Use of Anycubic Photon for precision components

Egbert Stellinga

STEERED Technology

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Contents

Introduction

In assignment of Steered Technologies, the usability of the Anycubic Photon for precision manufacturing is investigated. Steered technology aims at an accuracy requirement of -0/+0.1mm.

The Anycubic Photon is an LCD-based SLA (**S**tereo**L**ithogr**A**phy) type 3d printer using UV-sensitive resin to build parts [1] with Chitubox [6] as slicer software.

The combination of machine settings and process capabilities determine product accuracy and quality. To determine optimal settings, eleven steps were developed starting from recommended settings given by the resin provider.

Results of the tests are recorded, discussed, and evaluated. Conclusions including views and recommendations are reported. Lastly, additional steps on research accuracy are discussed.

Management summary

The use of Anycubic water washable resin with the Anycubic Photon does not suffice the desired production applications. The requested -0+0.1mm accuracy cannot be met with the investigated setup. To achieve the requested accuracy, more expensive resin printers could be considered. The setup is suitable for 'show and tell' samples.

Initial settings

The research will be performed with water-washable resin. The testing will start with the following settings which are found to be the reference settings for water-washable resin. [2]

Setting	Start value
Exposure time	7000 ms
Layer height	0.05
Bottom exposure time	50000 ms
Number of bottom layers	4
Light out time	1000ms
Wash time	10 min
Cure time	5 min
Lifting speed	65,000 mm/min
Tolerance compensation	0-0 mm
Bottom tolerance compensation	0-0 mm

Approach

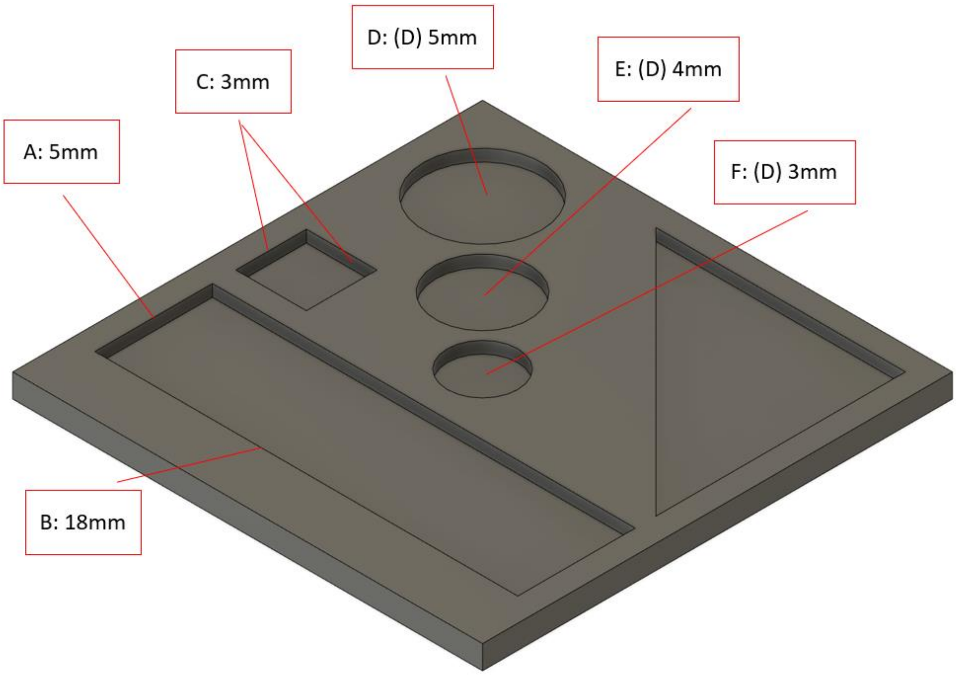
The approach taken to find the optimal settings and the achievable accuracy has been divided into eleven steps. The order of these steps is based on the suspected relations between variables and factors that influence the process. For the overview of variables and factors that influence the printing process and the relations between them, a mind map is created in Miro [c] which is documented in Appendix A. For every step, the goal and approach are described.

Step 1: Washing quality

For step one, the optimal washing time will be determined such that all excess resin is removed from the model. In that case, only the cure time and print settings could have an influence on the model dimensions. For washing (and curing) an Anycubic wash and cure plus station is used [7].

First a bottom line is set by cleaning the model in an ultrasonic cleaner and removing any visible resin by hand. It is assumed that the ultrasonic cleaner can remove all resin from the model. Then the washing time from the washing station will be varied until the same dimensions of the reference print are reached while maintaining all other settings constant.

The test block is depicted below and has 7 dimensions that will be measured. The washing times will be varied from 2 to 30 minutes with 2-minute intervals with three test samples each. If the same quality as the reference print is reached before 30 min the rest of the tests will be discarded. If the same quality as the reference print is not reached it will be required to use the ultrasonic washing station.



Step 2: Cure time

The goal of this step is to determine if the post-cure time influences the dimensions of the model. A too long cure time is known to cause warping [10]. A curing time that is too short will result in a model with undesirable material properties.

This test will determine if a longer curing time has an influence on the dimension and will give additional insight on warping. Only the post curing time will be variated, the test block from step 1 will be reused.

The curing time is expected to also vary for part size. Because the test block is small the cure times will be varied between 1 and 16 minutes. The Anycubic wash and cure plus station will again be utilised.

Step 3: Light off delay

If the light off delay is too short a phenomenon called blooming can occur. This is caused by the resin still moving while the UV light is turned on, which causes a rough surface [3]. It can be prevented by increasing the light off delay such that the resin has time to settle.

With default settings no blooming has been observed. To optimize the print time, it the delay could be decreased until blooming is observed but this step can also be skipped for time-conserving reasons. Blooming can most easily be observed on a flat surface thus a square box will be utilized.

Steps 4 and 5: Optimal exposure time vs layer height

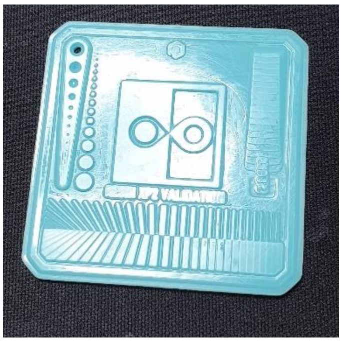
Steps 4 and 5 are closely related and probably most important for the accuracy of the printer. The goal of this step is to determine the combination of layer height and exposure time with the greatest accuracy.

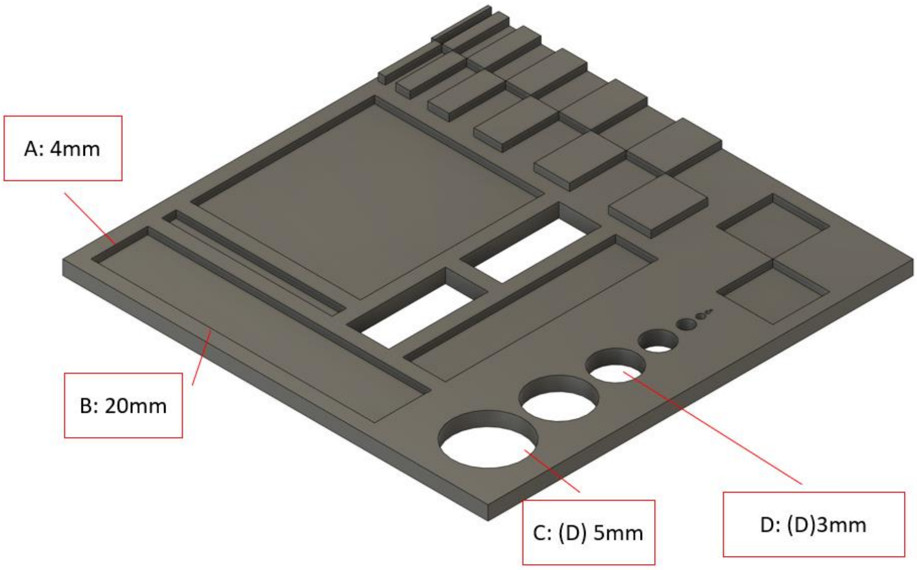
In the SLA process every layer is a picture with X-Y accuracy, but it also has a certain layer height. A greater layer height requires a longer exposure time to cure the layer which can affect the X-Y accuracy. Thus, for every layer height the optimal exposure time will be different.

