3D PLATFORM

FFF 3D Printing Masters for Casting and Molding Applications

March 19 – 23, 2017

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Market Development, 3D Platform

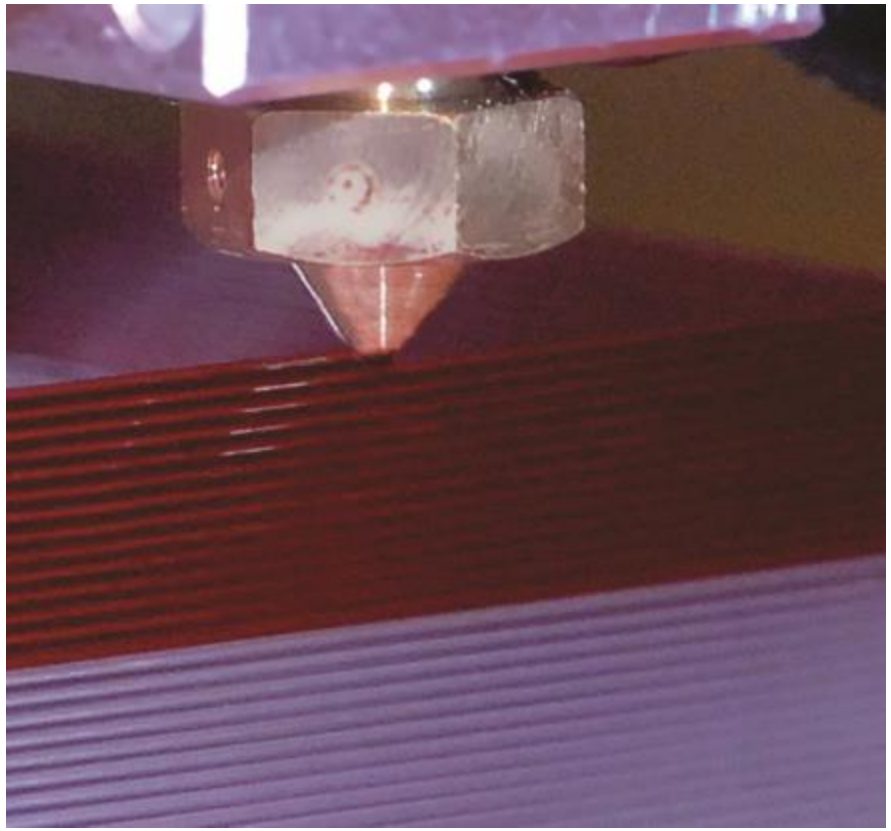
Focus on FFF Process

Everything in this presentation is in relation to the

FFF

(fused filament fabrication)

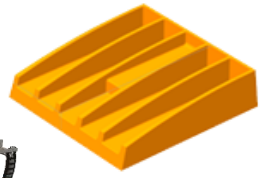
method of 3D printing



3DP 3D PLATFORM

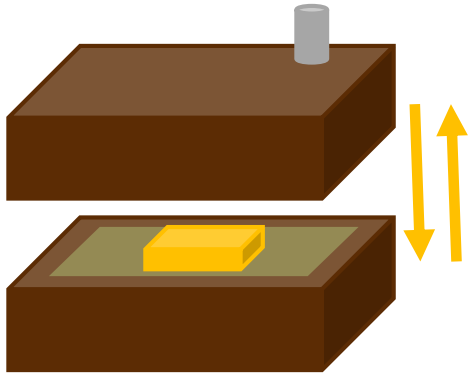
Basic Casting Process

CAD Model



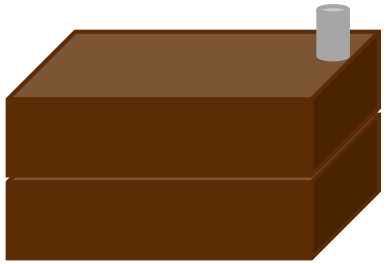
3D Printed Master

OR

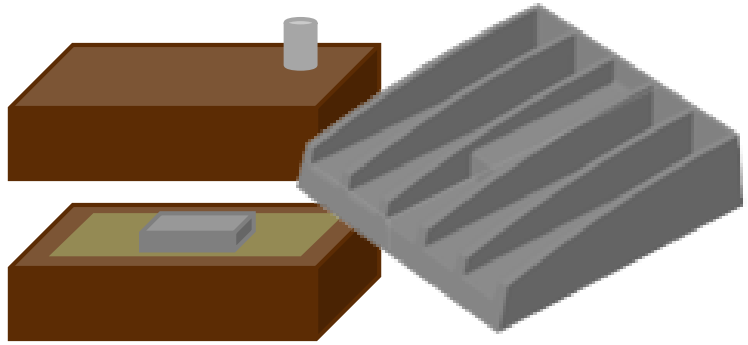


Master shape pressed into sand and removed manually

Master left in core box to be burned out



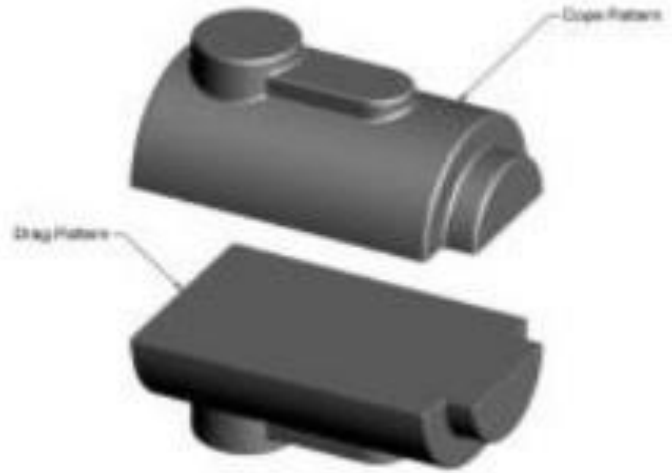
Molten metal poured into mold



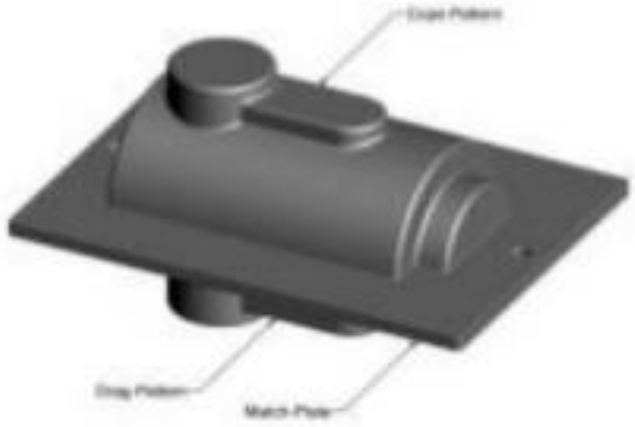
Remove the final metal part

Applies to Various Types of Sand Casting Patterns

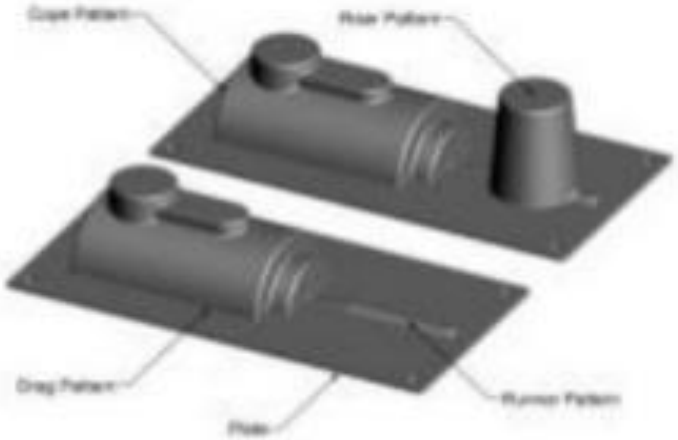
One piece or Solid Pattern



Split Pattern

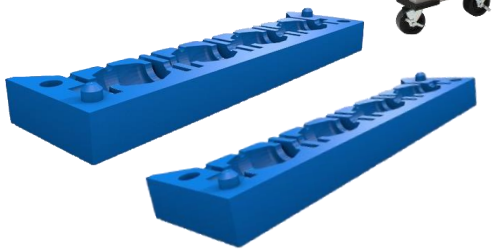


Match Plate Pattern



Cope & Drag Pattern

Basic 2-Part Mold Process



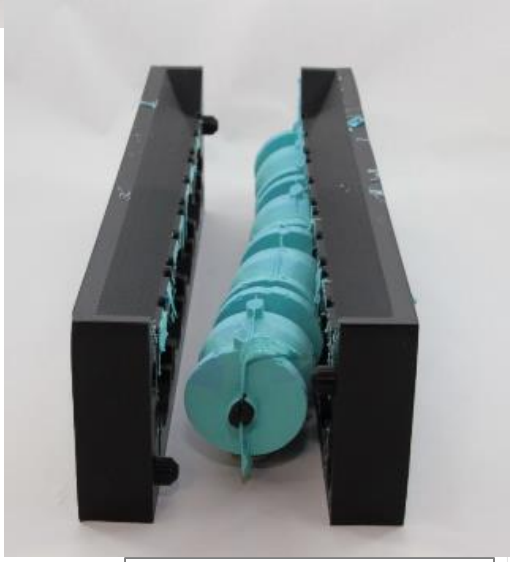
3D Printed
Mold Master

OR

Join the mold and pour
in a 2-part mixture

Layup over mold master

Remove final part
from the mold



Vibration Dampener Mold for Quadcopters (2 sizes) by xack
Published on March 25, 2015
www.thingiverse.com/thing:740176

