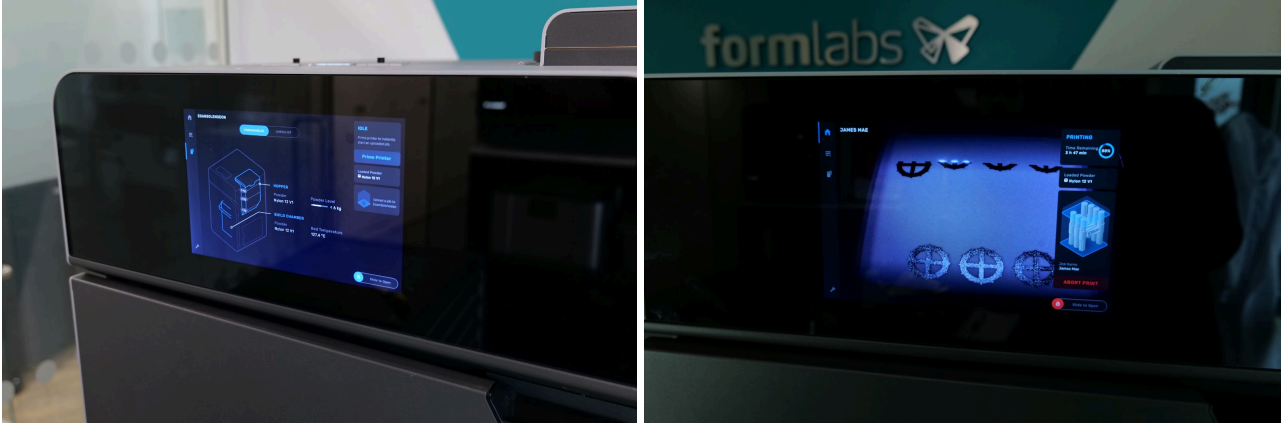


Fig.9: Screen



Fig.10: Screen, WiFi, and USB

7. Powder hopper

The printer is equipped with an internal powder tank. This system allows users to store the powder inside the machine, in a dry environment.



IV. Sift hardware

V. Architecture

The **Formlabs Sift** is the post-processing station associated with the Fuse 1 SLS 3D printer. Equipped with a **full metal chassis**, an PETG glass protective casing borders the workspace with one opening for users to put their hands inside in order to work on it.

This station is used for the **post-processing** of parts printed with the Fuse 1. It includes all the necessary tools for **cleaning** the parts, **recycling** the powder, and **unpacking** the build. It is equipped with a **sieve** for separating and recycling the used powder, a **industrial vacuum** for cleaning the Fuse 1 between each print and for cleaning the Sift station, a **dosing device** for mixing the recycled powder with the new powder, a **mixer** for mixing the two powders once the tank is full. Also included are a range of **tools needed to clean the parts** (brushes of all sizes, spikes, etc.). The Fuse 1 and Sift are the perfect duo to carry out your printing operations with SLS technology.

VI. Components

a. Build volume elevator

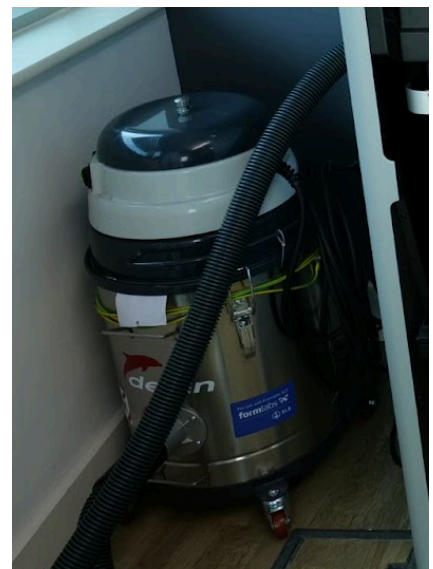
When a print is finished and has cooled down, the build chamber must be transferred to the Sift. A system is used to raise the print volume in order to recover the parts and start cleaning them. The system requires the same operations as when inserting a new build chamber into the Fuse 1. After this, the user only has to activate the system on the user interface.



Fig.14: The build volume elevator

b. The hoover

The hoover isn't included in the package, it is a \$3,000 additional cost on top of Sift, but it is a part of the ecosystem. This connects to the Sift and can be switched on and off directly via the user interface. This is used only to suck the powder off the parts and to clean the post-processing station. A fan system inside the Sift is used to create the negative airflow rather than this hoover.



c. The sieve

The machine is equipped with a sieve for recycling the used powder. This system makes the work extremely easy and efficient, the sieve is covered with a grid with 5mm round holes, which allows the powder to pass through. This grid keeps the parts and tools out of the sieve. Once the powder is on the sieve, it is possible to vibrate it via the user interface. The powder that is still usable passes through the sieve and into a tank below. The pieces of powder that have been overheated or deformed will remain on the top. It is therefore sufficient to clean the sieve from time to time with the Hoover.



Fig.12: The sieve to refresh used powder

d. Powder hopper

This area is only used to fill the machine with fresh powder. The tank is fitted with a rubber stopper to make the seal airtight so that no used powder can contaminate the fresh powder by accident. Again, nothing to report on this side, everything is well thought out and very ergonomic.

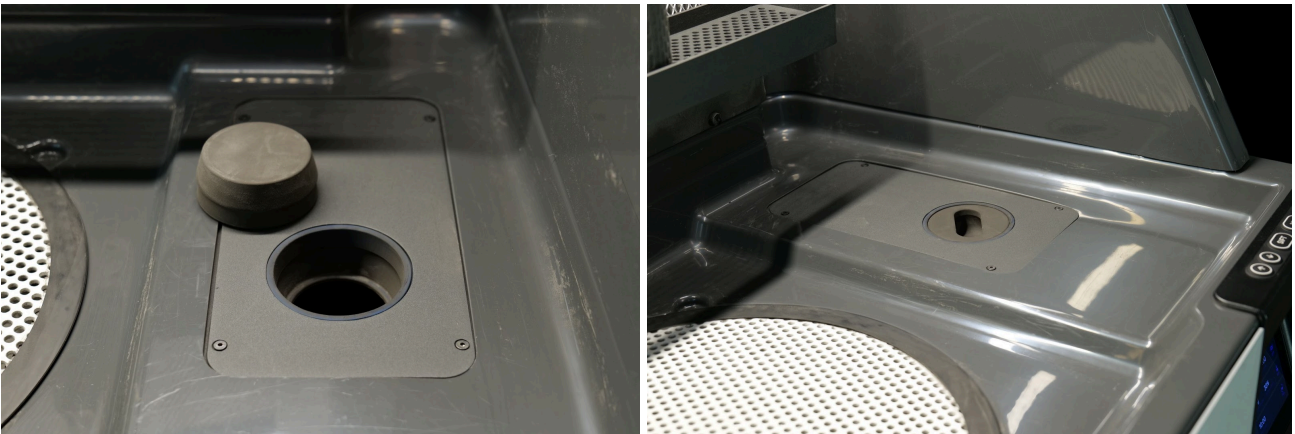


Fig.16: Fresh powder tank

e. The mixer

When you want to fill the Fuse 1 tank with powder to continue or start a new print, you have to go through the Sift. Once the cartridge drawer is filled, the Sift is equipped with a cartridge rotating system on the right hand side that allows for a perfect mix of fresh and recycled powder. Simply attach the cartridge drawer to the system and activate the rotation for 10 minutes via the user interface.



Fig.13: The Sift powder mixer

f. User interface

The user interface is, like all Formlabs products, very simple, complete, and clear. You will find everything you need between the buttons and the screen. Once again, congratulations to Formlabs for the ergonomics of their system, there is absolutely nothing to complain about in this respect.



Fig.15: The user interface

g. The workspace

The work area is very well thought out. On the left is where the print “cake” comes out, in the middle, there is the sieve, and on the right, the tank fills the machine with fresh powder. At the bottom, a large air filter with an air extraction system so that there is always a flow of air coming into the machine. This prevents the user from breathing in the powder and spilling it outside the machine. This system is very efficient and works perfectly well. Just below this filter, Formlabs has included a shelf to store all the tools needed to post-process the prints without cluttering up the workspace. And finally, on the left beside the machine, is the Hoover to clean the Sift and keep it in good condition after each use.



Fig.11: The Sift workspace

VII. Slicer

I. First view

Formlabs provides its own slicing software which is named PreForm. It is described as a very easy-to-use slicer but also a complete one for advanced users. Auto-arrange, stacking, and scale models are some of the features available on the software. The following section will explain the different functionalities of the slicer. The interface is quite similar to most other slicers which make it easier to handle for a first-time user. The interface is clear without any superfluous features. The buttons on the left of the screen enable the model to move by repositioning, rotating, or scaling it.

The screenshot below shows the three main elements of the software - the Menus, the Icons, and the Build Plate.

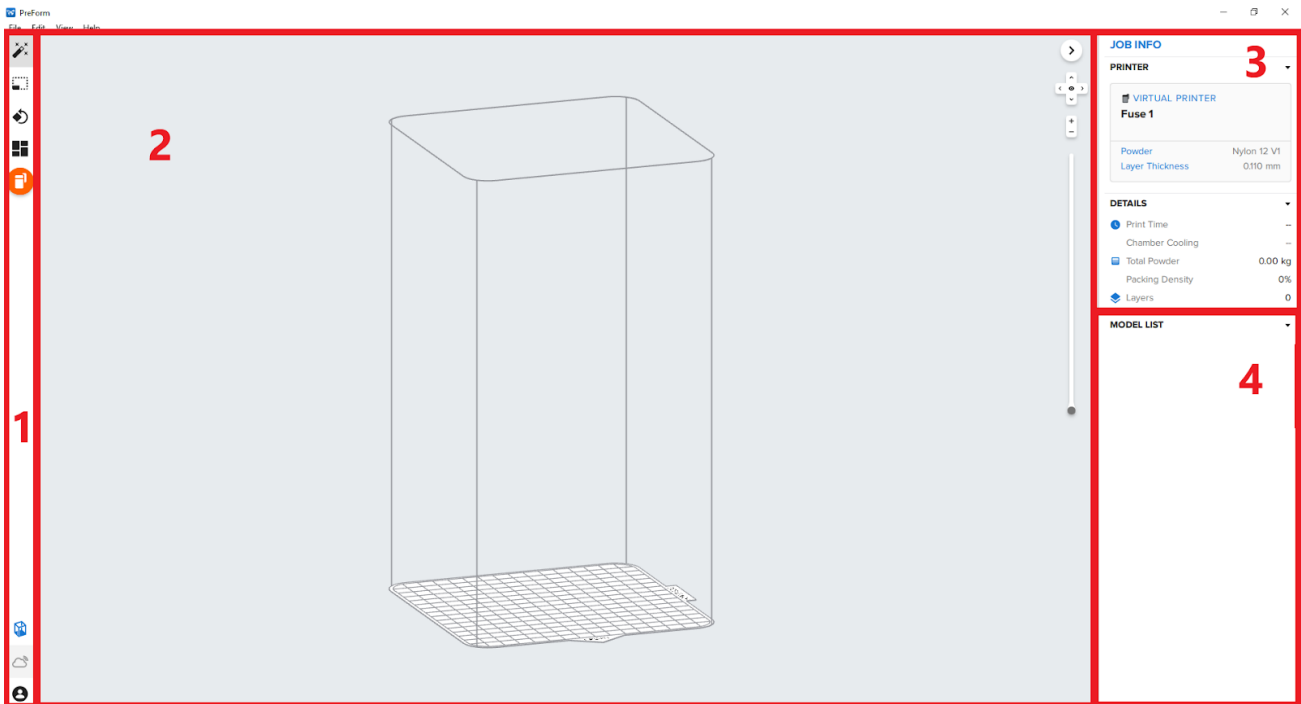


Fig.17: Slicer interface

- 1.** Toolbar: Configure the position, size, and print your model.
- 2.** Workspace: View, position, and orient a model. It also previews any changes made by items in the toolbar, such as changes in a model's orientation.
- 3.** Job Info tab: Reports the estimated print time, material usage, packing density, and the number of layers of your models.
- 4.** The model list: Shows all of the models currently stored in the file, allowing you to view, group, and hide certain models.



One-click print

One-click print will automatically orient and pack the models into the minimum amount of powder so you can get to print as fast as possible.



Size

Scales the size of the model.



Orientation

Rotates the model around the X/Y/Z plane.



Layout

Auto arranges models, duplicates them, packs them...



Print

Send the sliced file to the printer



Workspace

See the build volume with all models on it.



Dashboard

Access to FormLabs



Account

Login, Logout, or access to your Formlabs account

II. Loading a File

PreForm supports two different ways to load a model or Gcode file, as outlined below.

- Drag and drop the file onto the main interface.
- Click File > Open, then select the file.

III. Print

The next step is simply to slice the model. This is very easy, as there are no parameters to set, unlike FFF, SLA, or DLP printers.

IV. Dashboard

The online dashboard allows users to track the status of their printers, materials, and prints. Once you've linked your printer to your Formlabs account, the printer will become visible on your dashboard. When you log in, you'll see a brief overview of each of your Formlabs machines, as well as the print jobs that have been queued, completed, or failed. You can also view the amount of powder that you have in use and each print job's respective details (such as print time and material usage). This is extremely useful as a workflow tool.

V. Conclusion

In comparison to other slicers used by the 3DPI engineering team, PreForm is probably one of the easiest to use. There are only a few buttons and no extra settings to worry about.

There are some interesting features such as the stacking settings, especially useful for SLS printers. An advanced user will still find everything needed to print properly. There is not much more to say about PreForm since, on the Fuse 1, parameters including layer height, laser scan speed, or laser power cannot be changed. This also means that this machine cannot be used with third-party materials. Users must use materials provided by Formlabs, currently, the brand only offers two materials (Nylon 11 and Nylon 12), but is working on expanding the range soon.