Not only the X-Y dimensions have to be measured but also the thickness is important. There are two theories that need investigation.

1. Does a smaller layer height lead to better X-Y accuracy for optimal exposure time settings?
2. Does a low curing time lead to a z-height offset on the final model?

Online the XP2 test print is popular for finding the optimal exposure time [4] [5]. The most key features of this test are the corners of the parallelograms that should barely collide. Under exposure will leave a gap between the edges, over exposure will fuse the edges. For the desired application it is also important that rectangular holes have the correct dimensions. To also include this a new test block is made that contains some features of XP2.



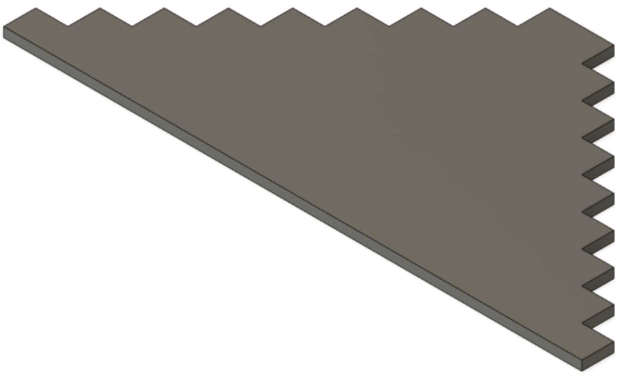


To conserve on the number of test prints that must be performed, first a large step-size in the exposure time is done for the different layer heights. After which the step-size is decreased between the best rough settings. The layer height can be set between 0.025mm to 0.1mm, increments of 0.025mm are used.

Step 6: Determine deviation type

Inside Chitubox there are two options for setting tolerance compensation. These are constant values that will be subtracted or added to the outer or inner edge of the model. This feature is most functional when the deviations are constant and not based on percentage or something different. Therefore, the goal of this test is to determine what deviation pattern there exist on the printer.

In the figure below the test sample is depicted. With this sample the deviation for 8 different dimensions ranging from 5mm to 50mm can be measured. The sample will be printed and measured 8 times.



Step 7: Find tolerance compensation

The goal of this step is to determine the best values for the tolerance compensation setting. The values will be determined using data gathered in steps 4, 5 and 6 and some additional test prints. The data will be analysed to find tolerance compensation values for which the dimensions of the test sample meet -0+0.1mm requirements. The setting will be validated using the test sample of tests 4 and 5.

Step 8: Find the optimal bottom exposure time

To make the print stick to the bed the bottom exposure time is set higher than the standard exposure time. It has been observed that bottom layers show large inaccuracies, caused by long exposure times. The goal of this test is therefore to investigate if the bottom exposure time can be minimised and what effect this has on the inaccuracies.

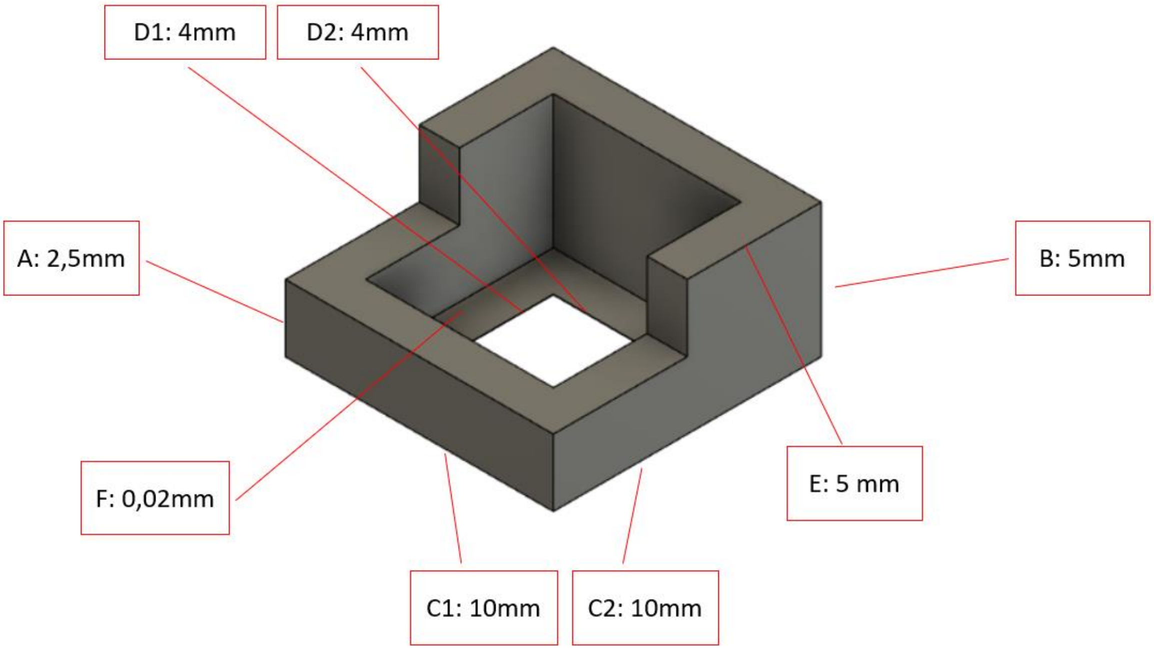
The minimal exposure time will be determined by decreasing the exposure time until print failure. The effect on the inaccuracies will be noted.

Step 9: Find bottom layer tolerance compensation

There is both a tolerance compensation for bottom layers and normal layers in Chitubox. The goal of the step is therefore to determine the optimal bottom tolerance compensation. The bottom tolerance will be determined by measuring the bottom layers of the test samples from step 6. The settings are validated by performing some additional arbitrary objects to observe the affect.

Step 10: Precision

With the final optimal settings, it must be determined what the precision of the printer is. The precision will be quantified by determining the standard deviation on multiple dimensions of the test sample in the figure below.



Besides the standard deviation the AQL level [11] must be determined. The required AQL level is 4 with a GIII General inspection level. The tolerance that will be graded on is +/- 0.1 for all dimensions.

Step 11: Repeat steps 1-11 for different resins.

All the settings can be different for different resins. Clear resins might for instance require lower exposure times than resins that are not clear. Therefore, the steps above should be repeated for other resins. Some settings might stay the same or require less testing because the general direction is already found in previous testing.

Results

All results are noted in Appendix B to I. In this chapter, these results are discussed. During testing, some deviation from the test plan occurred. Some tests where not performed and some other tests that are not described were performed.