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3DP
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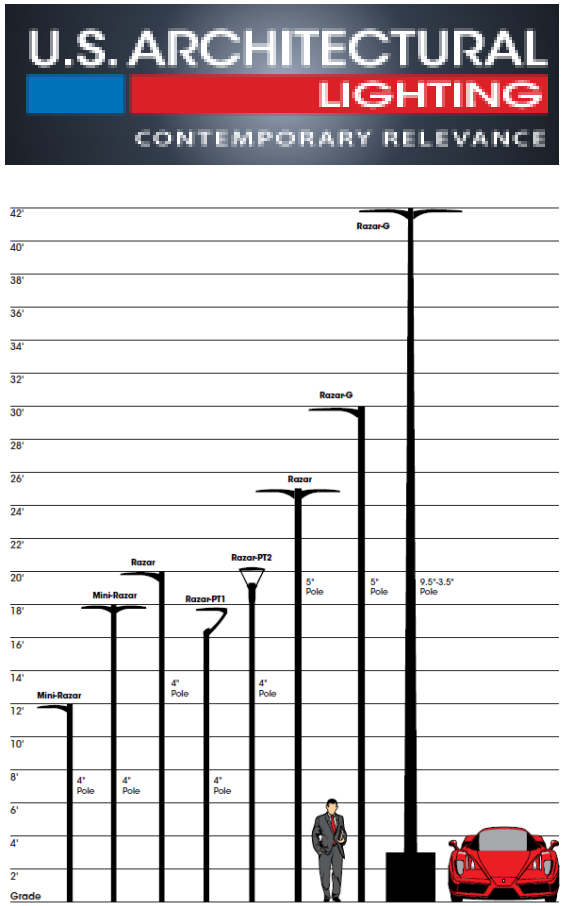
Advantages of 3D Printing for Casting & Molding

- Remove process steps
  - Time savings
  - Cost reductions
- Faster speed to market
- Gain competitive advantage

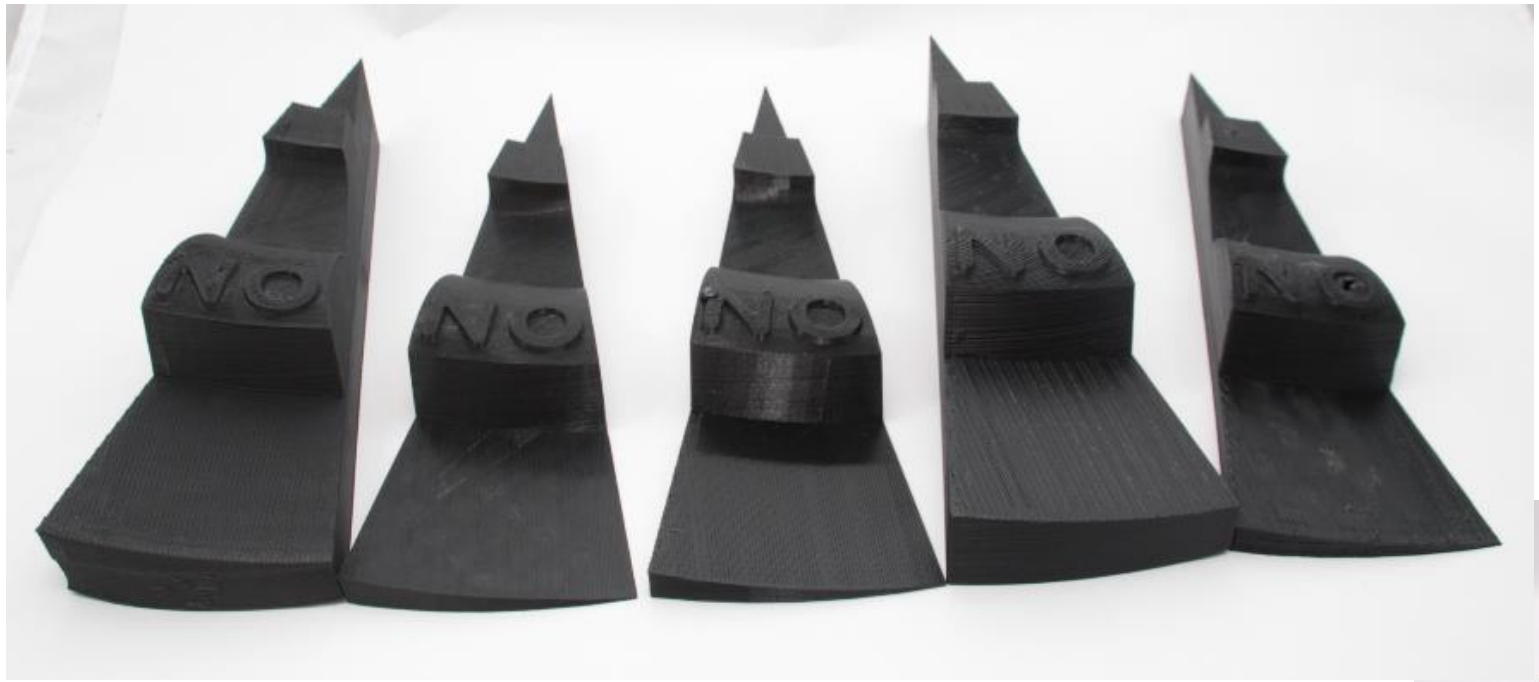
$50,000 annually

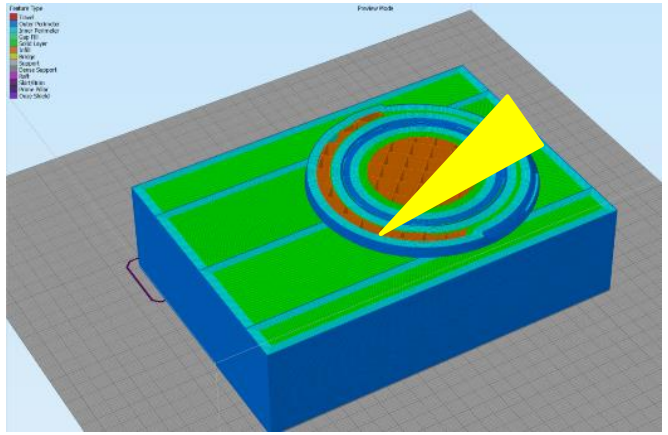


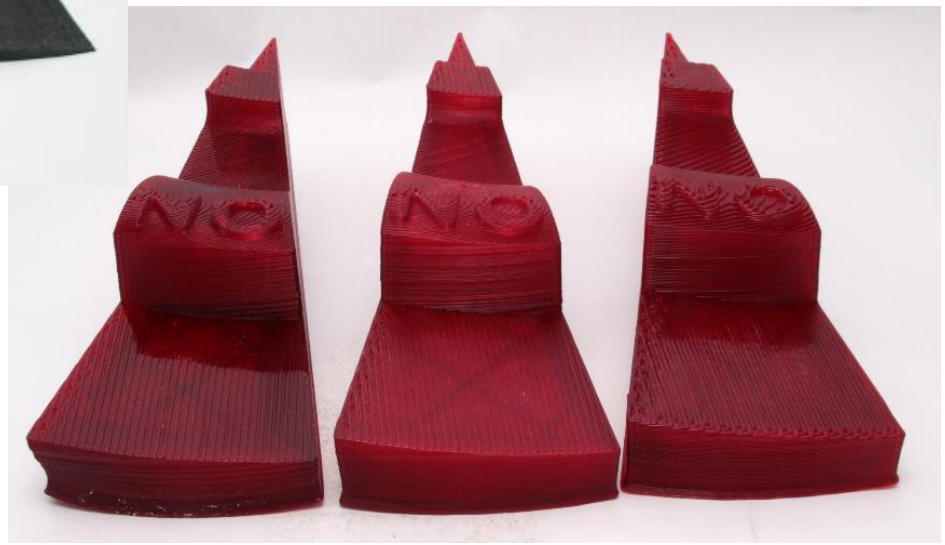
http://www.usaltg.com/

But what about the *surface finish* of fused filament 3D printing?