V. Use of the printer

1. Set-up

a. Recycling power

The Fuse Sift stores used powder from previous prints as well as fresh powder. Used powder captured by the Fuse Sift can be reused with new powder for future prints. Use the Fuse Sift to refill cartridges for the Fuse 1's hopper.

The Fuse Sift dispenses the powder from the bottom of the machine using gravity. An empty powder cartridge must be inserted into the drawer below the Fuse Sift before dispensing the powder.

To insert a powder cartridge into the Fuse Sift:



1. Pull the handle on the bottom right of the Fuse Sift to slide the cartridge drawer open.



2. Insert an empty cartridge into the drawer with the directional valve facing up and the cartridge handle pointing away from the Fuse Sift.
3. Pull the cartridge knife handle and open the cartridge valve fully.



4. Close the cartridge drawer in the Fuse Sift. Once you have inserted an empty cartridge into the Fuse Sift, you have to fill it with a mix of fresh and used powder with the user interface by clicking on the **"Fill"** button. Before that, on the touch screen, check that the mixture between new and recycled powder is set to the desired ratio. Formlabs recommends 70% used to 30% new Nylon 12. To change the refresh rate, click on **"Refresh Rate"**. The refresh rate will be displayed on the screen, then set the ratio between fresh and used powder. Tap on **"Fill"**, The Fuse Sift dispenses the powder into the inserted cartridge. The Hoover will also start to capture any loose powder in the work area.
5. When it's done, open the cartridge drawer, close the cartridge valve and remove the cartridge from the drawer. Now the cartridge is ready to be placed on the rotary mixer.

b. Mixing powder

After dispensing the powder into the cartridge, mix the powder to ensure that it is homogeneous. Below is the process to mix the powder in the powder cartridge:



1. With the cartridge valve facing the Fuse Sift, slide the cartridge onto the mixer on the right side of the Fuse Sift until the locking tabs snap around the cartridge.
2. On the touch screen press **"Mixing Time"**. Use the touch screen to set the time the Fuse Sift will mix the powder. Formlabs recommends mixing for at least ten minutes. Press **"Mix"** to start mixing.
3. When mixing is complete, eject the cartridge. Pull the two blue tabs outwards with your thumbs and lift the cartridge out with the handles.

c. Loading powder into the Fuse 1



Once the powder is well mixed and homogeneous, the hopper on top of the Fuse 1 must be filled. To do this, simply open the lid of the printer's powder hopper, then place the full cartridge on the hopper with the valve facing down. Simply open the valve and the powder will fall into the hopper. During this operation, it is very important to **wear a mask to avoid any powder inhalation**.

d. Calibration

Unfortunately, we were not able to go through the calibration wizard of the machines during our visit to Solid Print3D as the machines have already been installed there for some time. However, the procedure seems to be very simple and everything is indicated on the onboard screen. The only thing to do manually is to calibrate the level of the machine itself so that the roller can apply a uniform and homogeneous layer of powder between each layer.

e. Clean IR sensor



Lift the IR sensor access door on the top of the printer and inspect the IR sensor. Clean the IR sensor if necessary.

This sensor is very important because it will measure the temperature of the powder. It is, therefore, necessary that it is clean in order to transmit the correct information during heating, printing, and cooling of the build area.

f. Clean the cassette



The cassette is the element through which the IR sensor sends its infrared waves to measure the temperature of the powder (through the hole in the middle of the cassette), but also through which the laser passes (through the large window on top), and finally where the camera take images (through the small window on the bottom). It is therefore very important to keep the cassette clean and in good condition to ensure good print quality. Inspect the Fuse 1 optical cassette after each print. If the optical cassette is contaminated or dirty, clean it before using it again.

The standard cleaning process requires ethanol. If the standard process is insufficient, perform a more thorough cleaning using Alconox, ethanol, and distilled water.

2. Printing

The 3D printing step is very intuitive. Once the sliced file is ready the user can directly send the file using the USB cable or via a private network.

To start the print, tap “**Start Print**” on the touchscreen. The printer begins heating the print enclosure as it prepares to print. This pre-print heating process takes approximately one hour. The print begins automatically once the printer has reached the correct temperature.

3. Areas for consideration

This section contains ideas and feedback which could be interesting for future developments.

- Providing several profiles for printing with Formlabs materials could be handy (Draft, Normal and High for example with different layer heights or different laser scan speed)
- Letting the user have access to the logs could allow the company to solve the problems itself in some cases.

VI. Printing tests

1. Basic test

This section contains the test results used to understand the performance of the printer.

a. Repeatability test

Repeatability is the printer's capacity to produce **multiple parts with the same or very similar dimensions**. The test is composed of three different parts which were all printed 12 times. As the reference dimensions are known from the original 3D model, we were able to determine the discrepancy between measured dimensions and original dimensions, and the dispersion between them. The parts are printed in groups of 3 (1 square, 1 polygon, 1 tube) with the following settings.

Profile	Layer thickness (mm)	Enclosure temperature (°C)	Laser power (%)	Material
Standard	0.110	180	100	Nylon 12

Tab.5: Repeatability setting

The normal distribution is studied - when the **mean of difference is under 0.1mm** and the **standard deviation is under 0.05mm**, the printer can be said to have had a **successful** repeatability test. After checking our measuring equipment, the accuracy of our measurements for this test is **±0.015mm**.

- Squares

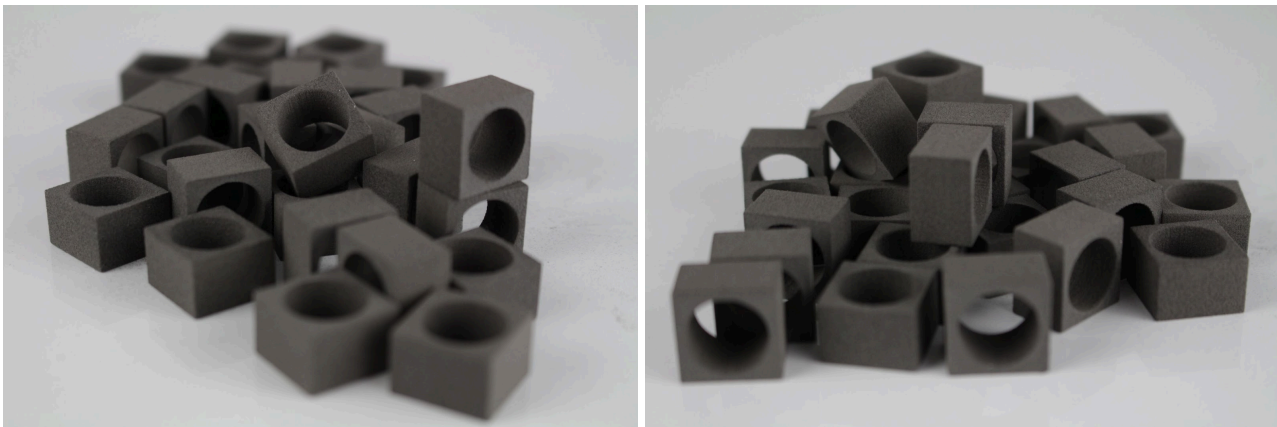


Fig.18: Repeatability testing of the square model

The measures are given in the table below. [Excel Database – Basic test – Formlabs Fuse 1]

SQUARES	Hole ϕ (mm)	Height (mm)	Length (mm)
Reference	12	10	15
Print 1	12,01	10,005	14,989
Print 2	12,01	10,067	15,016
Print 3	12,04	10,095	15,036
Print 4	12,01	10,049	15,007
Print 5	12,02	9,964	14,953
Print 6	12,01	10,087	14,957
Print 7	12,01	9,963	14,955
Print 8	12,03	10,074	15,000
Print 9	12,02	9,958	14,947
Print 10	11,98	10,092	15,005
Print 11	12,02	9,913	14,897
Print 12	12,02	10,099	15,067
Mean of differences	0,018333333	0,064166667	0,036083333
Mean of real values	12,015	10,0305	14,98575
Standard deviation (σ)	0,014459976	0,066116289	0,046023956
Estim. Stand. Dev. (s)	0,015102952	0,069056211	0,048070454
Mean + 3.σ	12,05837993	10,22884887	15,12382187
Mean - 3.σ	11,97162007	9,832151134	14,84767813

Tab.6: Squares dimensions

Explanations:

- The mean of differences is the mean of the differences between the measurements and the reference. We commonly say that a difference between reference and measure under 0.1 is good for an SLS 3D printer.
- The standard deviation represents the dispersion of the sample.
- If we assume that the process follows a normal dispersion law, we can say that 99.6% of the part will belong to the interval [mean - 3 σ ; mean + 3 σ].
- In our case, we use samples of 12 parts. When estimating the dispersion around the mean of a statistical character in a large population from a sample of size “n”, we use the following value for the

$$\text{standard deviation: } S = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2} = \sigma \sqrt{\frac{n}{n-1}}$$

To illustrate the table, the following graphs represent the dispersion of the hole diameter, the height, and the length (first measure). 99.6% of the hole diameters will be between [**Mean - 3 x σ**]mm and [**Mean + 3 x σ**]mm. Moreover, as we can see, most of the hole diameters will be near the mean which is [**Mean**]. **12mm** is the targeted dimension.