Step 1

During step one only two samples were assessed per washing time and 14 to 30 min washing times are missing. These have not been performed because they were judged to be unnecessary. Between all prints that have been performed, there is no visual difference indicating leftover resin in the corners. Looking at the results there is no relation to be found between the washing time and the dimension of the part. Something that has been noted throughout all the tests is that resin is most likely to not get washed out of small holes. The results of step 1 are noted in Appendix B. Step 1 measurements.

Step 2

From the curing time test itself, no warping or difference in the dimensions was found for the tested curing times. What has been observed is that longer curing times cause stiffer but more brittle products. There has not been made a quantification of the observation.

Step 3

Due to no signs of blooming with the 1s light off delay, it has been decided to not perform this test regarding time considerations.

Steps 4-5

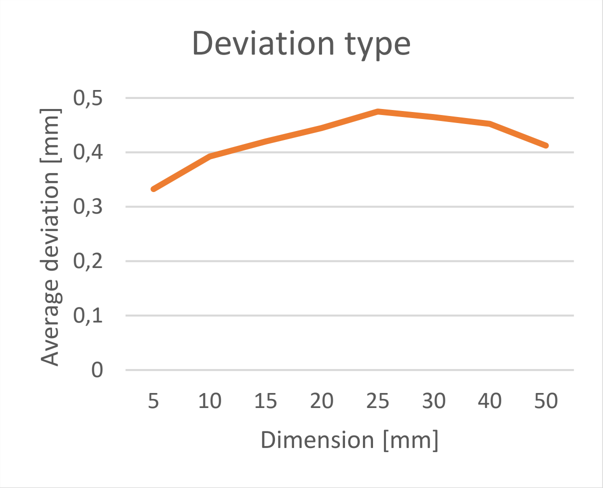
It is to be noted that the tests with an exposure time of 4s and 5s are missing for several layer heights. The reason here fore is that the four tests that where performed showed real bad quality and assumed was this would be the case for the other settings as well.

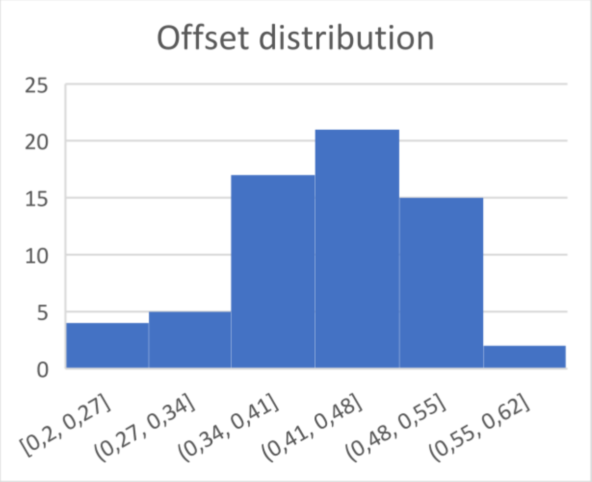
From the results of this and previous tests it is observed that there is a relatively consistent offset from the CAD dimension. Therefore, a division has been made between accuracy and precision this step and further steps. The accuracy is the difference between the CAD model and the measured dimension. The precision is the difference between the average measured dimension and each individual measurement. For each of the layer height and cure time the worst and best standard deviation is highlighted (red and green).

The results of steps 4-5 are recorded in Appendix C. Steps 4 and 5 measurements.

Step 6

Over an average of 8 prints, the absolute deviation is plotted against the dimension in the graph below. For 5 to 25 mm the deviation gets larger as expected but for larger dimensions, the deviation drops again. The cause of this might be the shape of the test part. Namely from 25mm onwards the dimensions are measured horizontally. There is some warping of these test part which would cause the horizontal measurements to be slightly less which might explain these results.





Also, the standard deviation for this test was calculated which for all measurements combined is 0.079 mm. The histogram above depicts the distribution of the data which is relatively normally distributed. Plotting the standard deviation against the dimension shows no clear pattern.

The results of step 6 are recorded in Appendix D. Step 6 measurements.

Step 7

The tolerance compensation setting in Chitubox will not be of significant use for normal layers in complex parts since the deviation is found to be heavily dependent on shape.

Some results of step 7 are recorded in Appendix E. Step 7 measurements.

Step 8

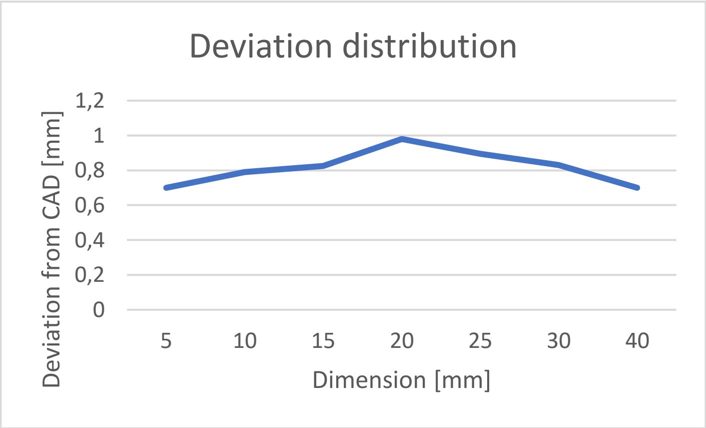
It has been found that the test print was successful up until 30s of bottom exposure time. For 25s or lower bottom exposure times the prints came loose from the build plate. While 30s may be the minimal this can cause reliability issues. A slightly higher bottom exposure time (45+s) gives more certainty for print success. Also, the inaccuracies at these layers were observed to stay roughly the same.

The results of step 8 are recorded in Appendix F. Step 8 measurements.

Step 9

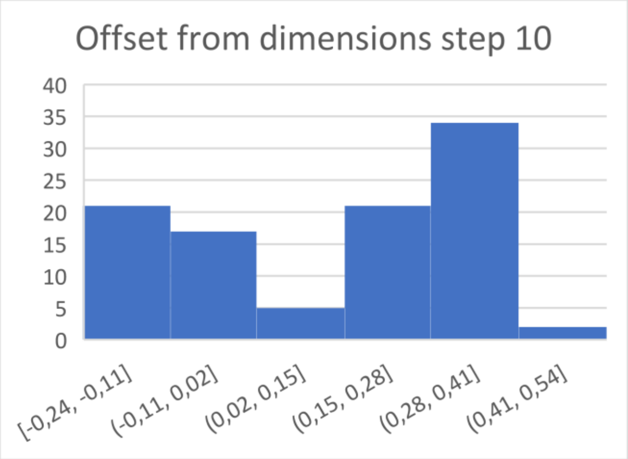
The distribution of the bottom layer deviations has a similar pattern to the deviations observed in step 6. Probably for the same reasons. A standard deviation for all measurements of 0.18mm has been found. However, throughout all tests it has been observed that also the bottom layer deviation differs throughout the part. For instance, on outside corners it is very small, applying an offset here will result in rounded bottom layer corners while the rest of the layers have square corners.

The results of step 9 are recorded in Appendix G. Step 9 measurements.



Step 10

The results from the tests of step 10 show a standard deviation of +/-0.042mm. The standard deviation for a single bottom layer is found to be +/-0.016mm. For determination of the AQL level, it is assumed the dimensions of the part are optimized such that only the precision is relevant the reason will be described in evaluation. On 20 parts with 100 measured dimensions 2 parts had 1 dimension exceeding a +/-0.1mm requirement. This corresponds to an AQL 4 level. When considering a +/- 0.05mm accuracy only 5 of 20 parts meet this requirement which does not satisfy any AQL level.