Surface Finish to Nozzle Size / Layer Height Testing







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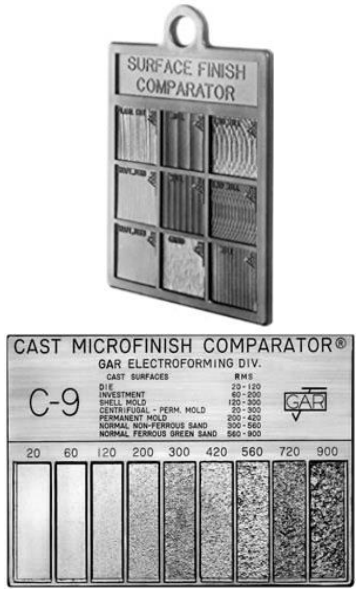
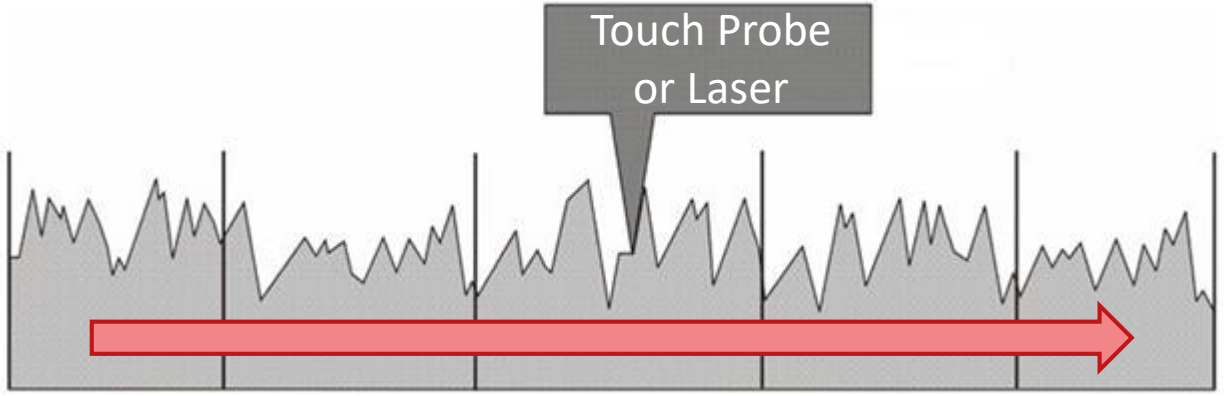
Surface Finish Check with Profilometer





Avg. size in µin or µm

Sample #2

Nozzle	0.6 mm
Infill	10%
Extrusion Width	0.63 mm
Layer Height	0.3 mm
Surface Finish	200 µin

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Sample #2

PBC LINEAR
A PACIFIC BEARING CO.

08/17/2016 08:58:00 AM

0.6MM VOLCANO NOZZLE
3D PLATFORM - SAMPLE #2

Evaluation Condition

Profile=R - Section=[1]	
Standard	OLDMIX
Kind of Profile:	R
Smplg Length(le):	0.25mm
No of Smplg(nle):	7
Lc	0.25mm
Kind of Filter:	Gaussian
Evltn Length(lm):	1.75mm
Pre-Travel:	0.4mm
Post-Travel:	0.125mm
Smooth Connection	Off
Mean Line Compensation	Off
Compensation:	Inclination All

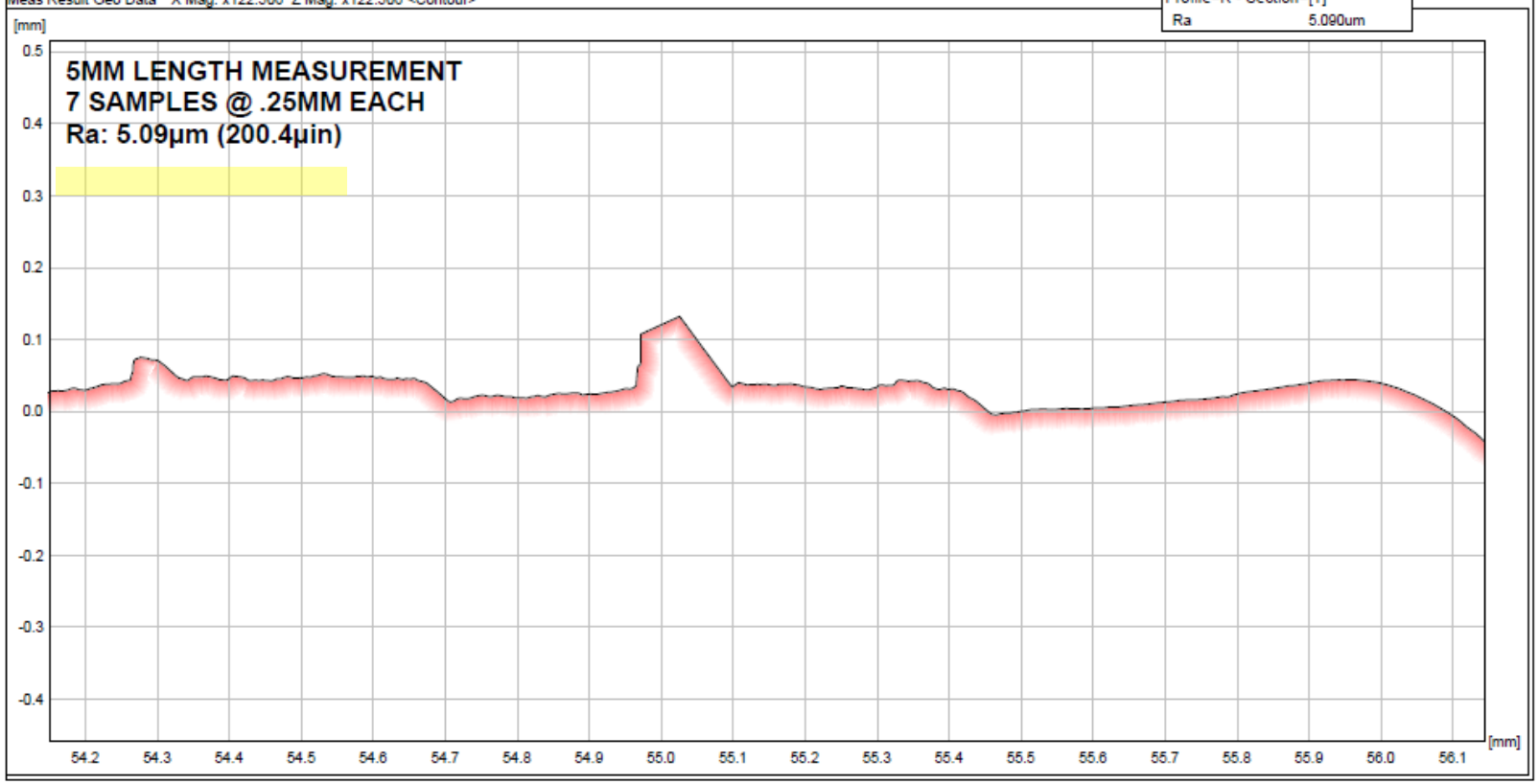
Measurement Conditions

Instrument	SV-C4500
Meas. Length(X)	4.7696mm
Meas. Pitch	0.0005mm
Measuring Speed	0.50mm/sec
Z1-axis Range	0.8000mm
Sampling Method	X-axis Pitch
Z Gain Adj. Ratio	1.000000
Symmetric Compensation	Non
Straightness Compensation(X-axis)	Non
Stylus Radius Compensation	0.005000mm
Polar Reversal	Non

Measured Result

Meas Cont	Meas Value
Roughness 2D<SurfAnalysis_1>	
Profile=R - Section=[1]	
Ra	5.090um

Meas Result Geo Data X Mag: x122.506 Z Mag: x122.506 <Contour>



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Sample #3

Nozzle	0.6 mm
Infill	15%
Extrusion Width	0.78 mm
Extrusion Height	0.15 mm
Surface Finish	146 µin

Sample #3

PBC LINEAR
A PACIFIC BEARING CO.