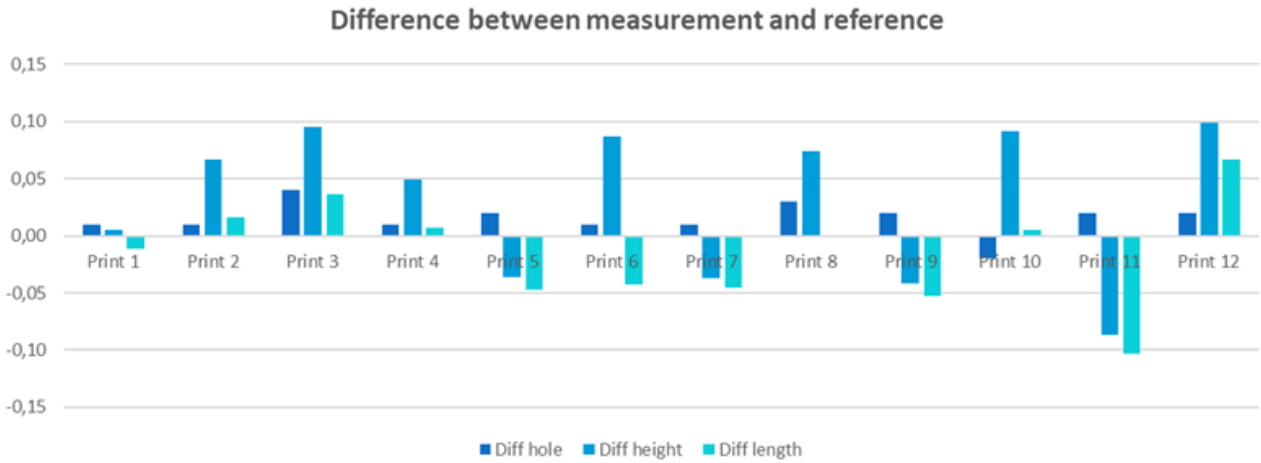


Fig.22: Difference between measurement and reference

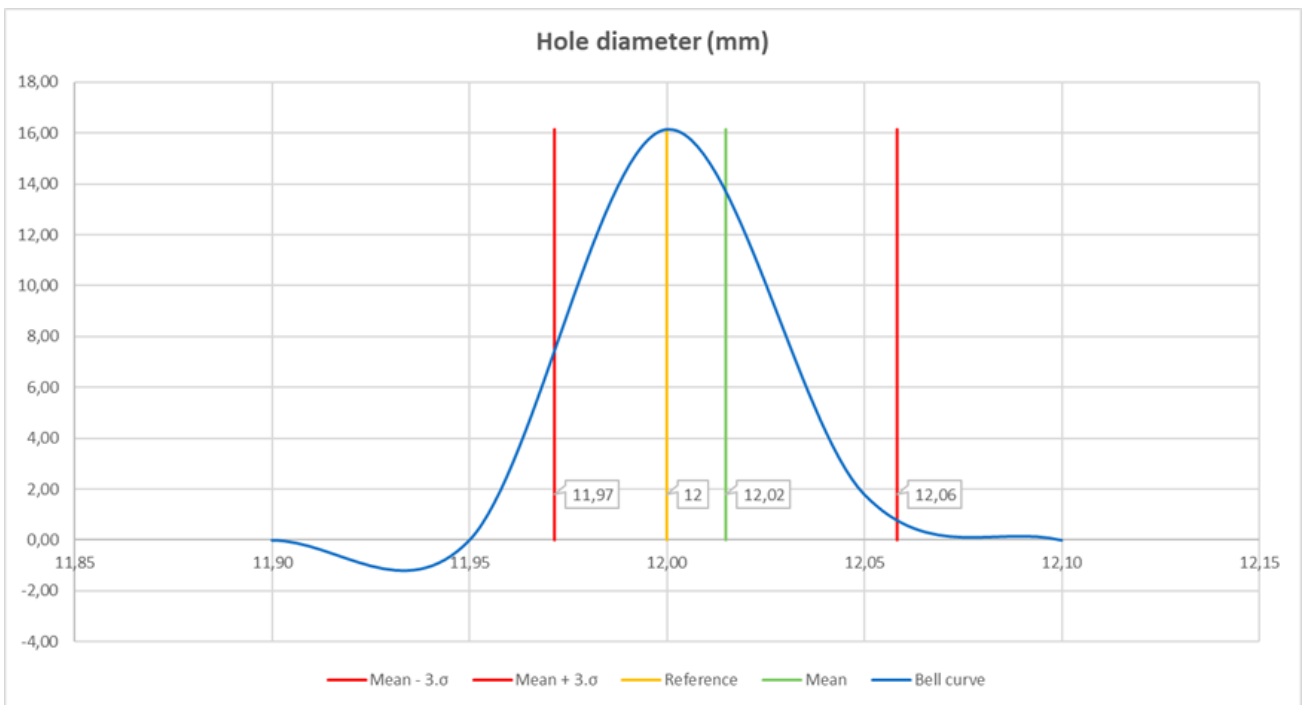


Fig.19: Normal distribution of the hole's diameter

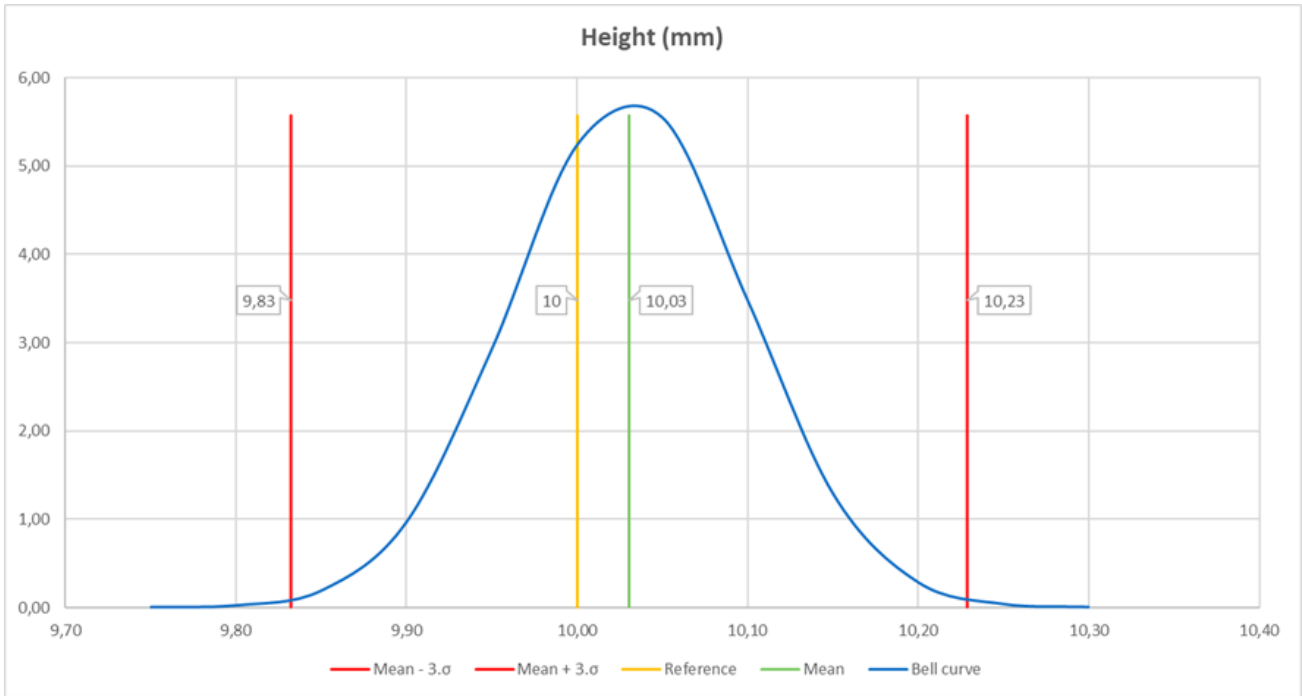


Fig.20: Normal distribution of the height

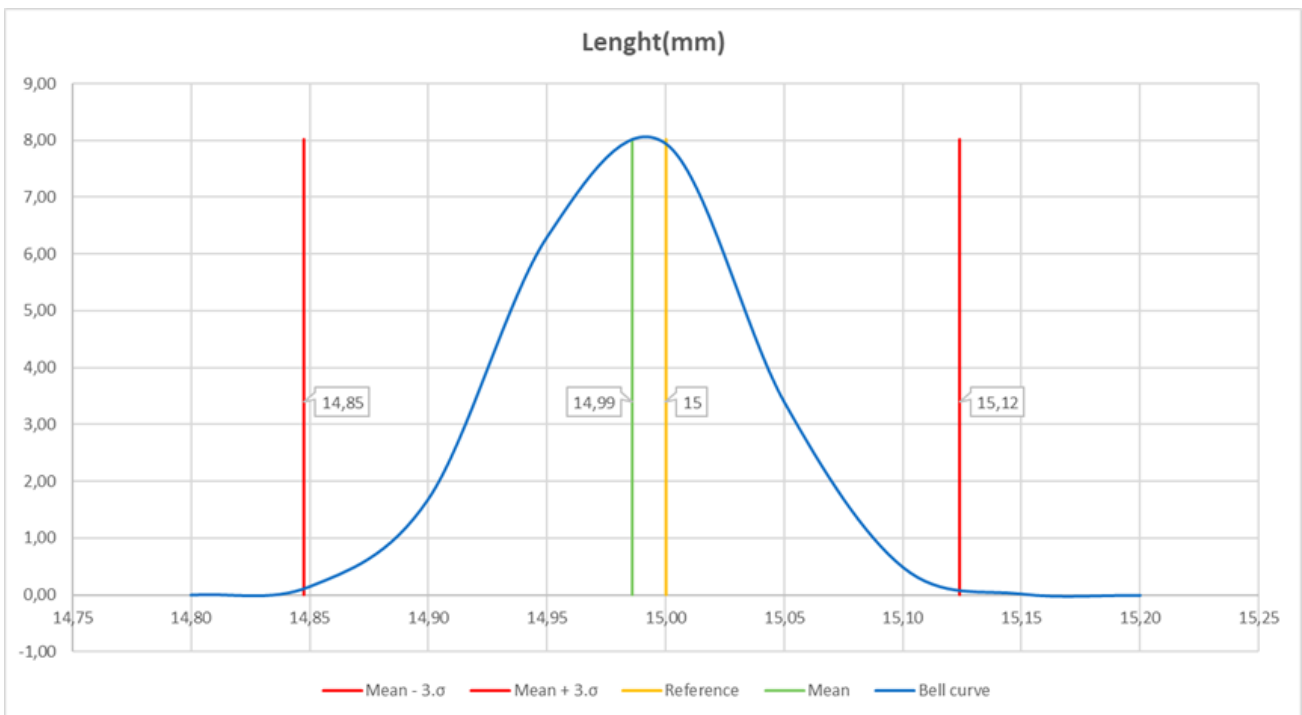


Fig.21: Normal distribution of the length

The mean of difference for all three ratings of the square part test is **0.0395mm** (under 0.1 mm) and the standard deviation is **0.0422mm** (under 0.05mm). The results are very good, the only test that was performed less successfully was the height (Z-axis). The standard deviation is higher for the height test (**0.0661mm**) than the other measured spacing. Same for the mean of the difference (**0.0642mm**). Other than the Z performance, the results are excellent.

- Hexagons

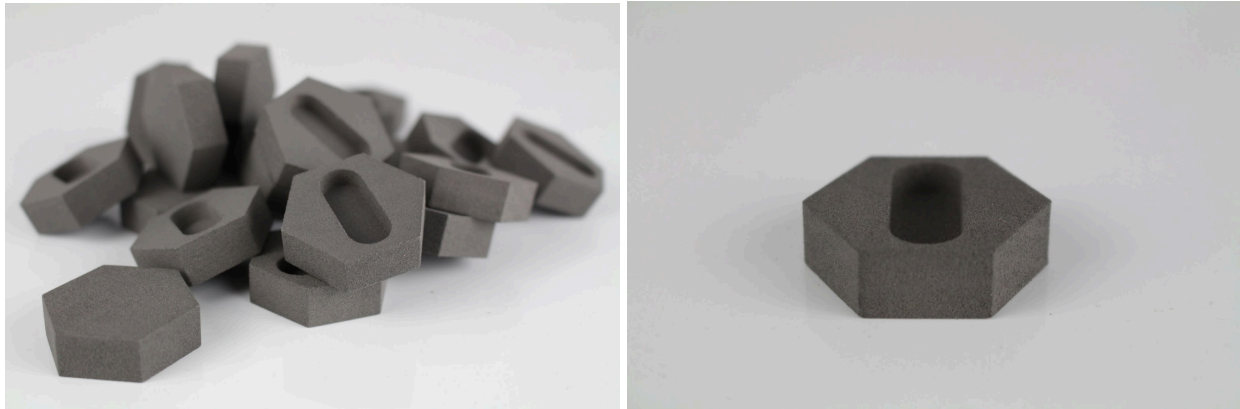


Fig.23: Repeatability testing of hexagons model

HEXAGONS	Length (mm)	Height (mm)	Groove depth (mm)	Groove width (mm)
Reference	30	10	5	10
Print 1	30,03	10,081	5,01	10,04
Print 2	30,04	9,802	4,95	9,93
Print 3	30,12	9,928	5,00	10,00
Print 4	30,10	9,984	5,00	9,95
Print 5	30,00	9,930	4,96	9,95
Print 6	30,05	10,070	4,98	9,97
Print 7	30,09	10,004	4,97	9,87
Print 8	30,01	10,075	5,02	10,05
Print 9	30,07	9,990	5,00	9,93
Print 10	30,08	9,892	5,04	10,00
Print 11	30,07	9,856	4,97	9,98
Print 12	30,00	10,001	5,01	10,01
Mean of differences	0,055	0,07075	0,020833333	0,043333333
Mean of real values	30,055	9,96775	4,9925	9,973333333
Standard deviation (σ)	0,039886202	0,088762323	0,026671401	0,05104959
Estim. stand. dev. (s)	0,041659779	0,092709223	0,02785737	0,053319557
Mean + 3. σ	30,17465861	10,23403697	5,072514203	10,1264821
Mean - 3. σ	29,93534139	9,701463031	4,912485797	9,820184564