The histogram in the figure to the right shows that the measurements are not normally distributed. This could be caused by the translation from negative to positive deviations and the combination of offsets for different CAD dimensions.

The results of step 10 are recorded in Appendix H. Step 10 measurements.

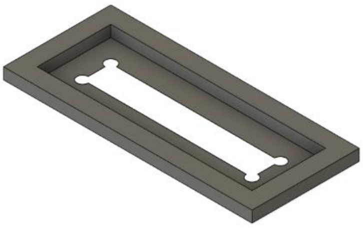
Step 11

So far, the tests have only been performed for black water washable resin.

Additional

In the interest of elastomer connectors some tests have been performed investigating a single bottom layer. For this test, the part in the figure below has been utilized. The barrier around the part is intended to prevent warping of the single layer. It turned out that the thickness off a single bottom layer is always 0.38mm and the initial testing showed this dimension had a high accuracy as confirmed by step 10. With a standard deviation of 0.016mm this steady bottom layer dimension could be beneficial for the use with elastomers. In earlier tests it has been observed that the X-Y deviations for bottom layers are particularly large. Therefore, both the part for the additional test and the part of step 10 contains cut outs in the middle which can be measured.

It has been noted that despite the use of the barrier, the inside single layer still warps, which has influenced the results. Also, the edges of the cut out were not straight.



The results of the additional polymer blocks are recorded in Appendix I. Additional measurements, Polymer block V1.

Evaluation

In this chapter the results of the tests are evaluated. Additional findings and occurrences are also discussed.

The cleaning of water washable resin is found to be a relatively effortless process. After 6 minutes all resin except for some resin in small holes is removed. When using water washable resin white precipitation on the part is observed after cleaning. It is presumed to be caused by dirty washing water. The procedure for cleaning the water consists out of long (1 hour in cure chamber) UV light exposure, settling, and filtering. Filtering is performed with a 190-micron filter. However, it has been noticed that not a lot of the residue is captured by this filter, most of the residue seems to be either too small or still fluid-like and passes through the filter. Another part of the residue precipitates onto the bottom of the vessel and can be wiped off. Also, it seems that the water-washable resin residue precipitates better on PMMA surfaces although this is not confirmed.

The time for post-curing of parts is mostly dependent on the size of the part. In general, a time of more than 5 minutes is enough to harden the part. Longer curing times appear to result in a stiffer but more brittle part. The exact curing time per volume is undetermined. Long curing times up to and over 30 minutes seem to have little to no additional effect to the stiffness. Although no actual measurements have been done on the stiffness.

Analysing the marked deviations from steps 4 and 5 it is remarkable that the worst and best performing setting lay next to each other in several cases. Also, in several cases the best setting for the precision is the worst setting for the accuracy. This probably shows that there were not enough measurements in this test to give a valid optimal exposure time for every layer height. But also, the values lay remarkably close in several cases, which might indicate that there is some room for play in these settings.

Results from steps 4 and 5 do not directly translate to an optimal exposure time for each layer height. Various aspects of the print quality deviate between the different exposure times. Therefore, the print quality has been graded on three points: Shape, Accuracy and Warping. In the following table, the best exposure time (or times) for each of these grading points is noted.

Layer height	Shape	Precision	Warping
0.025	5-6-7s	7s	8s
0.05	6-7-8s	7s	7s
0.075	7s	6s	7-8s
0.1	7s	6s	8s

The shape grading has been based on the XP2 corner test and did generally not deviate much between 6 and 8 seconds. It has been observed that smaller features have more overlap in corners than larger features.

In consideration of warping, it is observed that a smaller layer height and a longer exposure time result in less warping. Further, the part always warps away from the print surface with respect to the original printed position. How much the part warps is also dependent on the shape and size of the part.

Combining the grading results on shape, precision, and warping an exposure time of 7s has been chosen for the layer heights of 0.025, 0.05 and 0.075 to be most optimal. For 0.1mm there is also the possibility that 9 or 10s would be even better, but this is not included in the tests.

Returning to the questions of steps 4 and 5, it appears that a smaller layer height does not lead to better X-Y accuracy for optimal exposure time settings. Also, a low curing time does not cause the z-height to offset of the final model. Rather this will cause print failure.

Another finding is that the deviation between the CAD model and dimension depends on the shape of the part. The results of step 6 attempts to show the distribution of the deviation for different dimensions. But considering the complete research done, the deviation is rather dependent on shape and dimension. The shape of the curve found from step 6 might be correct, but the values will be different for another testing sample. This could be an explanation for the significant differences between different tests.

In the additional tests the CAD dimensions of the polymer block V2 were altered after measuring the average absolute deviation on the part. It has been found that the correlation between differing the CAD dimension and the resulting average final dimension is very linear (~1 to 1). With these tests it has been shown that by iterating the CAD dimensions multiple times the accuracy can be increased. The ideal settings therefore should focus on getting good precision.

Dimensions that are printed in the X-Y plane deviate differently from dimensions in the z-axis. The results in step 6 show that the deviations on the outside dimension for parts between 5 and 50 mm lay between 0.2 and 0.62mm. The standard deviation of all measurements has been found to be 0.079mm. According to step 6 and assuming a symmetric standard deviation, 95.4% of the dimensions will achieve +/- 0.158mm tolerances. The standard deviation found in step 10 for dimensions from 2.5 to 10mm is 0.042mm. This is significantly lower and could be caused by an improper assumption of normal distribution. According to step 10 and assuming a symmetric standard deviation, 95.4% of the dimensions will achieve +/- 0.084mm tolerances. When considering a requirement of +/- 0.1mm tolerances the parts from step 10 will accord with an AQL 4 level.

The x-y dimensions of the bottom layers are less accurate than the x-y dimensions of normal layers. The standard deviation found in step 9 for bottom layers is 0.18mm which is more than twice as high as the standard deviation found in step 6. Also, the absolute offset is much higher for the bottom layer on average 0.77mm. Further, corners on these parts are rounded off.

The additional research on polymer block 1 resulted in tolerance compensation b=-0.25mm; -0.4mm for exposure time 60s. But the main conclusion is that for every bottom exposure time, there is a corresponding bottom tolerance compensation to retrieve the correct dimensions. However, using the bottom tolerance compensation does not solve the problem since inaccuracies remain.

Another interesting aspect which is found from step 10 is the transfer from negative to positive deviations. Between CAD dimensions of 5 and 10 mm the average measured part deviation goes from negative to positive. The exact dimension of this transfer point has not been determined. Again, this is most likely also dependent on the shape of the part.

The additional research and step 10 shows that the accuracy on the first layer is very high. On average the thickness is 0.38mm with a standard deviation of 0.016mm. The issue around utilising the first layer is that the x-y accuracy is very low as shown from steps 6 and 10. Also the single layer is affected heavily by warping.

Conclusions and vision

In this chapter the conclusions of the total research will be presented. Besides definite conclusions some visions are presented. Also, the final advice on the use of the Anycubic photon for precision parts manufacturing is given. Finally, the most important findings are summarized.

Conclusions

To clean parts of water-washable resin 6 minutes in the wash and cure station is sufficient. The use of an ultrasonic cleaner only helps for small features such as holes with a diameter below 0.5mm.

When exposing the water contaminated by resin residue for an extended period with UV-light not all resin residue can be captured by a 190 micron filter. An alternative approach to capture resin residue should be investigated.