08/17/2016 08:56:19 AM

0.6MM VOLCANO NOZZLE
3D PLATFORM - SAMPLE #3

Evaluation Condition

Profile=R - Section=[1]	
Standard	OLDMIX
Kind of Profile:	R
Smplg Length(le):	0.25mm
No of Smplg(nle):	7
Lc	0.25mm
Kind of Filter:	Gaussian
Evltn Length(lm):	1.75mm
Pre-Travel:	0.4mm
Post-Travel:	0.125mm
Smooth Connection	Off
Mean Line Compensation	Off
Compensation:	Inclination All

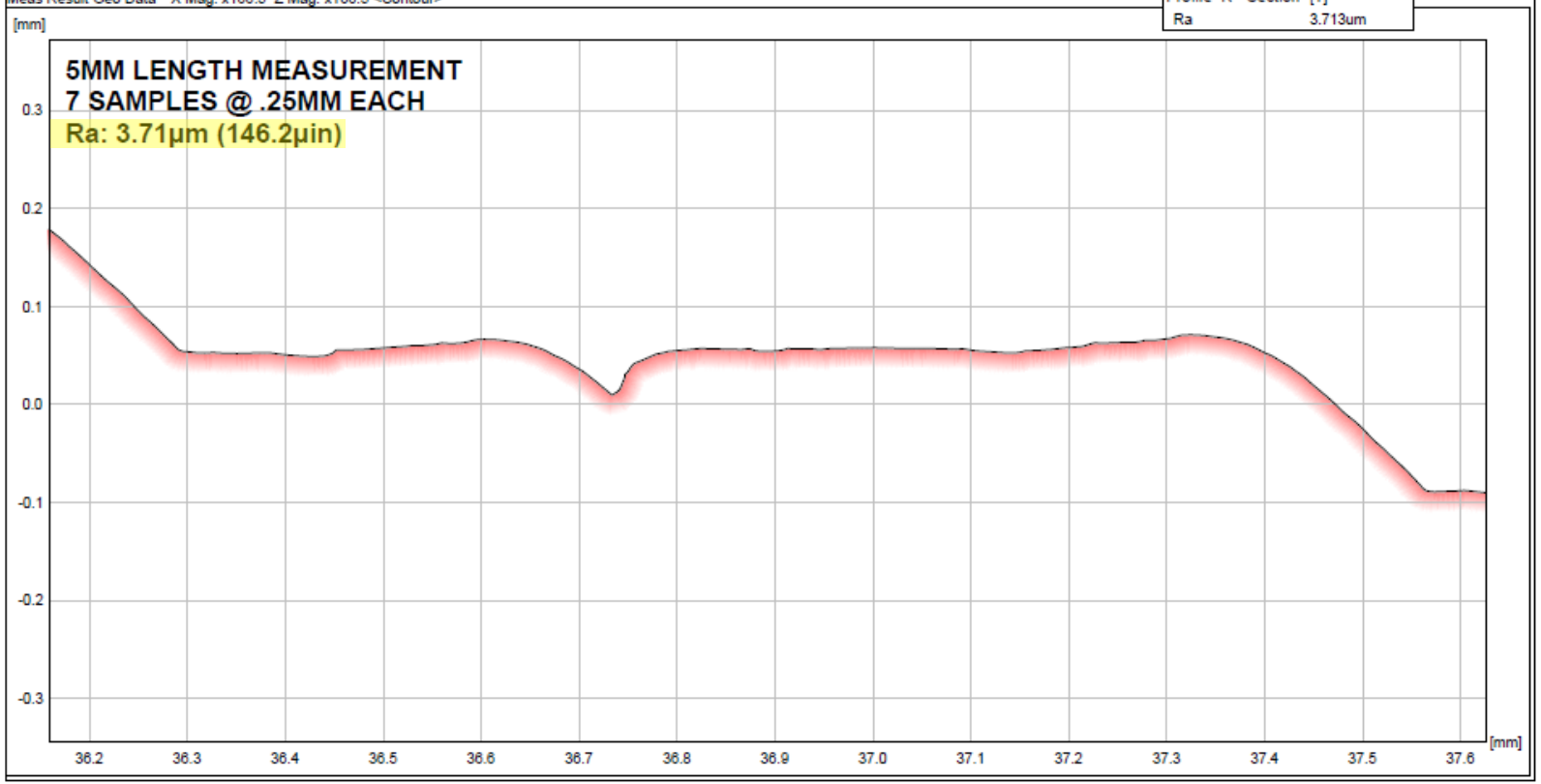
Measurement Conditions

Instrument	SV-C4500
Meas. Length(X)	5.8330mm
Meas. Pitch	0.0005mm
Measuring Speed	0.50mm/sec
Z1-axis Range	0.8000mm
Sampling Method	X-axis Pitch
Z Gain Adj. Ratio	1.000000
Symmetric Compensation	Non
Straightness Compensation(X-axis)	Non
Stylus Radius Compensation	0.005000mm
Polar Reversal	Non

Measured Result

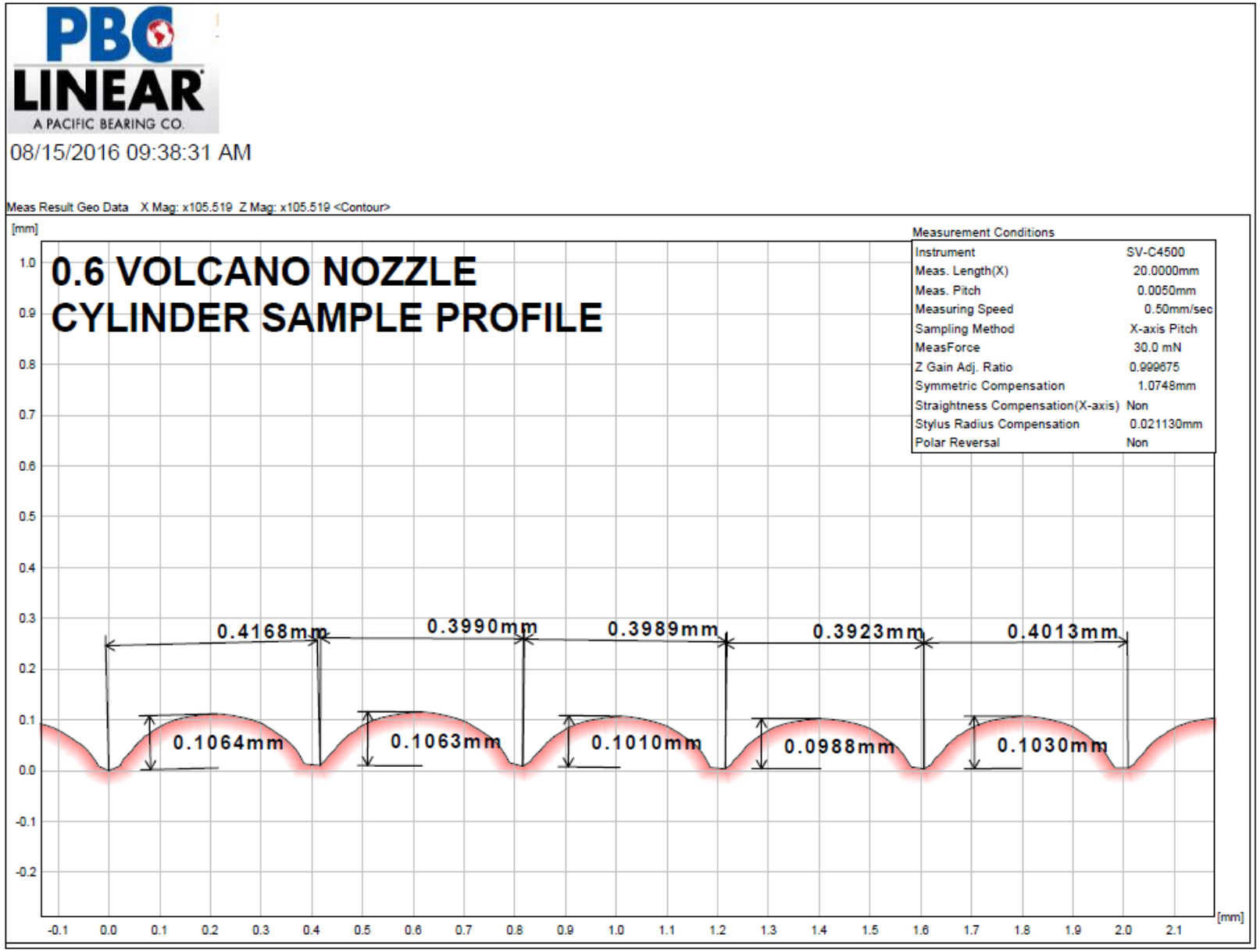
Meas Cont	Meas Value
Roughness 2D<SurfAnalysis_1>	
Profile=R - Section=[1]	
Ra	3.713um