Tab.7: Hexagon's dimensions

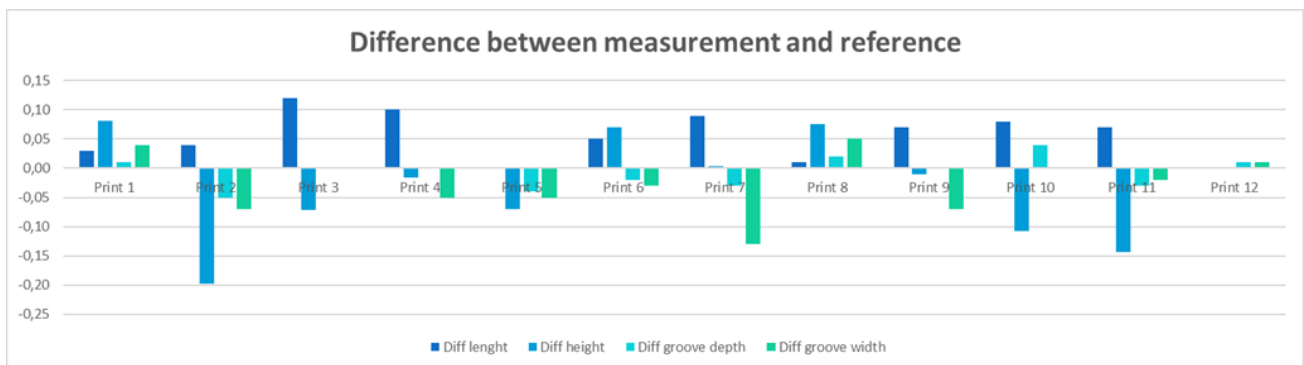


Fig.24: Difference between measurement and reference

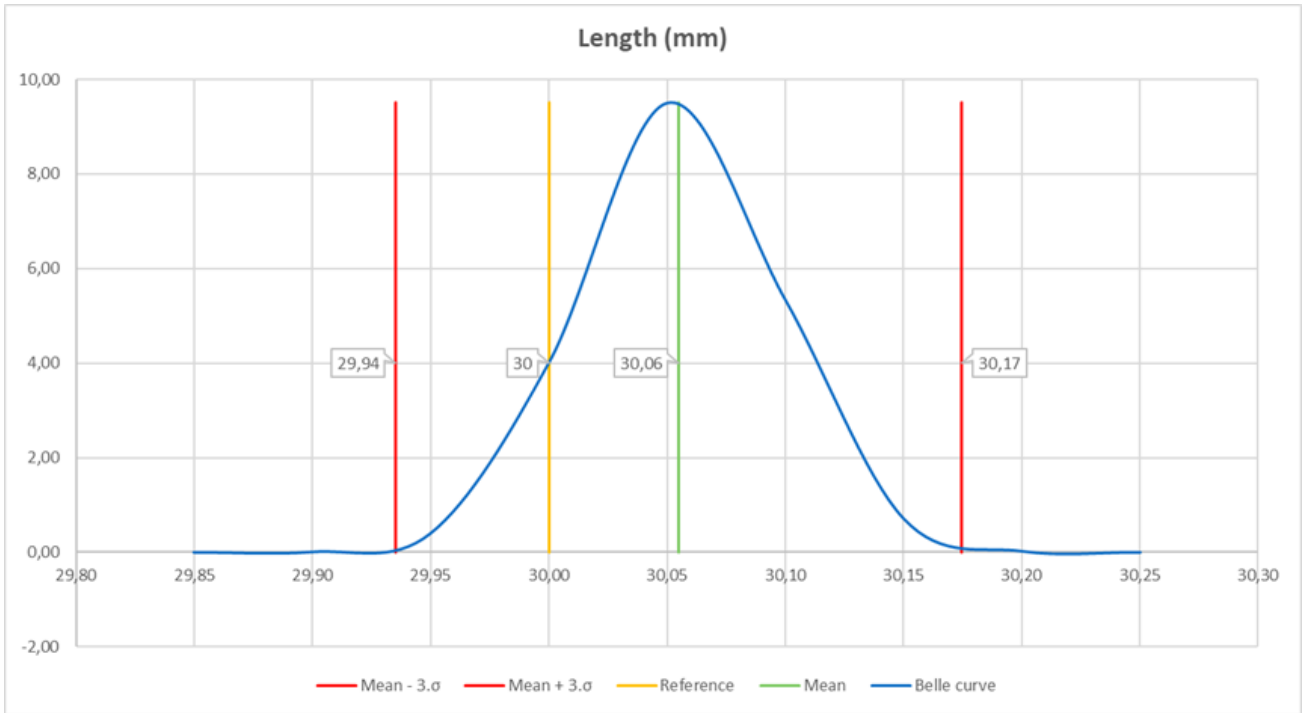


Fig.25: Normal distribution on the length

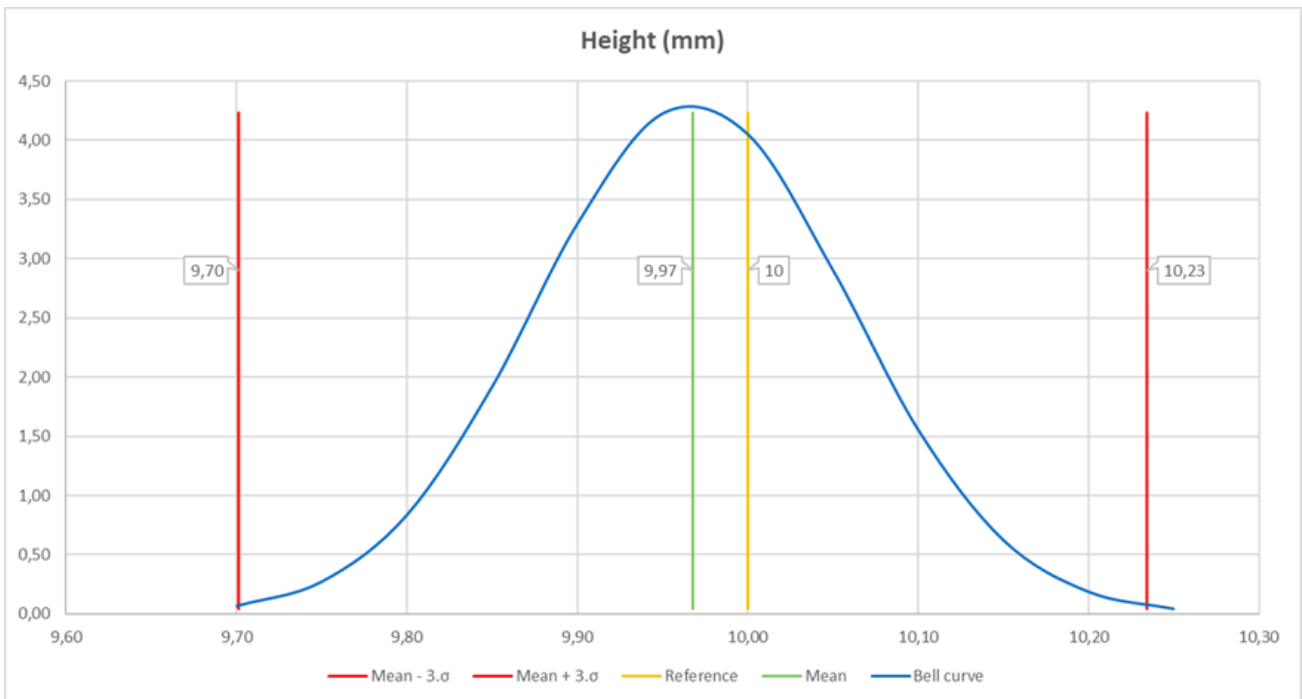


Fig.26: Normal distribution on the height

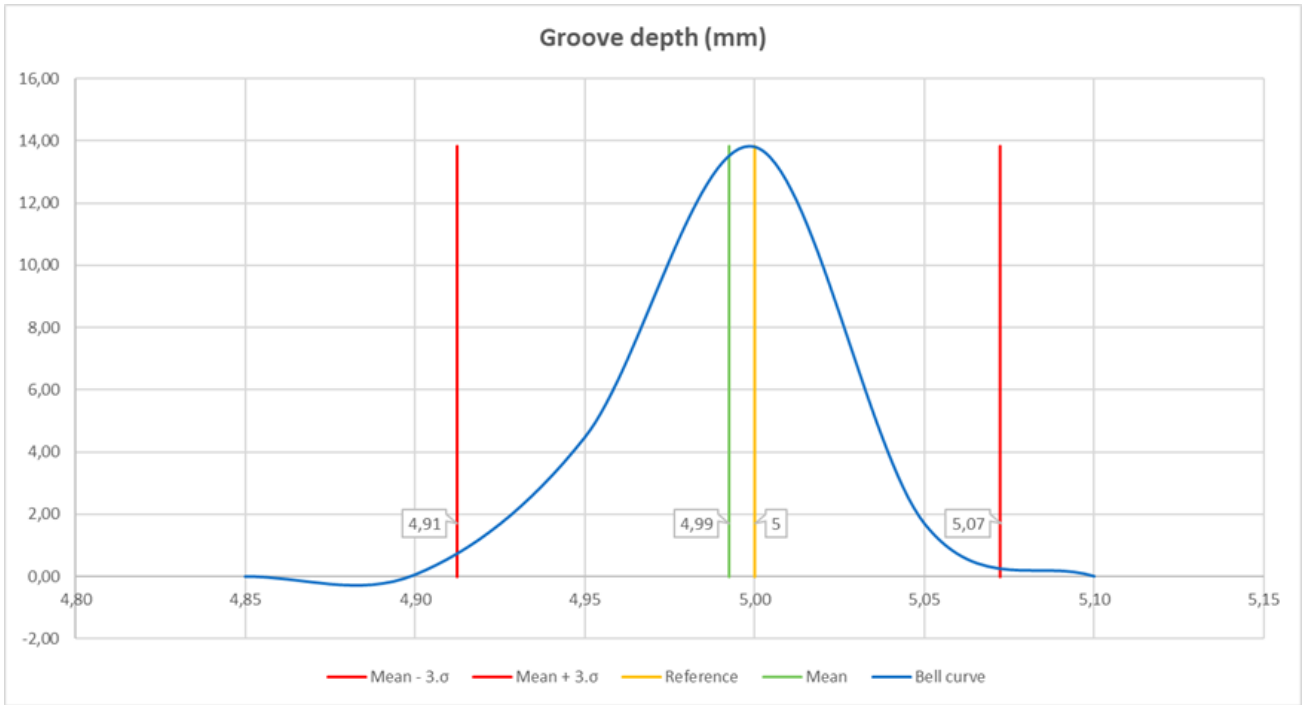


Fig.27: Normal distribution on the groove depth

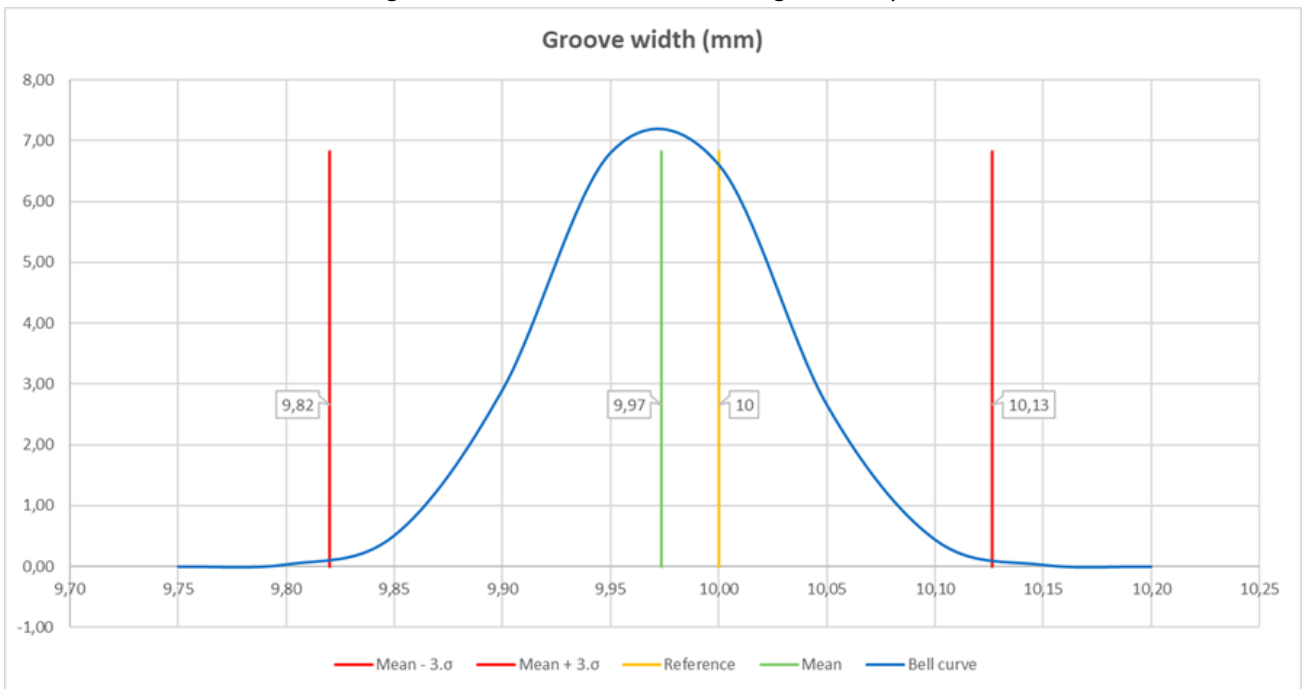


Fig.28: Normal distribution on the groove width

The results of the hexagon tests are excellent. The mean of difference for all ratings is **0.0475mm** (over 0.1mm) and the standard deviation is **0.0516mm** (just over 0.05mm). This second study confirms some of the findings from the square test by poorly repeating the height. The pill-shaped slot with rounded edges is almost perfect. This shape is extremely difficult to achieve on an FFF printer for example, but on an SLS printer, it poses no problem. The groove depth is almost always the same (between **4.96mm** and **5.04mm**), but the groove width is less precise and oscillates between **9.93mm** and **10.05mm**. Once again, the height is this test that lowers the score for the hexagon with a standard deviation of **0.0888mm** and a difference in the averages of **0.0707mm**. When a measurement is far from the rest of the batch, we can consider that the part is defective or that there was a problem during the measurement. The results are correct and much better than the square test.

- Tubes

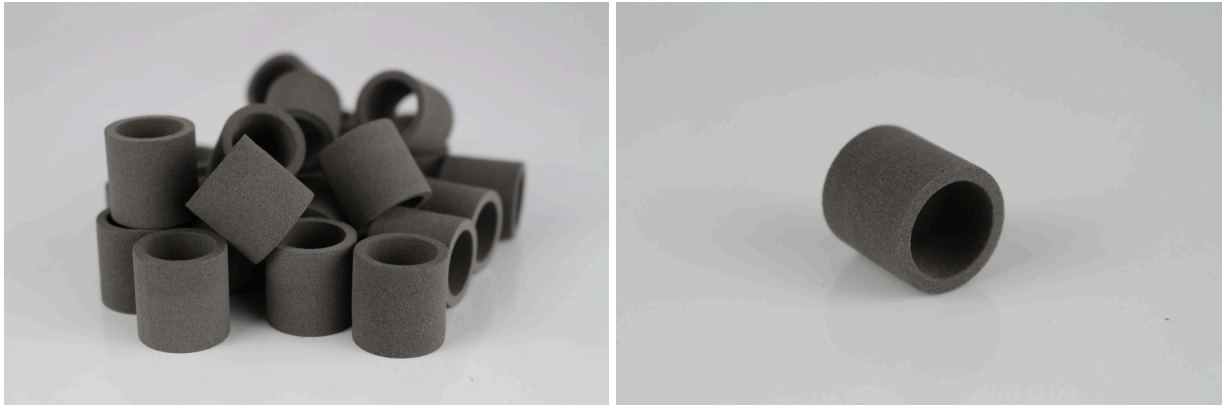


Fig.29: Repeatability testing of tubes model

TUBE	Ext ϕ (mm)	Total height
Reference	20	20
Print 1	19,998	19,925
Print 2	20,049	19,730
Print 3	20,042	19,991
Print 4	20,059	19,777
Print 5	20,056	19,774
Print 6	20,025	19,740
Print 7	19,952	19,769
Print 8	19,974	19,780
Print 9	19,953	20,029
Print 10	19,963	19,743
Print 11	19,983	19,890
Print 12	19,985	19,984
Mean of differences	0,03525	0,1605
Mean of real values	20,00325	19,84433333
Standard deviation (σ)	0,040850337	0,11169466
Estim. stand.dev. (s)	0,042666785	0,116661267
Mean + 3.σ	20,12580101	20,17941731
Mean - 3.σ	19,88069899	19,50924935