Post-curing the parts between 5 and 10 minutes in the curing station is sufficient. The post-curing time of the part has no influence on the dimensions of the part apart from warping. When exposed to sunlight the part will cure over time indefinitely. Warping can occur due to both controlled and uncontrolled exposure to UV-light. This is an important aspect that needs to be considered when deciding if the material is appropriate for the application. It has been noticed that a smaller layer height and longer exposure time reduces warping.

The optimal exposure time of a layer height between 0.025 and 0.075 is around 7s. A more exact number cannot be given from the tests performed in this research. The minimal bottom layer exposure time is 30s but for trustworthy operation, 50s is recommended.

The accuracy of the printer is dependent on the shape of the part and can be finetuned by performing an iterative process. In this process the dimensions of the part are measured and adjusted to fit the CAD-model. If this process is applied the following accuracies can be achieved:

- For a layer height of 0.05mm, an exposure time of 7s, and a dimension between 5 and 50mm the tolerances are minimally +/- 0.16mm.
- For a layer height of 0.05mm, and exposure time of 7s, and a dimension between 2.5 and 10mm the tolerances are minimally +/- 0.08mm.
- The bottom layers of part with a layer height of 0.05mm, an exposure time of 50s and a dimension between 5 and 50mm have a minimal tolerance of +/- 0.36mm.

The thickness of the first layer is consistently 0.38 +/- 0.05mm. This result is independent of the set layer height thus for a layer height of 0.025mm or 0.05mm the thickness of the bottom layer will be 0.38mm. These results are found when calibrating the build plate height using a 0.11mm thick paper. If this phenomenon is consistent for every printer of this model is unknown.

A part manufactured on the considered setup with dimensions between 2.5mm and 10mm can maximally reach AQL 4 level if the required accuracy is+/-0.1mm.

Vision

This category printers is not usable for the desired accuracy. However improved printed parts can be used as 'show and tell samples' in discussion with customers. Especially if the quality is further improved based on the following:

- It would be interesting to investigate what possibilities slicers and new features of slicers could give to compensate inaccuracies in small mechanical parts. I expect higher accuracies can be reached that way. Further investigation necessary.
- Post processing (washing, handling, curing) looks to have an influence on product quality. Additional investigation required.

SLA 3d printers of a price up to 500 euro will not achieve desired accuracies in the near future. More expensive (higher resolution) printers or other manufacturing techniques should be considered.

From post processing point of view water-washable resin looks preferred. However, material properties seem to be less favourable. Further investigation required.

Advice

The Anycubic Photon in combination with black water washable resin does not meet the requirements to manufacture parts in house. Both accuracy and material properties do not meet the requirements. It is recommended to outsource production of plastic parts with a required accuracy smaller then +/-0.1mm. Alternatively, a more expensive resin printer (above 500 euro) could show more reliable results, ease of use and higher accuracy. In this case more research should be performed on higher quality printers.

To check if the printing capabilities of companies or printers suffice with the required accuracy it is advised to test print parts with small features of known dimensions such as the Ameralabs town [9].

List of most important findings

1. A washing time of 6 minutes is more than appropriate to remove all excess resin.
2. The first layer height when calibrating with the use of a 0.11mm paper is 0.38mm +/- 0.05.
3. The standard deviation for parts with dimensions between 2 and 10mm is 0.037mm. Thus 95.4% of dimensions will achieve +/-0.75mm tolerances.
4. When considering an accuracy of +/- 0.1mm the AQL level is 4.

New proposed standard settings

The Final settings for the black water washable resin can be seen in the table below.

Setting	Start value	Final value
Exposure time	7000 ms	~7000 ms
Layer height	0.05 mm	0.05 mm
Bottom exposure time	50000 ms	~50000 ms
Number of bottom layers	4	4
Light out time	1000 ms	1000 ms
Wash time	6 min	6 min
Cure time	~5 min	~10 min
Lifting speed	65,000 mm/min	65, 000 mm/min
Tolerance compensation	0; 0 mm	0; 0 or -0,2; -0,2 mm
Bottom tolerance compensation	0; 0 mm	0; 0

Discussion and next steps

In this chapter the inconsistencies and mishaps of the research are discussed as well as the next steps to further improve or build on this research.

All measurements have been done by hand. This might have caused some faulty measurements within a range of approximately +/-0.02mm. This can be improved in further research by using a measurement tool that is less sensitive to errors and making the test prints easier to measure.

For the tests in step 4 and 5 only 2 blocks per combination of layer height and exposure time have been printed. This number of measurements is insufficient to give a solid conclusion on the optimal exposure time for layer height. In further research the number of measurements should be increased to give a more certain conclusion.

During the research there has not been a division between x, y, and z dimensions. This might affect the results since there could be a difference between the x-y and z accuracy. Further investigation required.

The tests have been performed with the printer in a relatively stable room temperature environment but the effect of temperature changes on the print quality has not been investigated. According to online resources it does affect the print quality.

Water washable resin is utilised because of favourable processing properties. Other resin types might however have a better performance. For instance, the Ameralabs engineering resins [8] could be tested in further research.

The default number of bottom layers is four, for which the minimal cure time has been found. However there has been no research on the minimal number of bottom layers. If the number of bottom layers is reduced the effect of their large deviations is also reduced. Ideally an approach to bypass the bottom layer deviations entirely is found. Placing the part completely on pillars could be the solution but further research is required.

Warping poses an issue to the print quality. Researching the underlying mechanism could show beneficial for preventing or decreasing warpage of parts. Two possible influences are:

- The texture difference between the built plate and FEP sheet.
- Uneven exposure of UV-light throughout the thickness of a layer.

As mentioned in the evaluation the white precipitation is caused by dirty washing water. This happens rather quickly which means that for clean prints the water must be cleaned very often. Further research on the water cleaning process is necessary to optimize the process. Some questions related to this are:

  - Do all dissolved resin particles cure from UV-light exposure?
  - How long does it take until all curable particles are cured?
  - After what time are all the cured particles settled?
  - What size are the cured particles?

To catch the cured particles, it should be researched to what surfaces they stick the best. This would then also confirm or deny the observation that the cured particles stick better to PMMA surfaces.

Further it would be interesting to investigate the relation between part volume and curing time. To define such a relation a definition of a ‘completely cured part’ is required.

Also, it has been observed that longer post-curing times resulted in stiffer products. This correlation could be further investigated to say something about the rate of change of the material when exposed to sunlight. Which will most likely be in relation to the volumetric curing time.

Finally, as mentioned in the evaluation, there is a turning point from dimensions that are too large to dimensions that are too small between 5mm and 10mm. To predict the deviation of parts the dimensions of different shapes between 0mm and 10mm should be investigated.

Writer

This report has been written by Egbert Stellinga. At the publishing date of this report, a student at Technical University of Eindhoven studying mechanical engineering and employed at Steered Technology.

References, resources, and further reading

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[11] Acceptable Quality Limit (AQL) for Product Inspections | QIMA. (n.d.). https://www.qima.com/aql-acceptable-quality-limit

Resources and further reading

Some general references that directly or indirectly have been used to support the research. For further info, these sources can be used.