Meas Result Geo Data X Mag: x166.5 Z Mag: x166.5 <Contour>



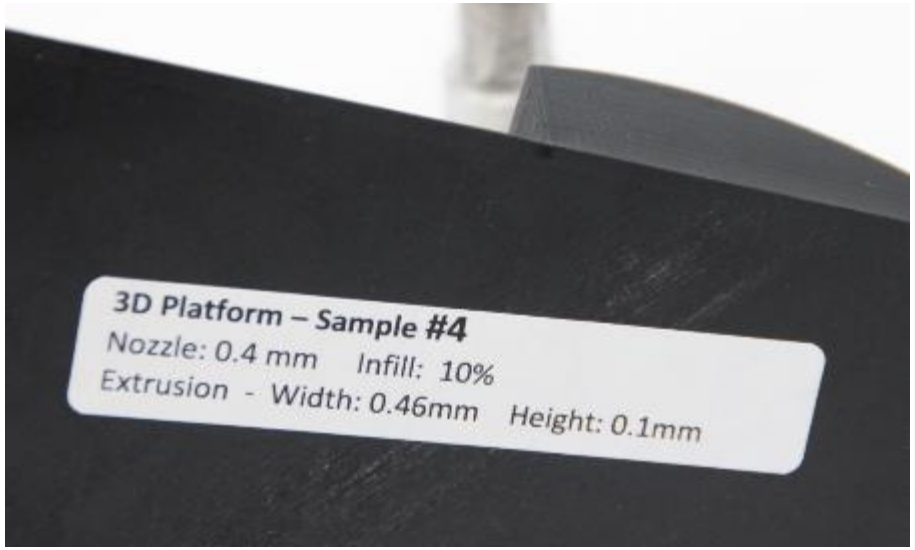
3DP 3D PLATFORM

Sample #3


PBC LINEAR
A PACIFIC BEARING CO.
08/15/2016 09:38:31 AM
Meas Result Geo Data X Mag: x105.519 Z Mag: x105.519 <Contour>
[mm]
0.6 VOLCANO NOZZLE
CYLINDER SAMPLE PROFILE
Measurement Conditions
Instrument SV-C4500
Meas. Length(X) 20.0000mm
Meas. Pitch 0.0050mm
Measuring Speed 0.50mm/sec
Sampling Method X-axis Pitch
MeasForce 30.0 mN
Z Gain Adj. Ratio 0.999675
Symmetric Compensation 1.0748mm
Straightness Compensation(X-axis) Non
Stylus Radius Compensation 0.021130mm
Polar Reversal Non
0.4168mm
0.3990mm
0.3989mm
0.3923mm
0.4013mm
0.1064mm
0.1063mm
0.1010mm
0.0988mm
0.1030mm
[mm]

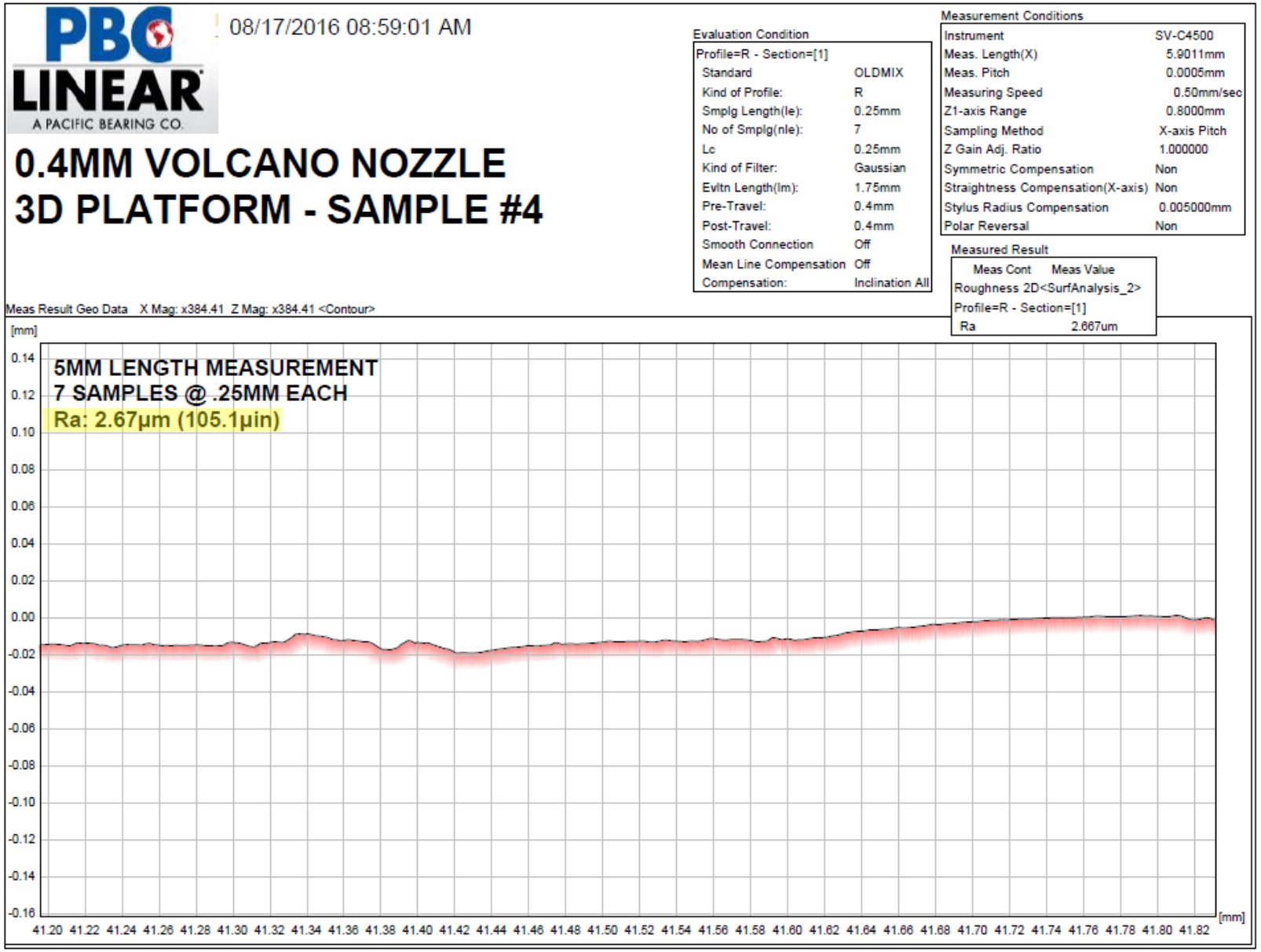
Sample #4

Nozzle	0.4 mm
Infill	10%
Extrusion Width	0.46 mm
Extrusion Height	0.1 mm
Surface Finish	105 µin