Tab.8: Tubes dimensions

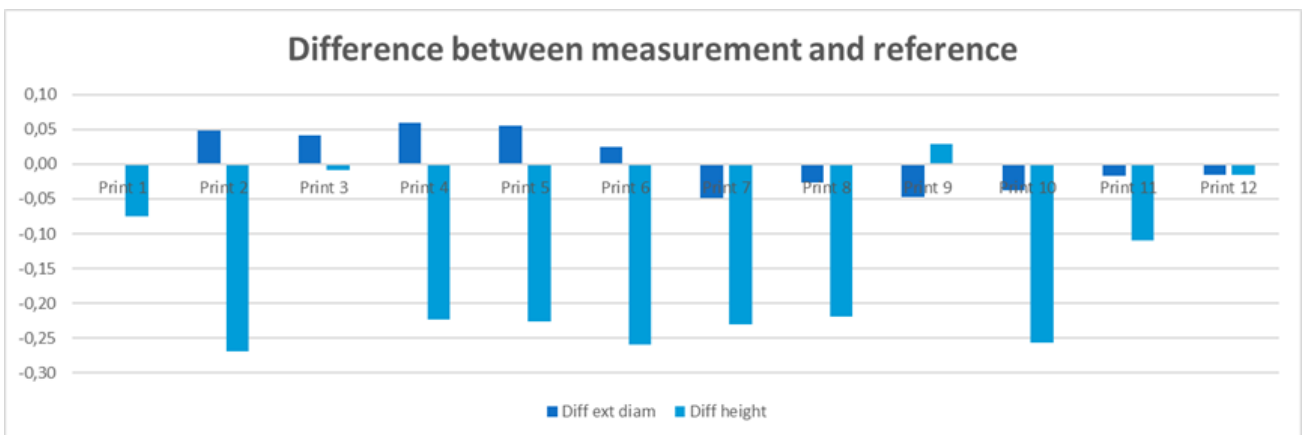


Fig.30: Difference between measurement and reference

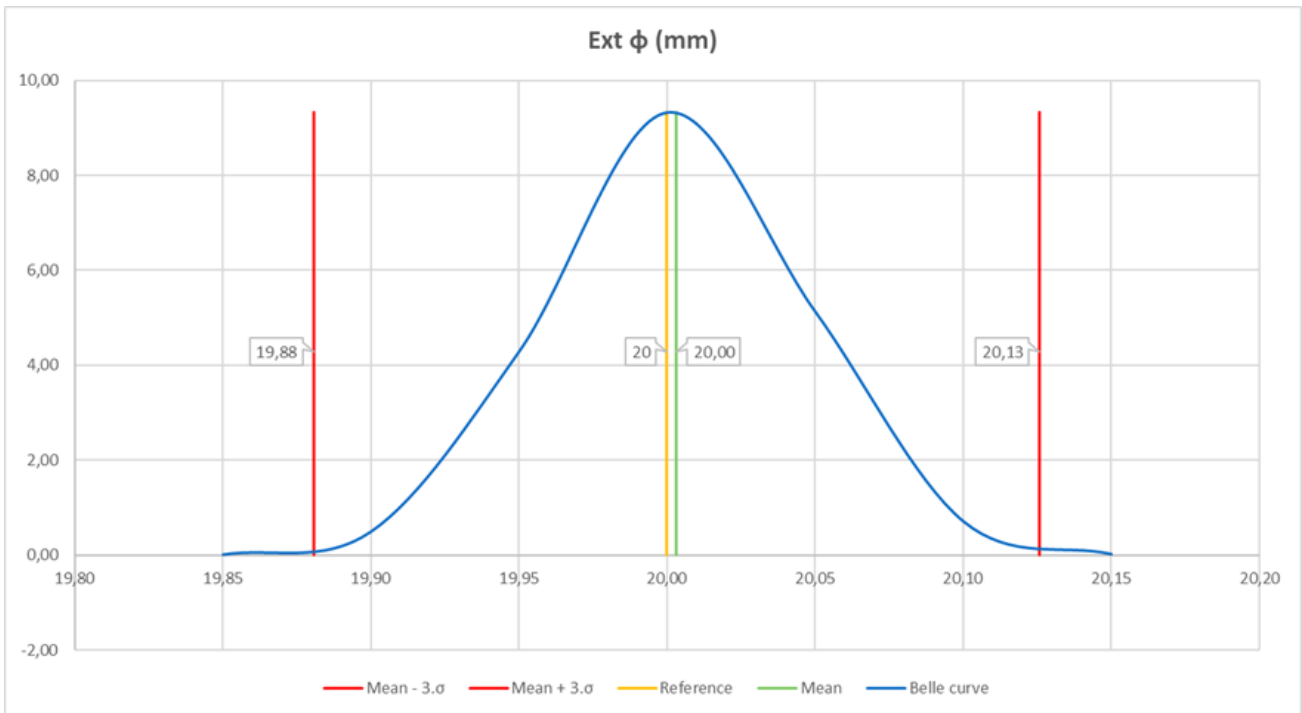


Fig.31: Normal distribution on the external diameter

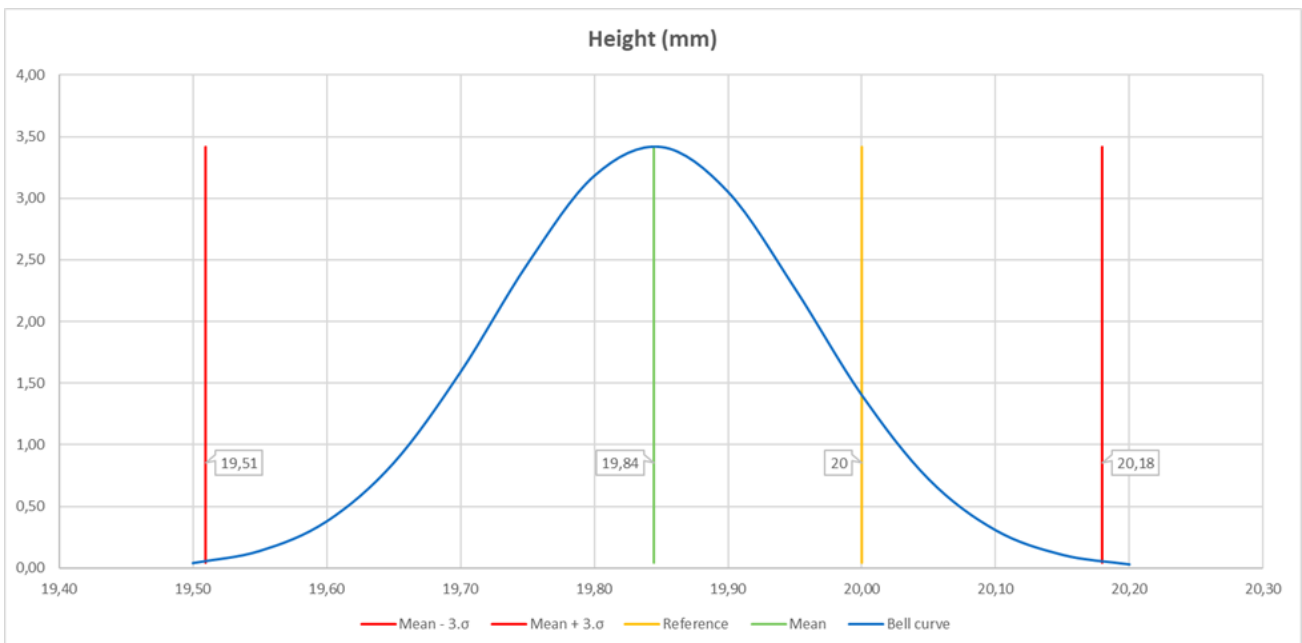


Fig.32: Normal distribution of the total height

The mean of difference for both ratings of the tube part test is **0.0979mm** (under 0.1 mm) but the standard deviation is **0.0763mm** (over 0.05mm).

Regarding the diameters, the results on the tubes are near the target diameter. Values range from **19.952mm** to **20.059mm**. This is a result better than the average. Circular trajectories will be explored in detail in the circular trajectory test section.

- Conclusion

In terms of repeatability, Formlabs Fuse 1 is better than average. The mean of the difference for all dimensions is **0.0616mm (0.0348mm** excluding height), which is under the reference (0.10mm). And the standard deviation for all dimensions is **0.0567mm (0.0365mm** excluding height), which is over the reference (0.05mm).

The standard deviation can reach 0.01mm which is good performance for the printer. But some differences between measures and targeted dimensions can be higher than usual. In our case, the test that performed the worst and that lowered the average score is the height on the tube tests.

This part shows results on the diameter are less consistent from a repeatability point of view because circles are less suitable than other shapes for printing on this type of system. This phenomenon will be studied further in part "[Circular trajectory test](#)".

b. Tower test

The goal of this test is to determine if the printer is able to realize tall and thin parts. This can be an issue for some 3D printers, this test also allows us to check that the manufacturer's data is valid and that the printer is capable of printing at its advertised dimensions. The test print is a rectangular-based tower with the following dimensions (20x20x300). The **295mm height** limit was reached on this print.

Profile	Layer thickness (mm)	Enclosure temperature (°C)	Laser power (%)	Material
Standard	0.110	180	100	Nylon 12

Tab.9: Tower setting

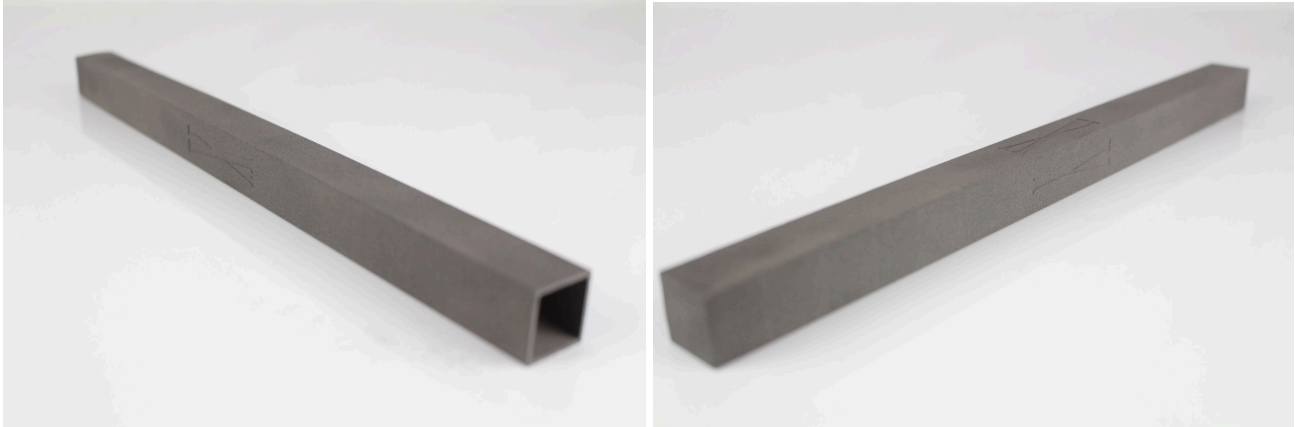


Fig.33: Tower test

The result of this test is very good. The length measured at the top of the tower is **20.048 x 19.954 mm** which is good, and the height is **294.8mm**, which is perfect. The quality of the print is also perfect:

- no defects between the layers
- the surface is smooth from the bottom to the top
- the angles of the tower are well printed.

So the max usable workspace is validated on the Z-axis. The print is 294.8mm instead of the 295mm mentioned by the manufacturer for Nylon 12 powder. The slicer does not accept parts above 295mm tall.

In the case of SLS prints, the powder contracts after printing, resulting in a final maximum build volume of **15.92 x 15.92 x 29.55 cm** (6.27 x 6.27 x 11.63 in).

That being considered, we can confirm that the Formlabs Fuse 1 can print to its maximum height.

DIMENSIONS x

Échelle ⓘ 1,000

X 20,00 mm

Y 20,00 mm

Z 295,00 mm

c. Width test

This test has a similar goal as the tower test. But this time, the width limits of the build area are tested. The model is a rectangular shape that is very close to the boundaries of the bed.

Profile	Layer thickness (mm)	Enclosure temperature (°C)	Laser power (%)	Material
Standard	0.110	180	100	Nylon 12

Tab.10: Width setting

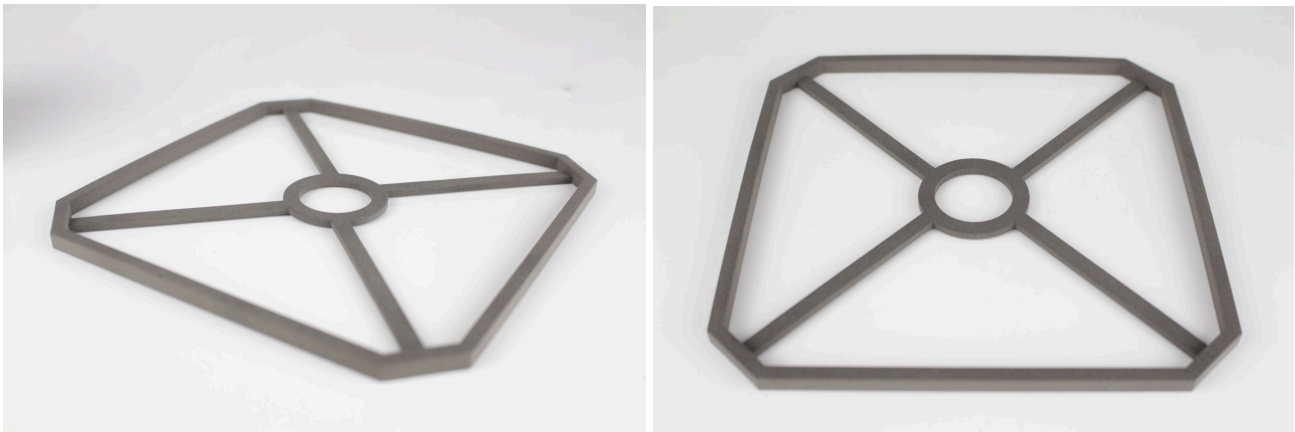


Fig.34: Width test

The slicer doesn't accept the model at the full boundary of the workspace (**165x165mm**). However, the **165x165x300mm** volume is the area that the laser can reach. The **159x159x295mm** area takes into account the shrinkage of the part after cooling.

The maximum size accepted by the slicer is **159.26x159.26mm**. On the print, the measured length is **159.2x158.9mm**, the printer is able to print close to its boundaries.

Moreover, the quality of the print is very good:

- no visual defects
- the sides are flat

So the max usable workspace is validated on the X and Y-axis.

d. Circular trajectory test

The circular trajectory test is designed to evaluate the printer’s ability to print parts with circular sections. This can be a problem, on some machines particularly on printers with a cartesian or polar axis system for example. The model is composed of 3 circular sections of 100mm, 65mm, and 20mm.