All3dp [A]

All3dp is an online magazine for the digital makers. They publish a lot of articles on 3d-printing, 3d scanning, CAD, laser cutting and much more. Their articles will most likely be one of the top results when doing research on 3d printers. For more information see: https://all3dp.com/

3d printerly [B]

3d printerly is an online website were a lot of articles with information on 3d-printing are published. They also offer a beginner’s course on 3d printing. For more information see: https://3dprinterly.com/

Miro [C]

Miro is an online platform to visually aid your team process by allowing to make diagrams. For more information see: https://miro.com/index/

YouTube [D]

YouTube is an open online video platform. There are several youtubers active on publishing informative videos for 3d printer users such as:

3D Maker Noob : https://www.youtube.com/@3DMakerNoob

Maker’s Muse: https://www.youtube.com/@MakersMuse

CNC kitchen: https://www.youtube.com/@CNCKitchen

Thomas Sanladerer: https://www.youtube.com/@MadeWithLayers

Some of these youtubers have websites where they publish articles besides their YouTube videos with additional information.

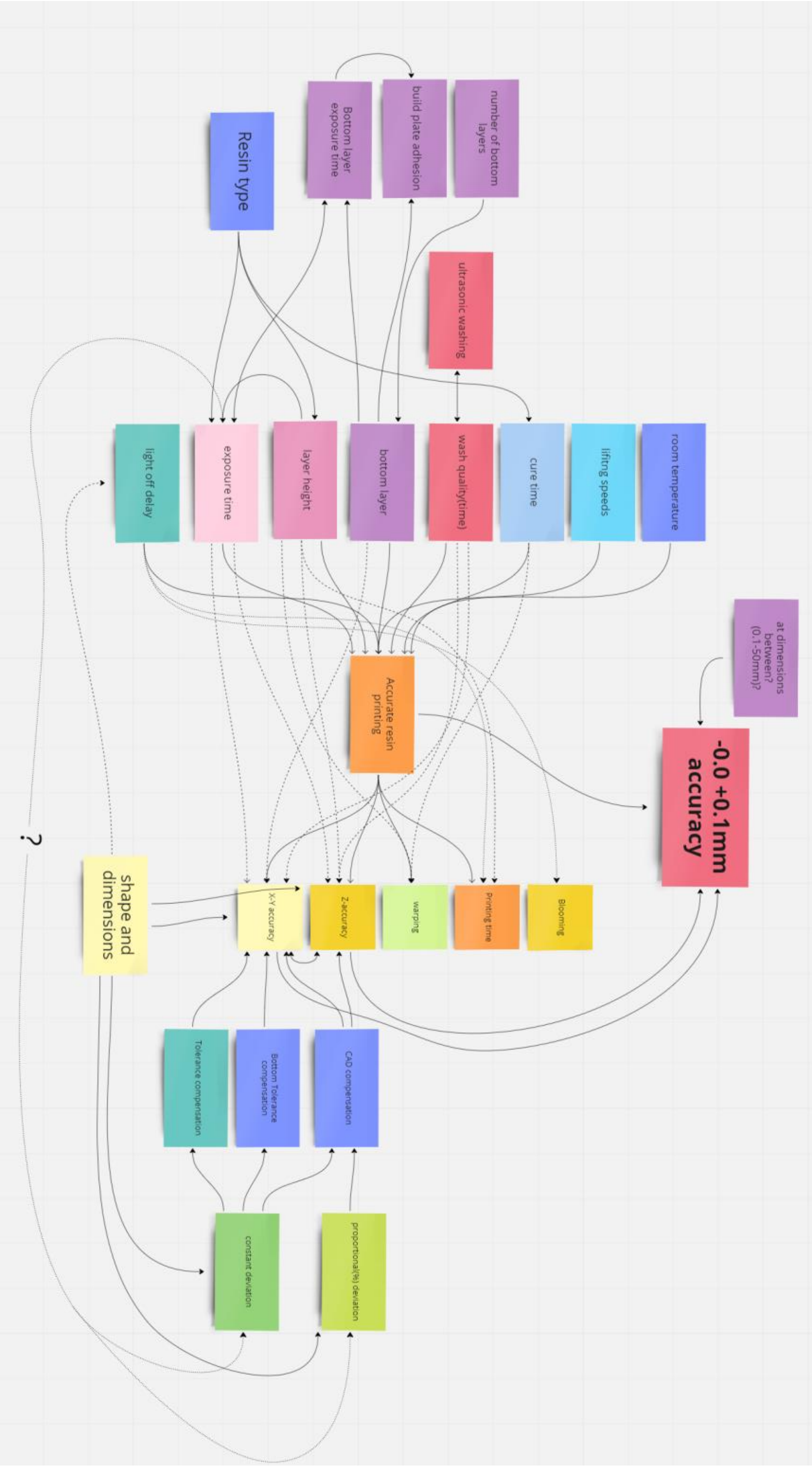
Ameralabs [E]

Ameralabs is a manufacturer of high-quality resins. On their website they have a blog where they publish articles on resin 3d printing. For more information see: https://ameralabs.com/

Appendix

A. Relation diagram

To get a clearer overview of all components involved with the accuracy of the print the diagram below has been created. The lines in the diagram correspond to the suspected relations between the different variables and factors for resin 3d printing. This diagram has been created in Miro see Resources and further reading for more info.



B. Step 1 Measurements

	print 1						
	dimensions	A(5mm)	B(18mm)	C(3mm)	D(5mm)	E(4mm)	F(3mm)
Ultrasonic washing		4,86	18,14	2,68	4,88	3,8	2,8
Washing time (min)							
2		4,86	18,04	2,74	4,8	3,76	2,82
4		4,9	18	2,82	4,78	3,76	2,84
6		4,82	17,98	2,74	4,84	3,74	2,78
8		4,82	17,96	2,76	4,8	3,68	2,76
10		4,9	18,02	2,76	4,8	3,74	2,78
12		4,82	17,96	2,76	4,72	3,76	2,76
	print 2						
	dimensions	A(5mm)	B(18mm)	C(3mm)	D(5mm)	E(4mm)	F(3mm)
Ultrasonic washing		4,88	17,98	2,74	4,82	3,76	2,74
Washing time (min)							
2		4,86	18,04	2,73	4,86	3,82	2,92
4		4,88	17,96	2,78	4,8	3,7	2,8
6		4,82	17,96	2,74	4,82	3,76	2,74
8		4,82	17,92	2,7	4,78	3,74	2,76
10		4,8	18	2,8	4,82	3,74	2,76
12		4,84	18,04	2,68	4,8	3,76	2,74

C. Steps 4 and 5 Measurements

layer height	0.025				
test 1					
Exposure time[s]	A(4mm)	B(20mm)	C(5mm)	D(3mm)	
4	3,88	19,88	4,8	2,76	
5	3,94	19,86	4,76	2,66	
6	3,84	19,92	4,82	2,74	
7	3,84	19,92	4,88	2,72	
8	3,78	19,72	4,68	2,66	
test 2					
Exposure time[s]	A(4mm)	B(20mm)	C(5mm)	D(3mm)	
4	3,88	19,86	4,72	2,66	
5	3,9	19,96	4,74	2,68	
6	3,84	19,88	4,78	2,68	
7	3,88	19,88	4,86	2,66	
8	3,84	19,72	4,66	2,62	
Relative difference					average
4	0	0,02	0,08	0,1	0,05
5	0,04	0,1	0,02	0,02	0,045
6	0	0,04	0,04	0,06	0,035
7	0,04	0,04	0,02	0,06	0,04
8	0,06	0	0,02	0,04	0,03
Absolute difference					average
4	0,12	0,12	0,2	0,24	0,195
5	0,06	0,14	0,24	0,34	0,1875
6	0,16	0,08	0,18	0,26	0,1875
7	0,16	0,08	0,12	0,28	0,17
8	0,22	0,28	0,32	0,34	0,29
4	0,12	0,14	0,28	0,34	
5	0,1	0,04	0,26	0,32	
6	0,16	0,12	0,22	0,32	
7	0,12	0,12	0,14	0,34	
8	0,16	0,28	0,34	0,38	