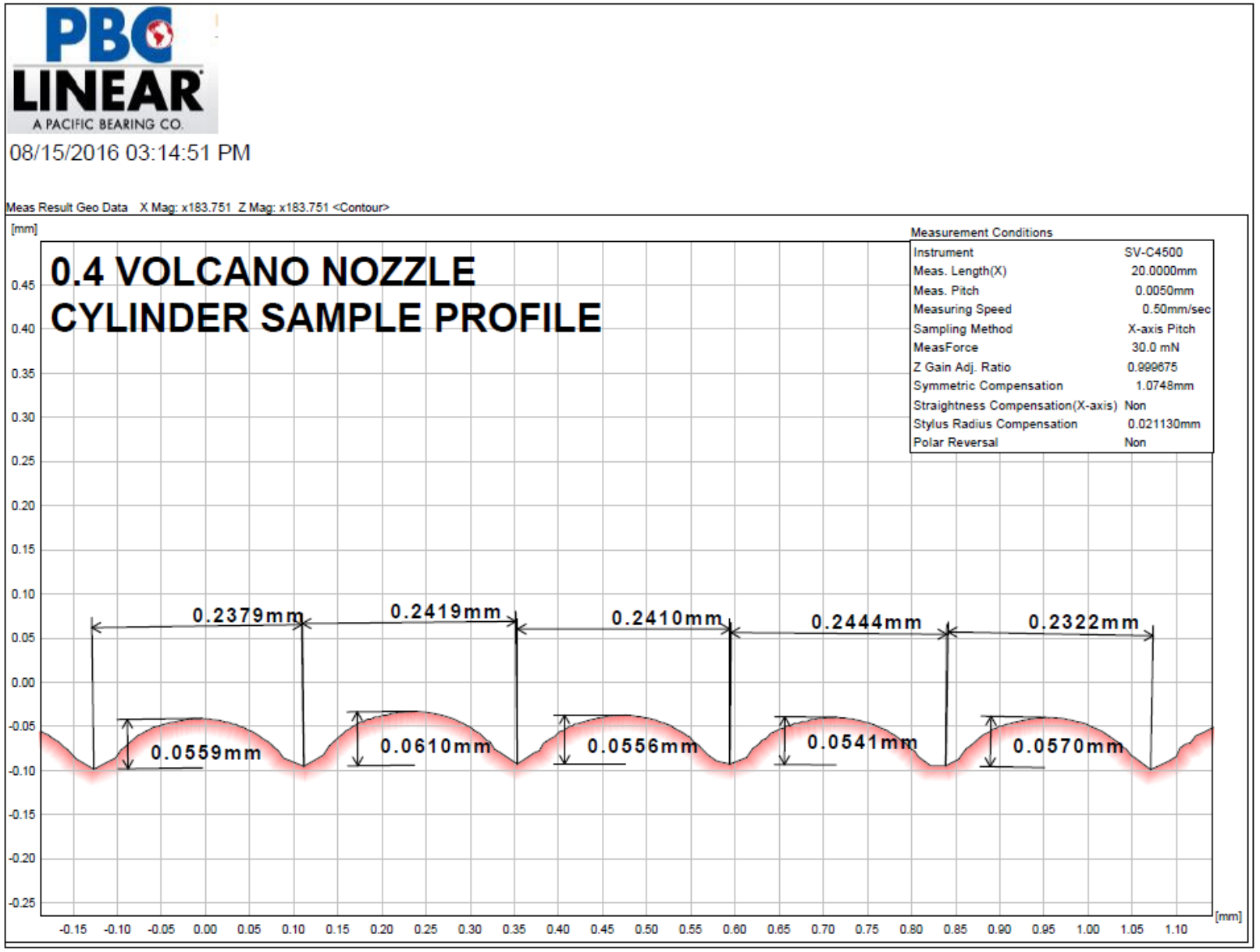
3DP 3D PLATFORM

Sample #4



3D PLATFORM

Sample #4


PBC LINEAR
A PACIFIC BEARING CO.
08/15/2016 03:14:51 PM
Meas Result Geo Data X Mag: x183.751 Z Mag: x183.751 <Contour>
[mm]
0.4 VOLCANO NOZZLE
CYLINDER SAMPLE PROFILE
Measurement Conditions
Instrument SV-C4500
Meas. Length(X) 20.0000mm
Meas. Pitch 0.0050mm
Measuring Speed 0.50mm/sec
Sampling Method X-axis Pitch
MeasForce 30.0 mN
Z Gain Adj. Ratio 0.999675
Symmetric Compensation 1.0748mm
Straightness Compensation(X-axis) Non
Stylus Radius Compensation 0.021130mm
Polar Reversal Non
0.2379mm
0.2419mm
0.2410mm
0.2444mm
0.2322mm
0.0559mm
0.0610mm
0.0556mm
0.0541mm
0.0570mm
[mm]

1.2mm Nozzle Testing

Sample #5

Nozzle	1.2 mm
Infill	10%
Extrusion Width	1.40 mm
Extrusion Height	0.6 mm
Surface Finish	1,666 µin
Note: 6 top, bottom, outside layers	

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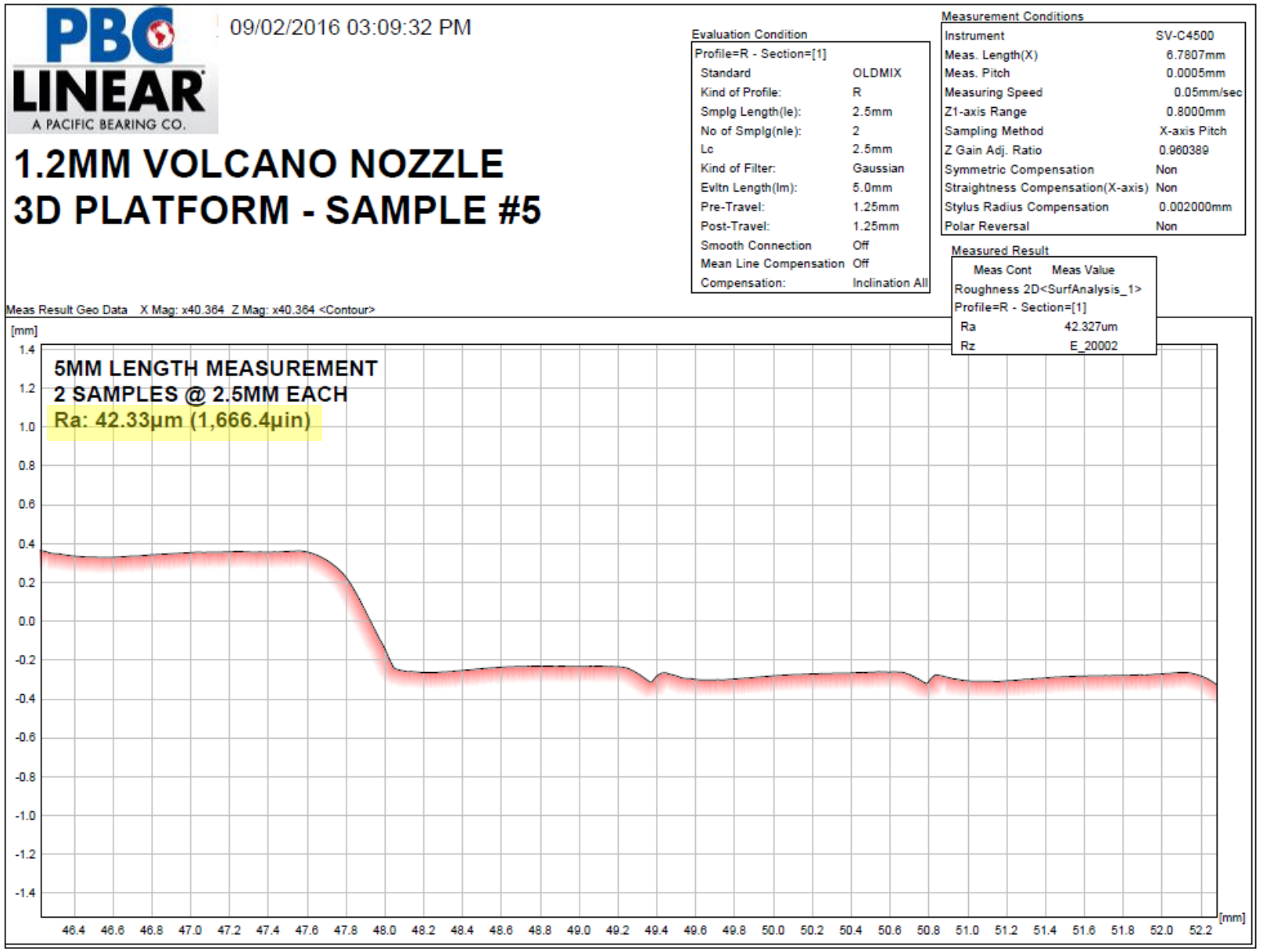
Sample #5