Profile	Layer thickness (mm)	Enclosure temperature (°C)	Laser power (%)	Material
Standard	0.110	180	100	Nylon 12

Tab.11: Circular trajectory setting

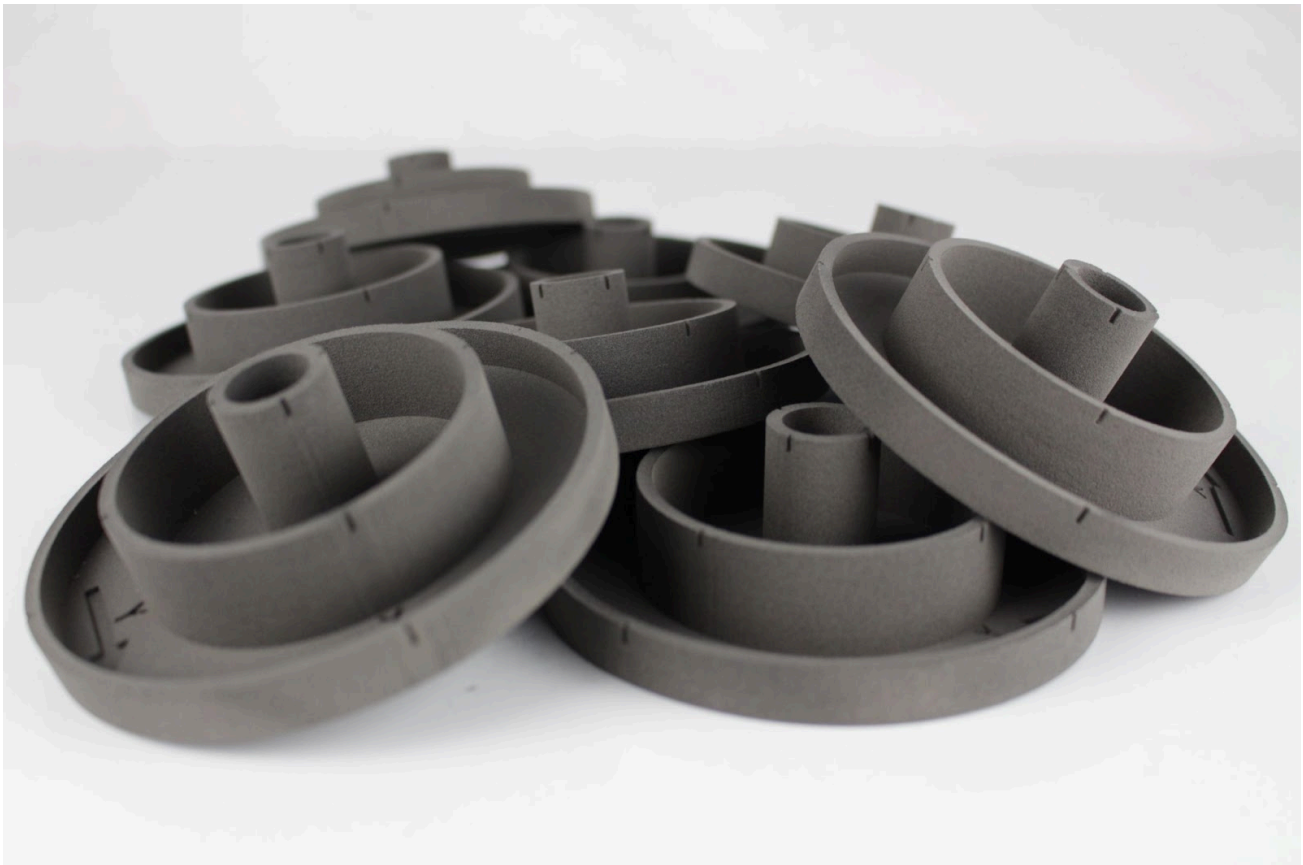


Fig.35: Circular trajectory test

CIRCULAR TRAJECTORY	Circle 1 (mm)		Circle 2 (mm)		Circle 3 (mm)	
Reference	20		65		100	
Axis	X	Y	X	Y	X	Y
Print 1	20,004	19,996	65,05	65,04	100,03	99,99
Print 2	19,952	19,939	64,96	65,01	100,00	100,01
Print 3	20,001	19,996	65,06	65,06	99,98	100,05
Print 4	20,008	20,005	64,97	64,98	100,02	99,96
Print 5	19,955	19,984	64,96	64,99	100,00	100,01
Print 6	20,009	19,937	64,84	64,94	99,97	99,96
Mean of differences	0,019166667	0,0255	0,063333333	0,033333333	0,016666667	0,026666667
Mean of real values	19,98816667	19,97616667	64,97333333	65,00333333	100	99,99666667
Standard deviation (σ)	0,027021596	0,030314463	0,079414524	0,043204938	0,022803509	0,034448028
Estim. stand.dev. (s)	0,029600676	0,03320783	0,086994253	0,047328638	0,024979992	0,037735925
Mean + 3.σ	20,06923146	20,06711006	65,21157691	65,13294815	100,0684105	100,1000108
Mean - 3.σ	19,90710188	19,88522328	64,73508976	64,87371852	99,93158947	99,89332258

Tab.12: Circular dimensions

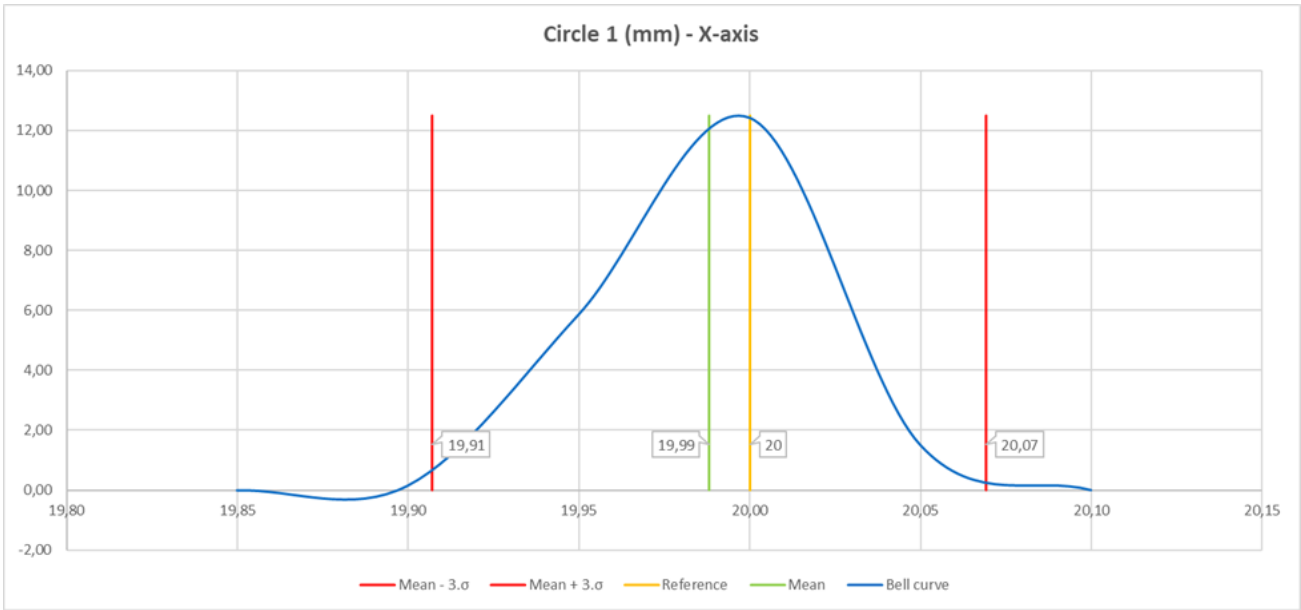


Fig.36: Normal distribution on circle 1 on the X-axis (100mm)



Fig.37: Normal distribution on circle 1 on the Y-axis (100mm)

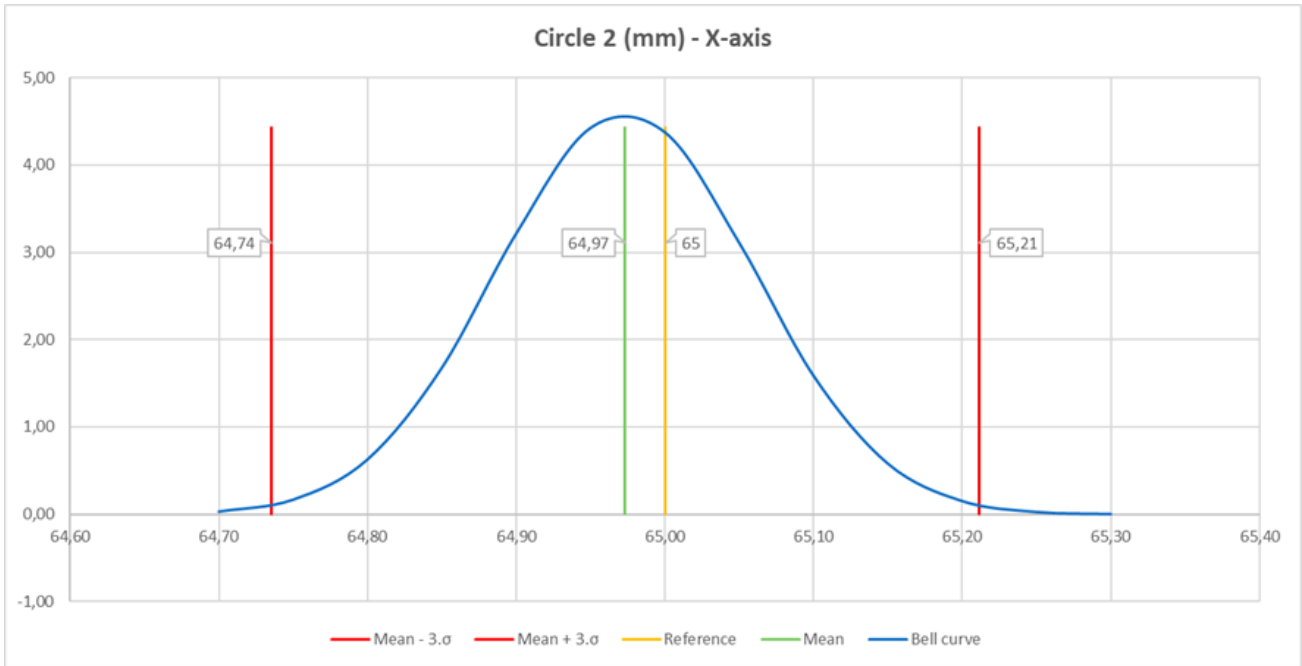


Fig.38: Normal distribution on circle 2 on the X-axis (65mm)



Fig.39: Normal distribution on circle 2 on the Y-axis (65mm)

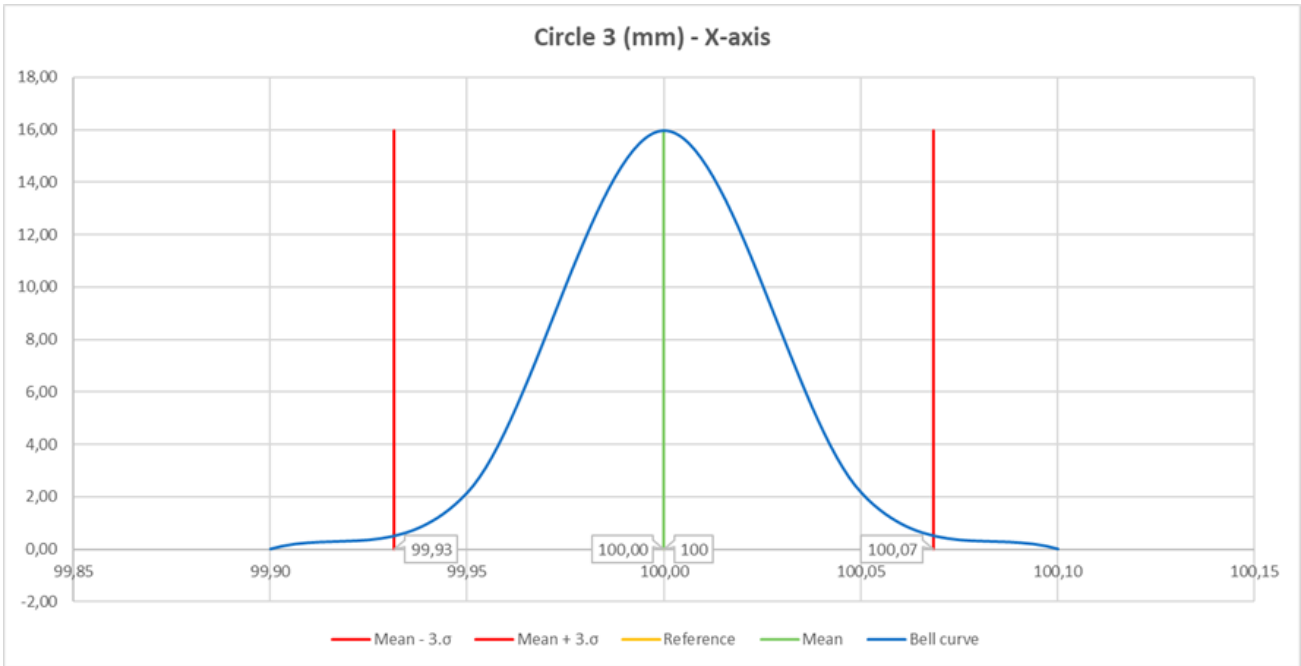


Fig.40: Normal distribution on circle 3 on the X-axis (20mm)