layer height	0.05				
test 1					
Exposure time[s]	A(4mm)	B(20mm)	C(5mm)	D(3mm)	
4					
5					
6	3,94	19,94	4,76	2,76	
7	3,82	19,84	4,68	2,6	
8	3,84	19,82	4,64	2,5	
test 2					
Exposure time[s]	A(4mm)	B(20mm)	C(5mm)	D(3mm)	
4					
5					
6	3,84	19,88	4,72	2,64	
7	3,84	19,9	4,62	2,62	
8	3,82	19,86	4,6	2,66	
Relative difference					average
4	0	0	0	0	0
5	0	0	0	0	0
6	0,1	0,06	0,04	0,12	0,08
7	0,02	0,06	0,06	0,02	0,04
8	0,02	0,04	0,04	0,16	0,065
Absolute difference					average
4					8
5					8
6	0,06	0,06	0,24	0,24	0,19
7	0,18	0,16	0,32	0,4	0,26
8	0,16	0,18	0,36	0,5	0,2825
4					
5					
6	0,16	0,12	0,28	0,36	
7	0,16	0,1	0,38	0,38	
8	0,18	0,14	0,4	0,34	

layer height	0.075				
test 1					
Exposure time[s]	A(4mm)	B(20mm)	C(5mm)	D(3mm)	
4					real bad quality hard to measure
5					
6	3,86	19,88	4,76	2,76	
7	2,76	19,86	4,76	2,72	
8	3,82	19,94	4,74	2,66	
test 2					
Exposure time[s]	A(4mm)	B(20mm)	C(5mm)	D(3mm)	
4					real bad quality hard to measure
5					
6	3,86	19,82	4,78	2,72	
7	3,82	19,74	4,88	2,6	
8	3,76	19,86	4,66	2,68	
Relative difference					average
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0,06	0,02	0,04	0,03
7	1,06	0,12	0,12	0,12	0,355
8	0,06	0,08	0,08	0,02	0,06
Absolute difference					average
4					8
5					8
6	0,14	0,12	0,24	0,24	0,195
7	1,24	0,14	0,24	0,28	0,3575
8	0,18	0,06	0,26	0,34	0,235
	4	20	5	3	
4					
5					
6	0,14	0,18	0,22	0,28	
7	0,18	0,26	0,12	0,4	
8	0,24	0,14	0,34	0,32	

layer height	0.1				
test 1					
Exposure time[s]	A(4mm)	B(20mm)	C(5mm)	D(3mm)	
4	3,88	19,78	4,9	2,9	
5					
6	3,94	19,88	4,88	2,76	
7	3,92	19,92	4,72	2,84	
8	3,84	19,92	4,86	2,7	
test 2					
Exposure time[s]	A(4mm)	B(20mm)	C(5mm)	D(3mm)	
4	4	19,86	4,92	2,8	
5					
6	3,98	19,92	4,88	2,84	
7	3,86	19,86	4,8	2,66	
8	3,88	19,94	4,78	2,74	
Relative difference					average
4	0,12	0,08	0,02	0,1	0,08
5					
6	0,04	0,04	0	0,08	0,04
7	0,06	0,06	0,08	0,18	0,095
8	0,04	0,02	0,08	0,04	0,045
Absolute difference					Average
4	0,12	0,22	0,1	0,1	0,12
5					
6	0,06	0,12	0,12	0,24	0,115
7	0,08	0,08	0,28	0,16	0,1775
8	0,16	0,08	0,14	0,3	0,1675
	4	20	5	3	
4	0	0,14	0,08	0,2	
5	4	20	5	3	
6	0,02	0,08	0,12	0,16	
7	0,14	0,14	0,2	0,34	
8	0,12	0,06	0,22	0,26	

D. Step 6 Measurements

Print 1			Print 2		
CAD dimension	measured dimension	offset	CAD dimension	measured dimension	offset
5	5,26	0,26	5	5,36	0,36
10	10,3	0,3	10	10,46	0,46
15	15,34	0,34	15	15,52	0,52
20	20,46	0,46	20	20,5	0,5
25	25,44	0,44	25	25,58	0,58
30	30,5	0,5	30	30,56	0,56
40	40,54	0,54	40	40,5	0,5
50	50,4	0,4	50	50,4	0,4

Print 3			Print 4		
CAD dimension	measured dimension	offset	CAD dimension	measured dimension	offset
5	5,3	0,3	5	5,38	0,38
10	10,38	0,38	10	10,5	0,5
15	15,34	0,34	15	15,52	0,52
20	20,42	0,42	20	20,5	0,5
25	25,54	0,54	25	25,46	0,46
30	30,32	0,32	30	30,54	0,54
40	40,5	0,5	40	40,4	0,4
50	50,5	0,5	50	50,38	0,38

Print 5			Print 6		
CAD dimension	measured dimension	offset	CAD dimension	measured dimension	offset
5	5,48	0,48	5	5,22	0,22
10	10,42	0,42	10	10,42	0,42
15	15,44	0,44	15	15,4	0,4
20	20,46	0,46	20	20,4	0,4
25	25,46	0,46	25	25,48	0,48
30	30,54	0,54	30	30,46	0,46
40	40,42	0,42	40	40,42	0,42
50	50,4	0,4	50	50,48	0,48

Print 7			Print 8		
CAD dimension	measured dimension	offset	CAD dimension	measured dimension	offset
5	5,46	0,46	5	5,2	0,2
10	10,4	0,4	10	10,26	0,26
15	15,44	0,44	15	15,36	0,36
20	20,42	0,42	20	20,4	0,4
25	25,4	0,4	25	25,44	0,44
30	30,38	0,38	30	30,42	0,42
40	40,42	0,42	40	40,42	0,42
50	50,38	0,38	50	50,36	0,36

E. Step 7 Measurements

bottom layer tolerance compensation

	From exposure time test prints				From single layer test prints	
exposure time	50s				50s	
Layer height	0.025		0.1			
	2,32	0,68	2,3	0,7	11,42	0,58
	2,32	0,68	2,38	0,62	11,72	0,28
	2,26	0,74	2,26	0,74	11,32	0,68
	2,26	0,74	2,3	0,7	11,48	0,52
	2,22	0,78	2,2	0,8	11,68	0,32
	2,28	0,72	2,32	0,68	11,68	0,32
	2,3	0,7	2,3	0,7	11,46	0,54
	2,26	0,74	2,36	0,64	11,56	0,44
	2,24	0,76	2,26	0,74	11,4	0,6
	2,32	0,68	2,3	0,7	11,42	0,58
	2,18	0,82	2,3	0,7	11,2	0,8
	2,26	0,74	2,36	0,64	11,3	0,7
avg	2,268333333		2,303333333		11,47	0,53
std	0,041197357		0,047492689		0,15631165	

F. Step 8 Measurements

Bottom exposure time [ms]	Failure/success
500	
1000	
1500	
2000	
2500	
30000	
35000	
40000	
45000	
50000	
55000	
60000	