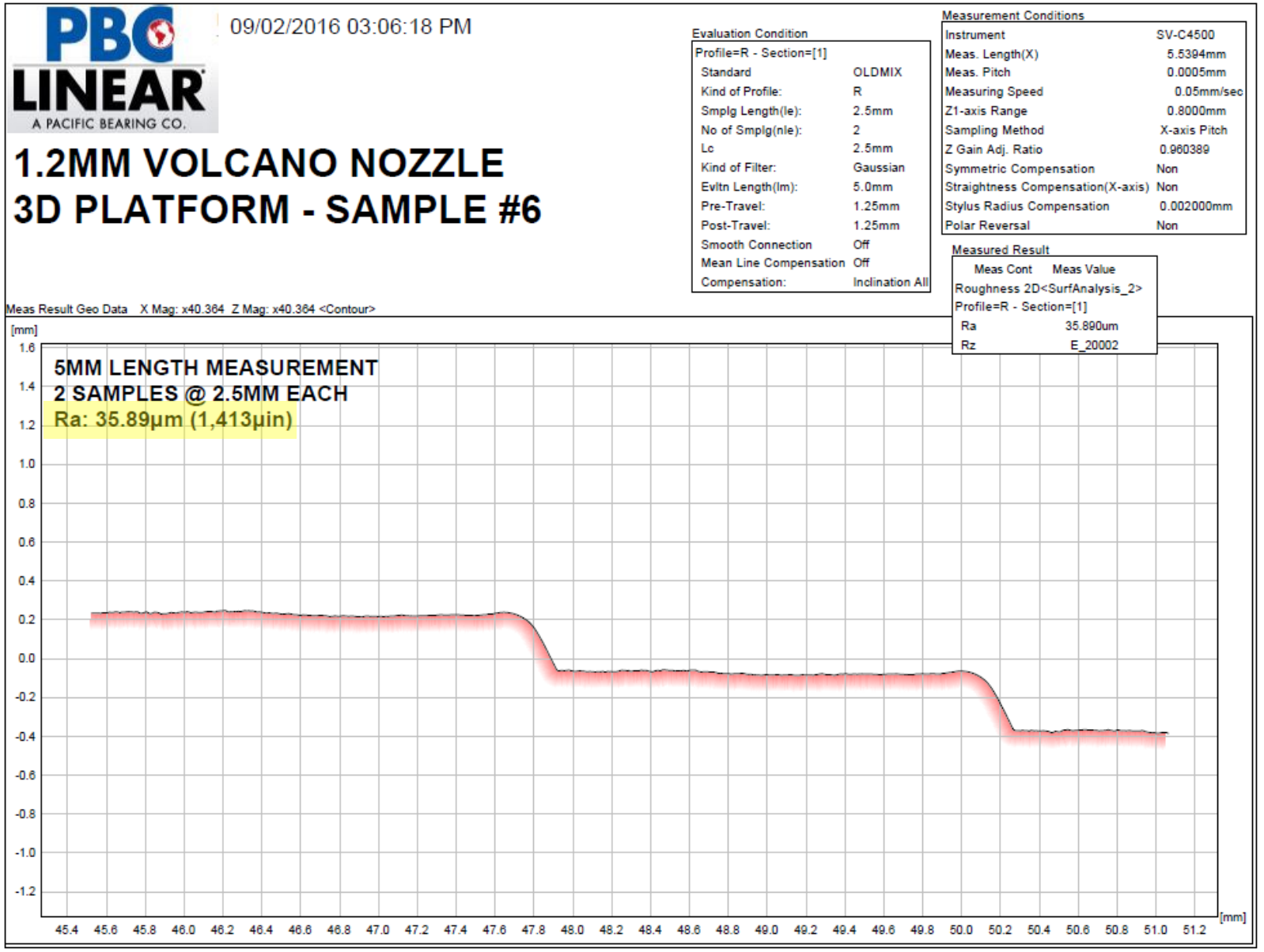

PBC LINEAR
A PACIFIC BEARING CO.
09/02/2016 03:09:32 PM
1.2MM VOLCANO NOZZLE
3D PLATFORM - SAMPLE #5
Evaluation Condition
Profile=R - Section=[1]
Standard OLDMIX
Kind of Profile: R
Smplg Length(le): 2.5mm
No of Smplg(nle): 2
Lc 2.5mm
Kind of Filter: Gaussian
Evltn Length(lm): 5.0mm
Pre-Travel: 1.25mm
Post-Travel: 1.25mm
Smooth Connection Off
Mean Line Compensation Off
Compensation: Inclination All
Measurement Conditions
Instrument SV-C4500
Meas. Length(X) 6.7807mm
Meas. Pitch 0.0005mm
Measuring Speed 0.05mm/sec
Z1-axis Range 0.8000mm
Sampling Method X-axis Pitch
Z Gain Adj. Ratio 0.960389
Symmetric Compensation Non
Straightness Compensation(X-axis) Non
Stylus Radius Compensation 0.002000mm
Polar Reversal Non
Measured Result
Meas Cont Meas Value
Roughness 2D<SurfAnalysis_1>
Profile=R - Section=[1]
Ra 42.327um
Rz E_20002
Meas Result Geo Data X Mag: x40.364 Z Mag: x40.364 <Contour>
[mm]
5MM LENGTH MEASUREMENT
2 SAMPLES @ 2.5MM EACH
Ra: 42.33µm (1,666.4µin)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
46.4 46.6 46.8 47.0 47.2 47.4 47.6 47.8 48.0 48.2 48.4 48.6 48.8 49.0 49.2 49.4 49.6 49.8 50.0 50.2 50.4 50.6 50.8 51.0 51.2 51.4 51.6 51.8 52.0 52.2
[mm]

Sample #6

Nozzle	1.2 mm
Infill	10%
Extrusion Width	1.40 mm
Extrusion Height	0.3 mm
Surface Finish	1,413 µin
Note: 6 top, bottom, outside layers	

3DP 3D PLATFORM

Sample #6


PBC LINEAR
A PACIFIC BEARING CO.
09/02/2016 03:06:18 PM
1.2MM VOLCANO NOZZLE
3D PLATFORM - SAMPLE #6
Evaluation Condition
Profile=R - Section=[1]
Standard OLDMIX
Kind of Profile: R
Smplg Length(le): 2.5mm
No of Smplg(nle): 2
Lc 2.5mm
Kind of Filter: Gaussian
Evltn Length(lm): 5.0mm
Pre-Travel: 1.25mm
Post-Travel: 1.25mm
Smooth Connection Off
Mean Line Compensation Off
Compensation: Inclination All
Measurement Conditions
Instrument SV-C4500
Meas. Length(X) 5.5394mm
Meas. Pitch 0.0005mm
Measuring Speed 0.05mm/sec
Z1-axis Range 0.8000mm
Sampling Method X-axis Pitch
Z Gain Adj. Ratio 0.960389
Symmetric Compensation Non
Straightness Compensation(X-axis) Non
Stylus Radius Compensation 0.002000mm
Polar Reversal Non
Measured Result
Meas Cont Meas Value
Roughness 2D<SurfAnalysis_2>
Profile=R - Section=[1]
Ra 35.890um
Rz E_20002
Meas Result Geo Data X Mag: x40.364 Z Mag: x40.364 <Contour>
[mm]
5MM LENGTH MEASUREMENT
2 SAMPLES @ 2.5MM EACH
Ra: 35.89µm (1,413µin)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
45.4 45.6 45.8 46.0 46.2 46.4 46.6 46.8 47.0 47.2 47.4 47.6 47.8 48.0 48.2 48.4 48.6 48.8 49.0 49.2 49.4 49.6 49.8 50.0 50.2 50.4 50.6 50.8 51.0 51.2
[mm]

Sample #7

Nozzle	1.2 mm
Infill	10%
Extrusion Width	1.40 mm
Extrusion Height	0.3 mm
Surface Finish	1,416 µin
Note: 10 top, bottom, outside layers	

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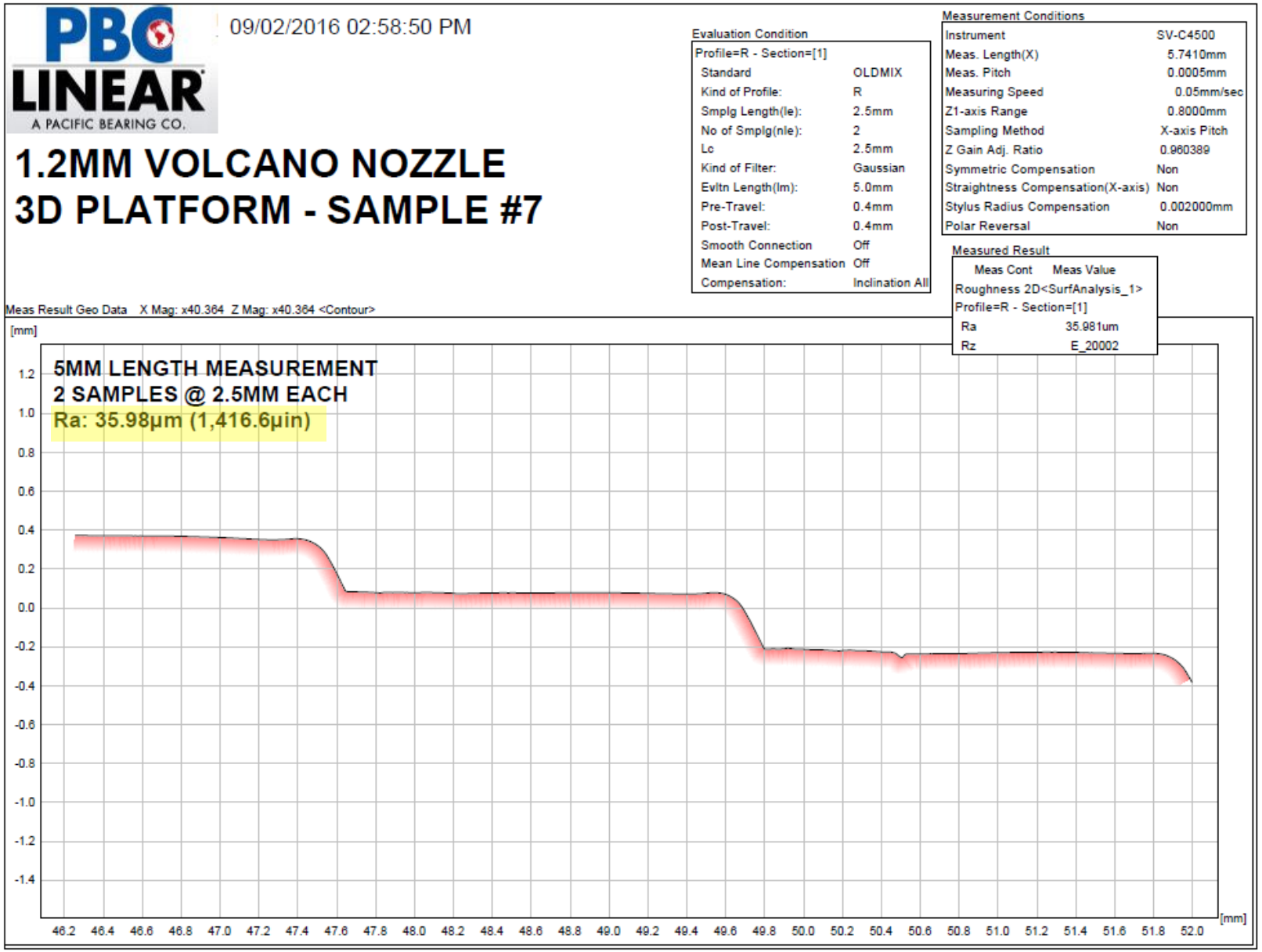
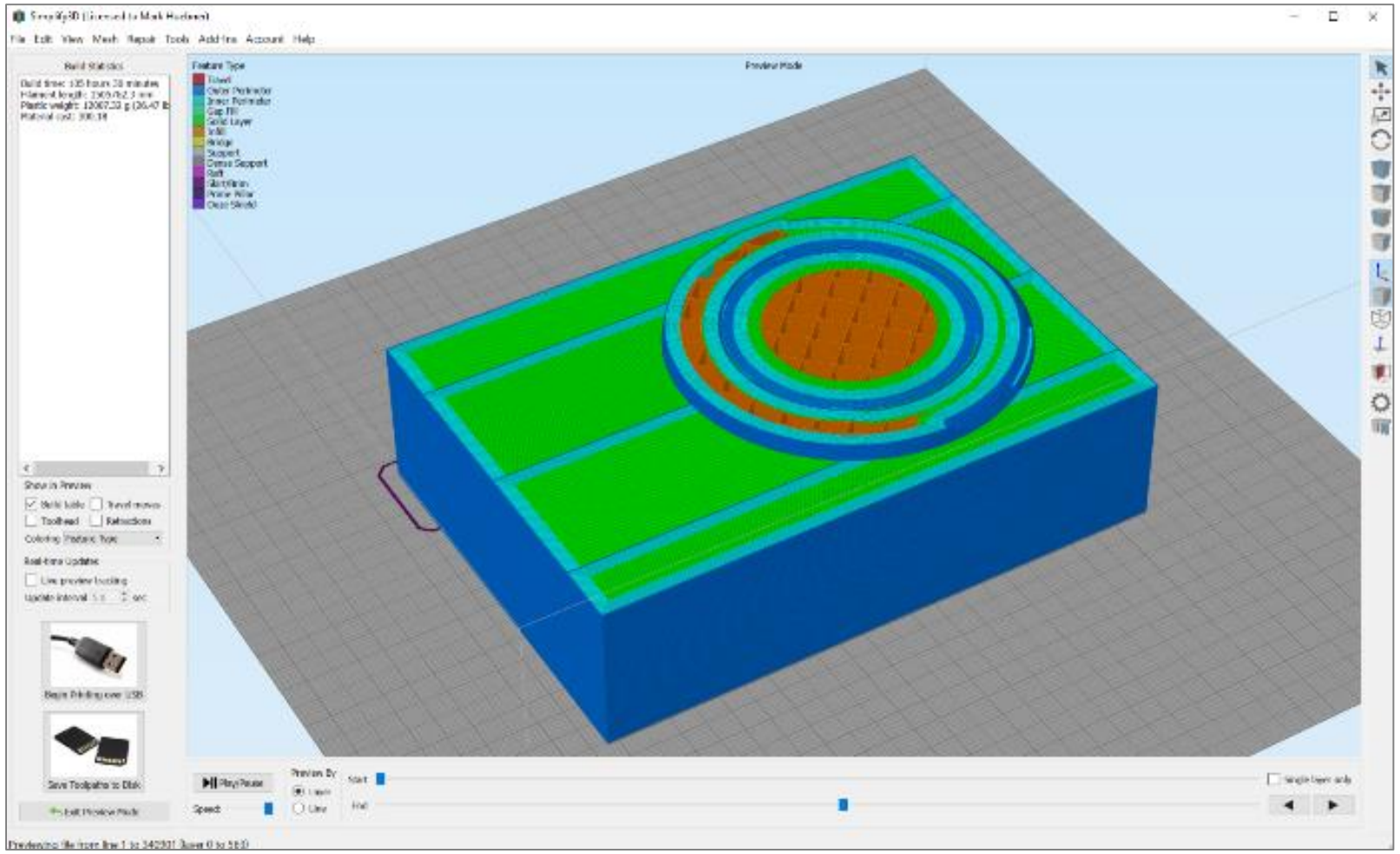
Sample #7