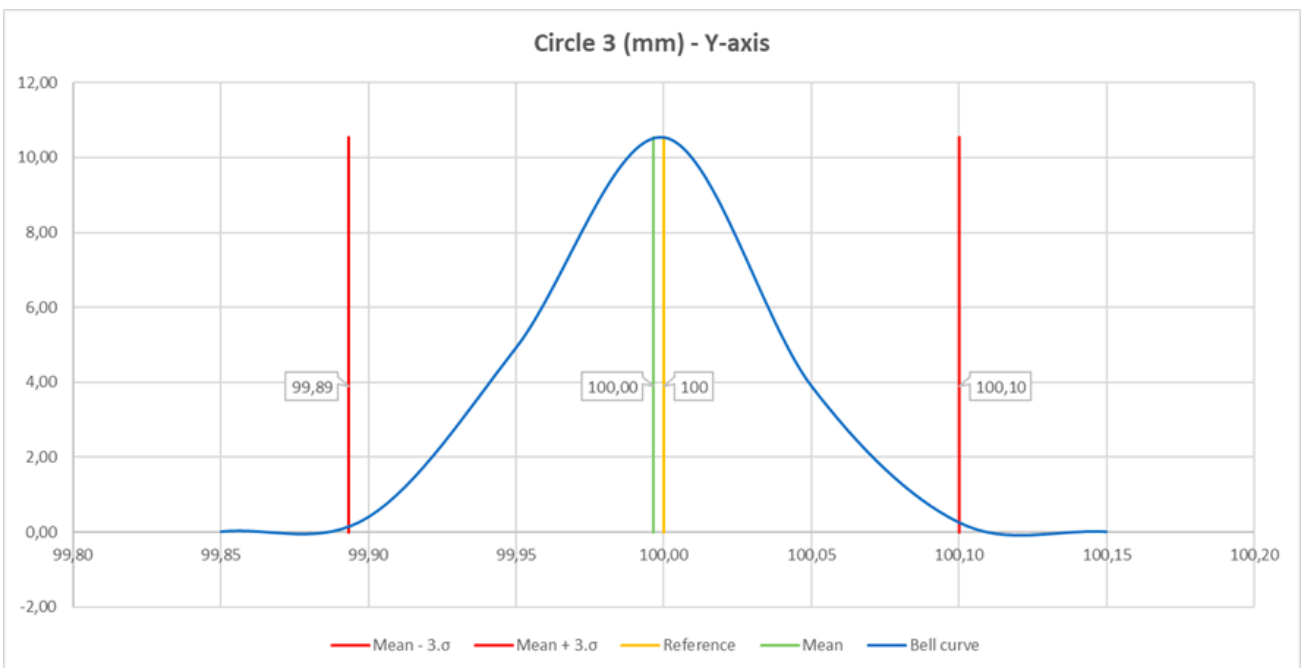


Fig.41: Normal distribution on circle 3 on the Y-axis (20mm)

The galvanometers used for the laser scanner of an SLS printer work with a polar coordinate system. Perfect circles can be difficult to manage for 3D printers: circles are not perfect but usually closer to oval. Depending on where the measurement is taken on the oval, it can be far from the targeted dimension.

The results of these tests are excellent again. The mean of the difference of all the tests is perfect (**0.0308 mm** compared to **0.1 mm** for the average of industrial printers), and the standard deviation is very low (**0.0395mm** compared to **0.05 mm** for an “accurate” printer). These values allow us to deepen the observations of the part “[Repeatability test](#)”. Indeed, the circles are not perfect but closer to oval, but overall the results are very good, the printer reproduces the same shape every time, even if sometimes dimensions do deviate from the target dimension.

For this kind of test, we will refer to the first measurement. After checking our measuring equipment, the accuracy of our caliper for this test is **±0.015mm**. Circle 1 (20mm) is measured with a micrometer. The accuracy of our micrometer is **±0.004mm**. Referring to circle 1 (20 mm), the results are excellent for the X-axis and slightly worse for the Y-axis. The mean of the difference is **0.0192mm** for the **X-axis**, and **0.0255mm** for the **Y-axis**. We can note that for circle 1 (20mm), the X-axis has better results than the Y-axis.

For Circle 2 (65mm), we have a bigger difference between the X and Y-axis. The mean of the difference is **0.0633mm** for the **X-axis**, and **0.0333mm** for the **Y-axis**. It is also important to note that the standard deviation on the X-axis is rather poor on this test with a result of **0.0794mm** on the X-axis against **0.0432mm** on the Y-axis. It is interesting to note that the printer handles the Y-axis better than the X-axis. In this case, whether it is the X or Y axis, the results are good.

In the study of Circle 3 (100mm), we obtain more or less the same results as Circle 1 (20mm), even if the performance of both axes remains a little weaker than in Circle 1 (20mm). The mean of differences is **0.0167mm** for the **X-axis** and **0.0267mm** for the **Y-axis**. Standard deviations are quite the same. **0.0228mm** for the **X-axis**, and **0.0344mm** for the **Y-axis**. Once again, the X-axis is better managed than the Y-axis. It is, therefore, preferable to favor the X-axis when printing parts with high tolerances.

The overall quality of the print is perfect. The surface is smooth and parts look perfect.

The common standard deviation limit on this type of SLS printer is between **0.05 mm** and **0.1 mm** when printing a circle. As a result, parts are printed well and the performance of this printer is over the average for 3D printers in the market. The overall mean of standard deviation on the Fuse 1 is **0.0395mm**. The mean of the difference is perfect with a score of **0.0308mm**. We, therefore, obtain an average accuracy of **0.0331mm** for the X-axis and **0.0285mm** for the Y-axis. The X-axis is better than the Y-axis on 2 of the 3 tests. However, on Circle 2 (65mm), the results bring down the average.

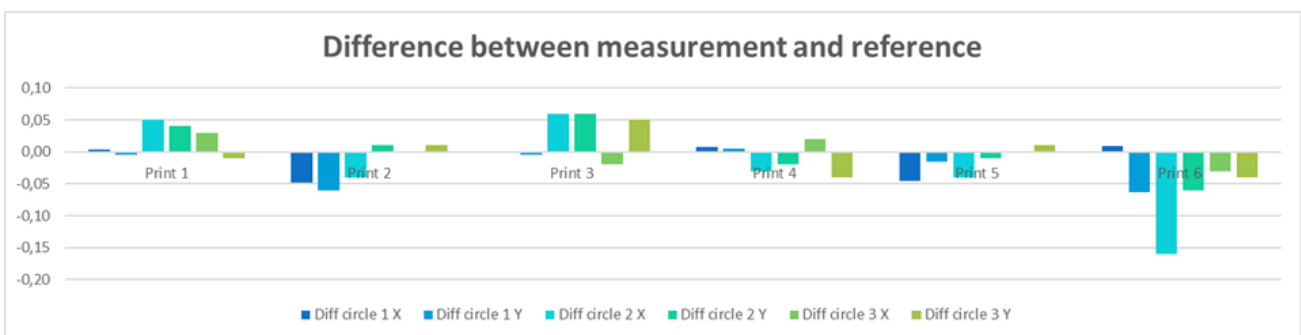


Fig.42: Difference between measurement and reference

e. Small and precise parts test

This test aims to determine if the printer can manage a print with very small dimensions and tolerances. The model is a nut and bolt model which should be functional. The length of the screw is 28mm.

Profile	Layer thickness (mm)	Enclosure temperature (°C)	Laser power (%)	Material
Standard	0.110	180	100	Nylon 12

Tab.13: Small and precise setting



Fig.44: Small and precise parts test

The small parts were successfully printed in very good detail. There are no defects on the thread. The parts can be easily screwed together. We tried to print this model multiple times and it all works perfectly. It is possible to screw them in without forcing. It's one of the best 3D printed screws we have had to date, so we can confirm that the Formlabs Fuse 1 passes the small and precise parts test with ease.

2. Real applications tests

This section contains use case examples of prints that allow us to understand what the printer is able to print in a real-world setting. The parts are printed mainly in Nylon 12, only one part is printed in Nylon 11.

a. Functional suspension model

This test aims to determine if the printer can manage a print in place mechanical print with very small tolerances. The model is a suspension assembly that should be functional.

Profile	Layer thickness (mm)	Enclosure temperature (°C)	Laser power (%)	Material
Standard	0.110	180	100	Nylon 12

Tab.14: Suspension print setting



Fig.45: Suspension part

The print is perfect, after a few forced movements to remove the powder from the moving areas, everything works perfectly and the suspension performs as intended.

b. Puzzle cube

The aim of this model is to print an intricate puzzle box in one print. There are complex parts and very fine tolerances between each piece of the puzzle. It is therefore a very good test to assess the accuracy of the printer on each axis.

I would especially like to thank Kurt Plagge who kindly provided us with this model. You'll find his YouTube channel below:

https://www.youtube.com/channel/UCuay5K_2BkZmnTXJ_JJvKw

Profile	Layer thickness (mm)	Enclosure temperature (°C)	Laser power (%)	Material
Standard	0.110	180	100	Nylon 12

Tab.15: Puzzle cube setting

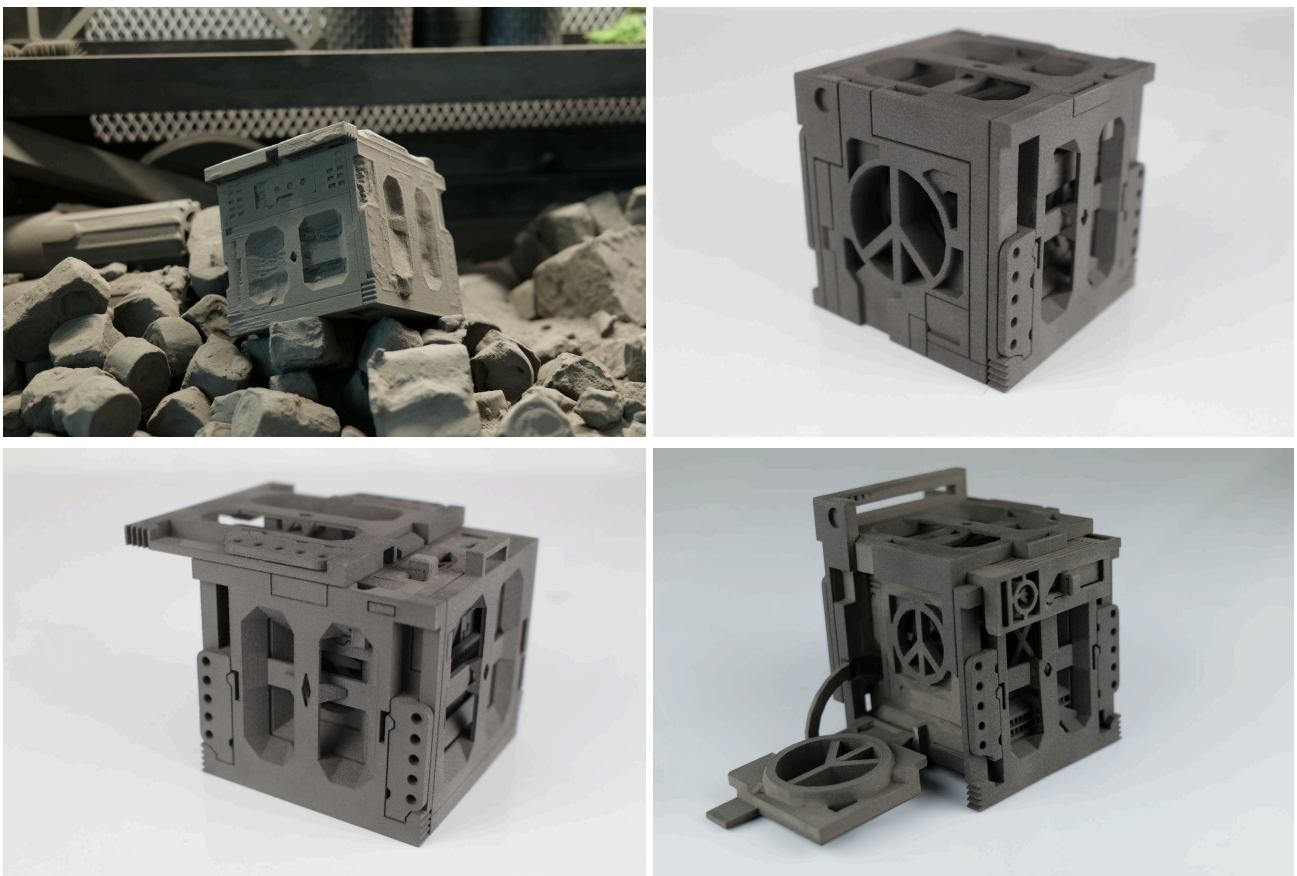


Fig.46: Cube puzzle

This is probably the most impressive model we were able to print with the Fuse 1. It is a print-in-place puzzle that prints fully assembled. After printing, we put the part through a sandblaster to do the first post-treatment. We then slowly disassembled the model to empty it of the remaining powder. We had no trouble opening the cube and none of the different parts were welded together. This is impressive as many people who have printed this part have reported that the dimensions were too tight to be printed on an SLS machine. In our case everything is absolutely perfect, the Fuse 1 handled the test with ease. The surface quality is perfect, there are no visible defects, no warping or delamination.

c. Car

This model is a car that Benjamin Keyser from the UK-based Formlabs distributor Solid Print3D designed. The model was then cleaned and painted without sanding. It is an MG-TF built-in 1954.

Profile	Layer thickness (mm)	Enclosure temperature (°C)	Laser power (%)	Material
Standard	0.110	180	100	Nylon 12

Tab.16: Painted car setting



Fig.47: MG-TF 54 painted car

We found this model very impressive and it defines the use of the printer well. For making highly detailed models or prototypes, the Fuse 1 is perfect. The print is clean and there are no visible defects. In addition, the paint was applied evenly to the model.

d. Prototyping prints

We have therefore selected several models related to prototyping for the automotive industry for our testing. We have a V6 engine block and an exhaust manifold.