G. Step 9 Measurements

print 1			print 2		
CAD dimension	measured dimension	offset	CAD dimension	measured dimension	offset
5	5,56	0,56	5	5,68	0,68
10	10,64	0,64	10	10,78	0,78
15	15,72	0,72	15	15,98	0,98
20	20,84	0,84	20	21,02	1,02
25	25,82	0,82	25	25,92	0,92
30	30,9	0,9	30	30,82	0,82
40	40,66	0,66	40	40,82	0,82
50	50,52	0,52	50	50,46	0,46
	average	0,7075		average	0,81

print 3			print 4		
CAD dimension	measured dimension	offset	CAD dimension	measured dimension	offset
5	5,86	0,86	5	5,7	0,7
10	10,9	0,9	10	10,84	0,84
15	15,76	0,76	15	15,84	0,84
20	21,12	1,12	20	20,94	0,94
25	25,9	0,9	25	25,94	0,94
30	30,78	0,78	30	30,82	0,82
40	40,68	0,68	40	40,64	0,64
50	50,32	0,32	50	50,32	0,32
	average	0,79		average	0,755

H. Step 10 Measurements

Test 1. layer height: 0.05 exposure time 7s

	Test	1	2	3	4	5	6	7	8	9	10
Dimensions											
A	2,5	2,5	2,37	2,48	2,43	2,45	2,44	2,35	2,49	2,41	2,45
B	5	4,82	4,8	4,8	4,77	4,79	4,79	4,78	4,81	4,76	4,81
C1	10	10,31	10,38	10,33	10,36	10,36	10,35	10,38	10,29	10,34	10,38
C2	10	10,32	10,35	10,31	10,32	10,28	10,28	10,35	10,27	10,35	10,28
E	5	5,2	5,12	5,19	5,22	5,22	5,11	5,12	5,22	5,18	5,15
F	0,02										

	Test	11	12	13	14	15	16	17	18	19	20
Dimensions											
A	2,5	2,51	2,49	2,55	2,47	2,52	2,46	2,45	2,49	2,43	2,44
B	5	4,99	4,87	4,86	4,85	4,86	4,86	4,82	4,83	4,86	4,8
C1	10	10,34	10,41	10,35	10,38	10,36	10,38	10,37	10,35	10,42	10,38
C2	10	10,32	10,31	10,31	10,29	10,29	10,39	10,38	10,29	10,4	10,37
E	5	5,22	5,17	5,22	5,18	5,24	5,2	5,24	5,25	5,21	5,26
F	0,02	0,39	0,39	0,41	0,38	0,39	0,36	0,37	0,38	0,38	0,35

Dimensions		Average		StD
A	2,5	2,459	-0,041	0,047212
B	5	4,8265	-0,1735	0,049424
C1	10	10,361	0,361	0,029983
C2	10	10,323	0,323	0,038872
E	5	5,196	0,196	0,042591
F	0,02	0,38	0,36	0,016125

I. Additional measurements

Polymer block V1

		layer height	exposure time	Bottom layer exposure time	tolerance compensation A	tolerance compensation B
	Slicer settings	0,025	7	50	-0,4	-0,4
		Block nr				
Dimension	Reference	1	2	3	4	5
A	5	5,2				
B	30	30,12				
C	0,025	0,4				
	Notes					

		layer height	exposure time	Bottom layer exposure time	tolerance compensation A	tolerance compensation B
	Slicer settings	0,025	7	20	-0,25	-0,4
		Block nr				
Dimension	Reference	1	2	3	4	5
A	5	FAIL	FAIL	5,18		
B	30	FAIL	FAIL	30,26		
C	0,025	FAIL	FAIL	0,35		
	Notes	Loosened from build plate during print	Broke during removal from the build plate	HEAVY warping		
		layer height	exposure time	Bottom layer exposure time	tolerance compensation A	tolerance compensation b
	Slicer settings	0,025	7	30	-0,25	-0,4
		Block nr				
Dimension	Reference	1	2	3	4	5
A	5	5,26	5,28	5,20		
B	30	30,40	30,30	30,10		
C	0,025	0,40	0,39	0,38		
	Notes	some warping	some warping	indent in slit		
		layer height	exposure time	Bottom layer exposure time	tolerance compensation A	tolerance compensation B
	Slicer settings	0,025	7	40	-0,25	-0,4
		Block nr				
Dimension	Reference	1	2	3	4	5
A	5	5,08	5,10	5,08		
B	30	30,18	30,18	30,16		
C	0,025	0,41	0,39	0,38		
	Notes					
		layer height	exposure time	Bottom layer exposure time	tolerance compensation A	tolerance compensation B
	Slicer settings	0,025	7	60	-0,25	-0,4
		Block nr				
Dimension	Reference	1	2	3	4	5
A	5	5,00	5,02	4,98		
B	30	30,04	30,06	30,06		
C	0,025	0,42	0,38	0,41		
	Notes					

		layer height	exposure time	Bottom layer exposure time	tolerance compensation A	tolerance compensation B
	Slicer settings	0,025	7	70	-0,25	-0,4
		Block nr				
Dimension	Reference	1	2	3	4	5
A	5	4,92	5	5,02		
B	30	29,96	29,98	29,9		
C	0,025	0,42	0,39	0,37		
	Notes					

Polymer block V2

Dimension	1	2	3	4	5	deviation	STD
3,8	4,1	4,14	4,2	4,13	4,16	0,346	0,033226495
4,8	5,06	5,08	5,03	5,07	5,03	0,254	0,02059126
4,2	4,48	4,54	4,54	4,53	4,53	0,324	0,022449944
6	5,56	5,54	5,58	5,6	5,62	-0,42	0,028284271
2,5	2,36	2,4	2,38	2,34	2,36	-0,132	0,020396078
15,5	15,42	15,44	15,4			-0,08	0,016329932
18,5	18,86	18,9	18,92	18,84	18,9	0,384	0,029393877
						Average STD	0,024381694

Polymer block V2A

Dimension	1	2	3	4	5	deviation	STD
3,8	3,8	3,75	3,76	3,77	3,78	-0,028	0,017204651
3,8	3,3	3,14	3,22	3,16	3,2	-0,596	0,055713553
4,8	4,78	4,78	4,79	4,81	4,79	-0,01	0,010954451
4,2	4,27	4,21	4,21	4,24	4,25	0,036	0,023323808
6	5,92	6,04	6,08	6,02	5,94	0	0,060663004
2,5	2,46	2,5	2,52	2,52	2,46	-0,008	0,02712932
15,5		15,52	15,6	15,58	15,58	0,07	0,03
15,5	15,28	15,22	15,22	15,26	15,32	-0,24	0,037947332
18,5	18,46	18,4	18,52	18,52	18,56	-0,008	0,056
						Average STD	0,035437346

Polymer block V2B

Dimension	1	2	3	4	5	deviation	STD
3,8	3,8	3,78	3,79	3,78	3,77	-0,016	0,010198039
3,8	3,8	3,66	3,68	3,74	3,82	-0,06	0,063245553
4,8	4,76	4,79	4,78	4,76	4,76	-0,03	0,012649111
4,2	4,21	4,19	4,21	4,18	4,16	-0,01	0,018973666
6	5,98	5,82	5,92	6,02	6,04	-0,044	0,079397733
2,5	2,46	2,5	2,46	2,54	2,46	-0,016	0,032
15,5	15,68	15,72	15,82	15,74	15,78	0,248	0,048332184
15,5	15,7	15,5	15,6	15,6	15,54	0,088	0,067646138
18,5	18,48	18,44	18,46	18,44	18,4	-0,056	0,026532998
						Average STD	0,039886158