Profile	Layer thickness (mm)	Enclosure temperature (°C)	Laser power (%)	Material
Standard	0.110	180	100	Nylon 12

Tab.17: Prototype setting

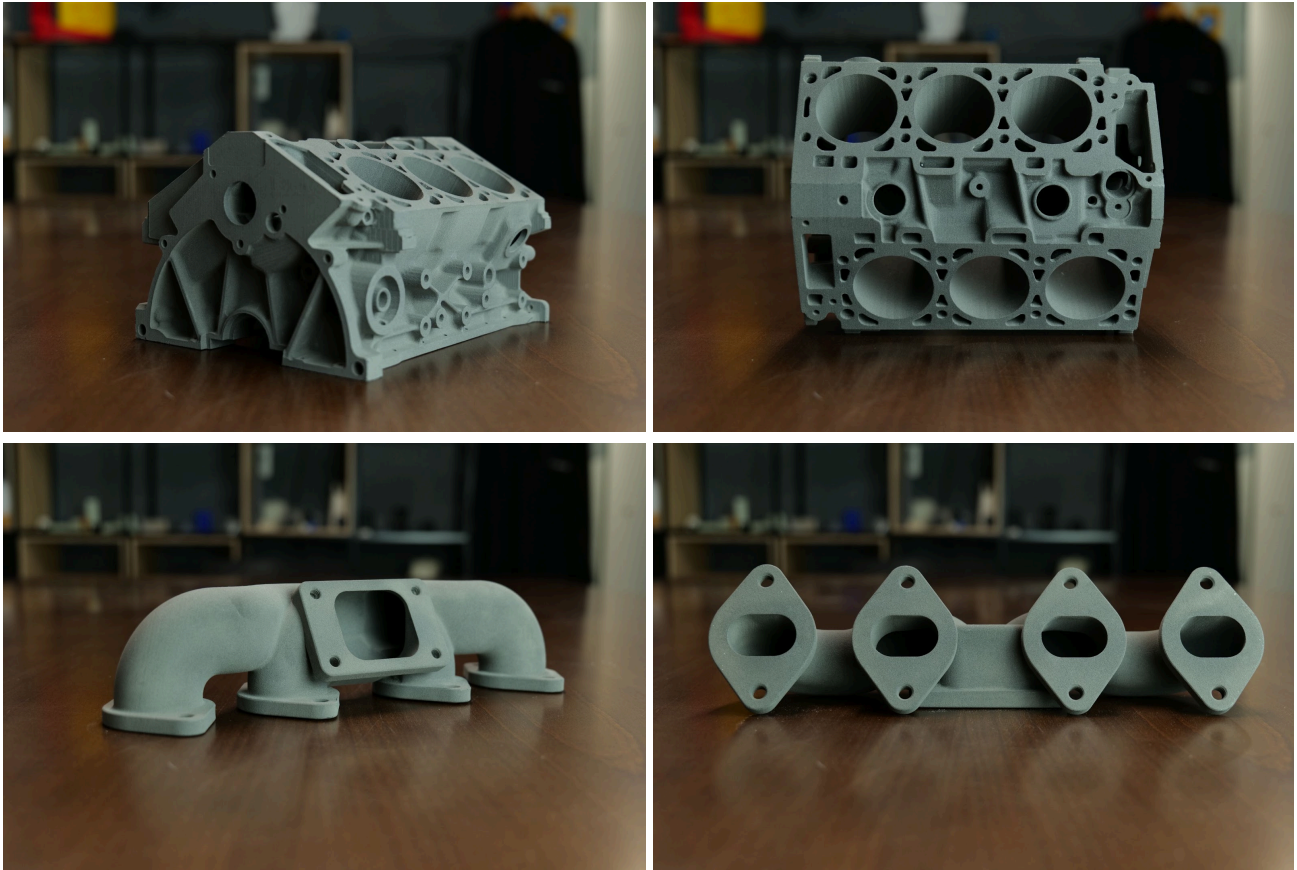


Fig.48: Prototype prints

As expected, the print is perfect, there are no defects and the diameters are consistent and precise. Nothing more to say, this printer is really Plug&Play.

e. Mechanical system

The model below is a planetary gear system. This test enables us to determine if the printer is able to print functional mechanical models that rely on high tolerances, in position. If the dimensions and tolerances of the original model are respected, the model should work well.

Profile	Layer thickness (mm)	Enclosure temperature (°C)	Laser power (%)	Material
Standard	0.110	180	100	Nylon 12

Tab.18: Mechanical system print setting



Fig.49: Planetary gearbox

Firstly, it is important to know that this is a print in place design. This kind of mechanical model is very useful in order to assess the machine because if the model prints correctly, and it works, it means that the printer is accurate. For a planetary gear of this type, the tolerances are very tight so precision is paramount.

The print came out very well, the quality of the surfaces is good and there are no discernable defects on any of the parts. There was also no post-processing required on his part aside from removing the excess powder.

The result is a high-quality mechanical print, the mechanism works very well and the part is strong. The Formlabs Fuse 1 can print mechanical parts reliably and consistently, as both copies of the part-work flawlessly.

f. Toys or educative models

This section will look into printing small moveable parts destined to be suitable for end-use applications. Whether these toys or educational models, we will test the printer's ability to make common, everyday models. The printed models include an articulated MiG-23 jet fighter, a scorpion, a fidget toy, chainmail, a spine, and a coaster.

Profile	Layer thickness (mm)	Enclosure temperature (°C)	Laser power (%)	Material
Standard	0.110	180	100	Nylon 12

Tab.19: Toy and educative models settings



Fig.50: Toy and educative models

As expected, these models have no defects. Every model that is supposed to move moves correctly. The surface is clean, you can't see the layers. You only have to sandblast the parts to remove the powder

residues. Once this is done, the parts are ready to use which is a great benefit when considering SLS 3D printing.

g. Other end-use cases

In this final case, we will test the printer on more common use cases that require the parts to be usable in real-world scenarios. The first model is a prototype housing to cover a PCB, the second is a structural part to join and mount tubes together.

Profile	Layer thickness (mm)	Enclosure temperature (°C)	Laser power (%)	Material
Standard	0.110	180	100	Nylon 12

Tab.20: Other use cases print setting

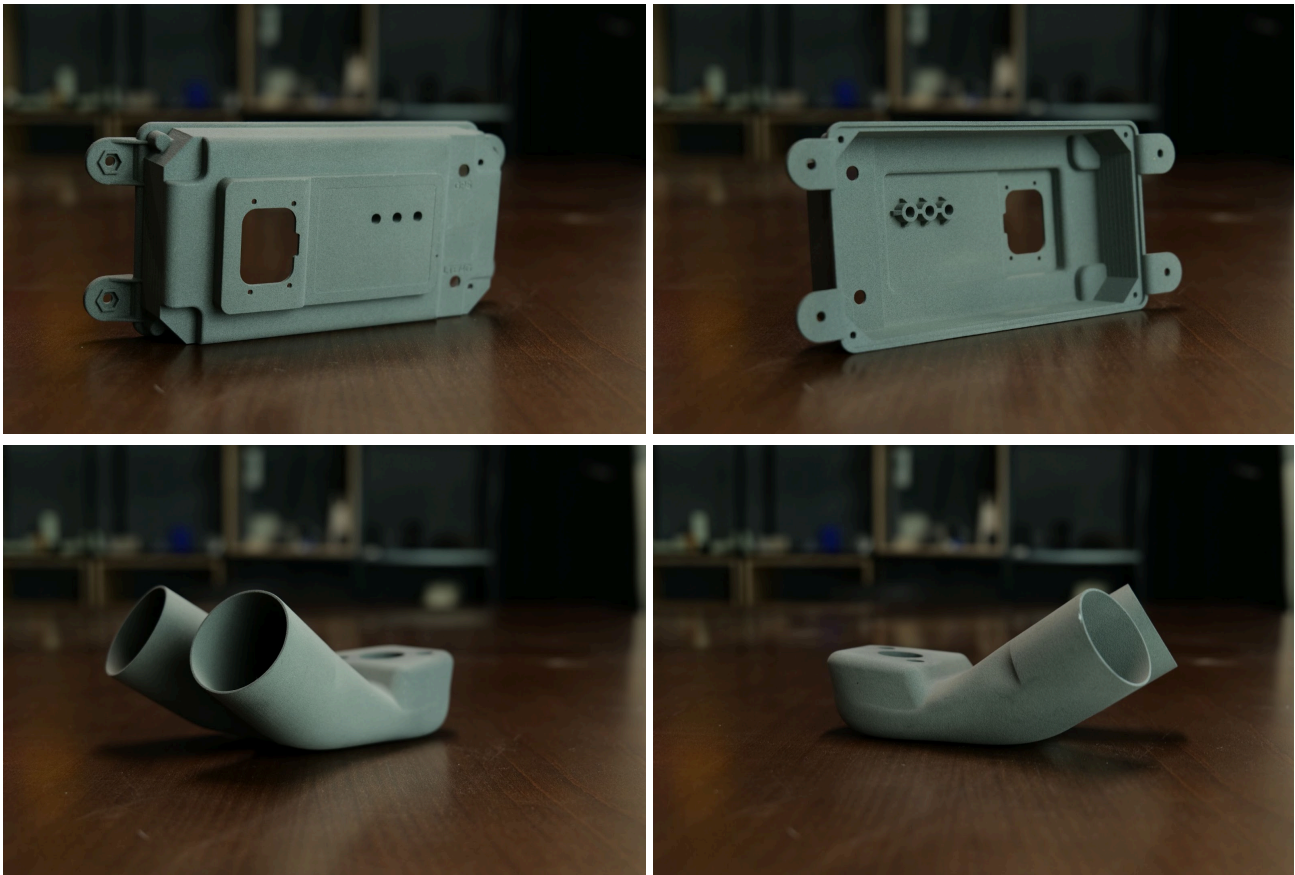


Fig.51: Other use-cases of the Fuse 1 printer

Both prints are once again perfect and ready to be used in their intended settings. The Fuse 1 has once again showcased that it is an ideal machine to use for the end-use production of functional parts. The easy setup, excellent surface finish, and minimal post-processing requirements make this system ideal for the short-run production of useable parts.

VI. Conclusion

1. Strengths

To conclude the report, this section summarizes the key observations from our work with the **Formlabs Fuse 1** printer and **the Fuse Sift** post-processing station:

- Hardware: This printer is impressive, all components are very well designed and robust. All mechanical parts are well thought out and clean, which can improve the durability of the printer. In addition, the dimensions of the workspace in relation to the overall size are well optimized compared to the competition. The printer feels solid at first impression. Having a roller to spread the powder instead of a scraper is a big advantage.
- Slicer: PreForm is well optimized and easy to use for beginners, It is easy to manipulate and print 3D models quickly. However, the software is also suitable for experienced users. The strength of Formlabs' slicing software is that the user does not need to change the available profiles in order to print, everything is pre-set and prints come out very well.
- Use of the printer: Thanks to the onboard touchscreen and the clear menu layouts, all operations are simple to carry out, the interface is very smooth, unlike some printers where there is a lot of latency. Apart from a little cleaning, there is absolutely nothing to do between each print meaning output on this system is good.
- Basic tests: It was successful in all the basic tests. The precision is good and the print quality is really remarkable.
- Real application tests: The Fuse 1 is able to print for a range of applications from prototypes to end-use parts. There are no defects to report on this side, apart from the small range of materials for the moment.

1. Weaknesses

However, some areas could be improved on future iterations of this 3D printer:

- Hardware: There is nothing to report on this side, the printer is robust and well designed. Congratulations to the Formlabs team.
- Slicer: PreForm is near perfect. The only complaint is that it is impossible to change certain parameters such as layer height and scanning speed as well as laser power. For an advanced user, this could be useful to improve part or production capabilities. Giving the user the possibility to use third-party materials could be a plus.
- Use of the printer: There is absolutely nothing to report on this side. The printer is very user-friendly with an easy learning curve.
- Real application tests: Nothing to declare on this side either. All the tests were a real success.
- Bug: We had no bugs to report during our testing.

2. Overall feeling

The Formlabs **Fuse 1 & Sift** is a really good system. For a professional/industrial user wanting a turn-key SLS printer, it will be perfect. All is well thought out and all options are working well. It's really easy to use the printer.

The slicer is really good and easy to use: all is fluent and well organized. Parts are moved easily and the stacking settings are working very well. Only one profile is available for the Fuse 1 per material, so the user will not be able to change the settings to their liking. Moreover, the slicing is faster than other slicers. This slicer is one of the best we have ever used. There is nothing superfluous, anyone can easily understand it for everyday use.

Basic tests are printed very well. All are useful following the need. The printer is accurate and precise in terms of repeatability. All our prints went well and we have no major defects to report. The quality of the surface is perfect, we can't really see the different layers. In addition, the post-processing machine works perfectly, which makes it a perfect combo for anyone wanting to buy a complete SLS system. Furthermore, with one Sift post-processing machine, you can use up to 3 or 4 Fuse 1 printers. This makes it one of the most competitive systems on the market.

In addition, Formlabs is one of the market leaders in additive manufacturing. If you have a problem, you can contact Formlabs directly, they will be able to look in the log file of your machine to analyze what is wrong. The customer service is perfect and worthy of a market leader. We highly recommend this company's after-sales service.

The main areas for improvement are the materials available with this machine and the slicer settings. This printer is above average in terms of repeatability and capability. Apart from that, I don't see how Formlabs could have come up with a better product, especially for their first printer on the SLS market.

So the printer has a high potential. Just some details can be fixed and it could become one of the best SLS setups. This printer is intended to become an industrial printer for professional users, but also for prosumers who want to do some prototyping with engineering materials. Personally, testing this printer was a pleasure. I tested the limits of the machine and it totally answers my requirement very well. Formlabs Fuse 1 printer and the Sift post-processing machine is a good setup, better than the average in terms of accuracy, build volume, and ergonomics compared to other printers in the same market range. For me, you can clearly say that Formlabs is the Apple of additive manufacturing.