3DP 3D PLATFORM

Full Size Part Analysis

- 16” wide
- 23” long
- 10” high



3D PLATFORM

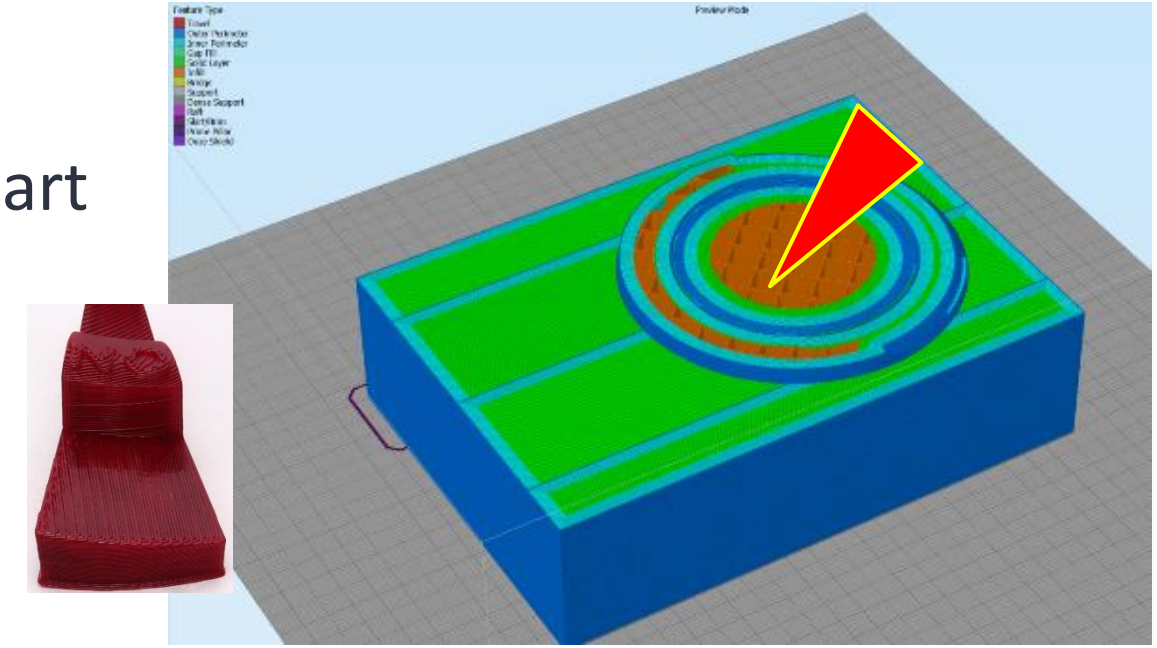
Surface Finish to Print Time Relationship

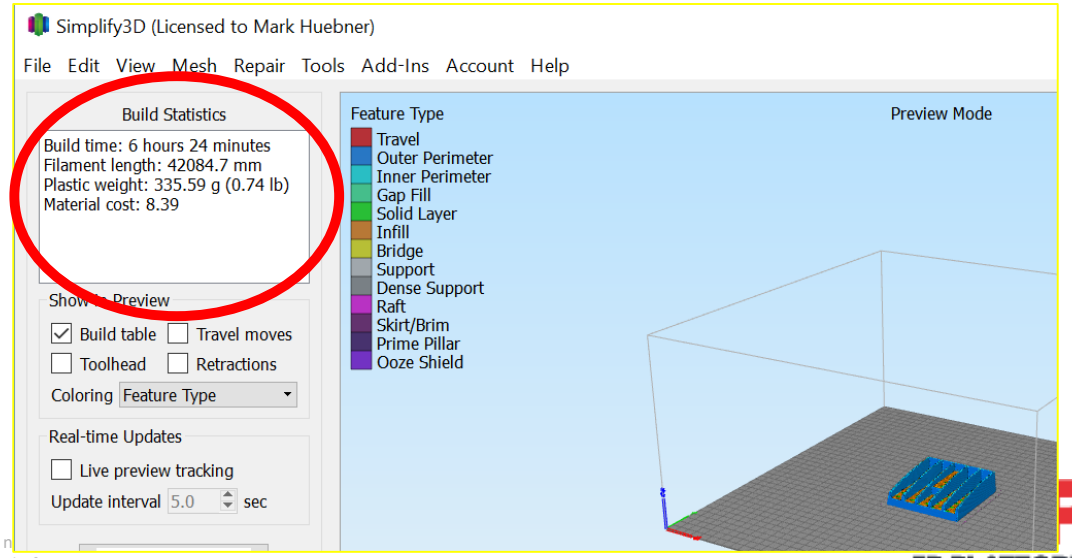
	Sample #2	Sample #3	Sample #4	Sample #5	Sample #6
Filament Dia. (mm)	2.85	2.85	2.85	2.85	2.85
Nozzle Dia. (mm)	0.6	0.6	0.4	1.2	1.2
Extrusion Width	0.63	0.78	0.46	1.4	1.4
Layer Height	0.3	0.15	0.1	0.6	0.3
Top Layers	10	10	10	6	6
Bottom Layers	10	10	10	6	6
Perimeter Shells	10	10	10	6	6
Infill %	10	15	10	10	10
Infill Pattern	Grid	Grid	Grid	Grid	Grid
Default Print Speed (mm/min)	4000	4000	4000	4000	4000
Surface Finish	200 µin	146 µin	105 µin	1,666 µin	1,413 µin
	5.09 µm	3.71 µm	2.67 µm	42.33 µm	35.98 µm
Estimated Print Time	171 hours 24 min	271 hours 0 min	547 hours 4 min	44 hours 48 min	80 hours 36 min
	7.1 days	11.3 days	22.8 days	1.875 days	3.4 days

3DP 3D PLATFORM

Analytic Methodology

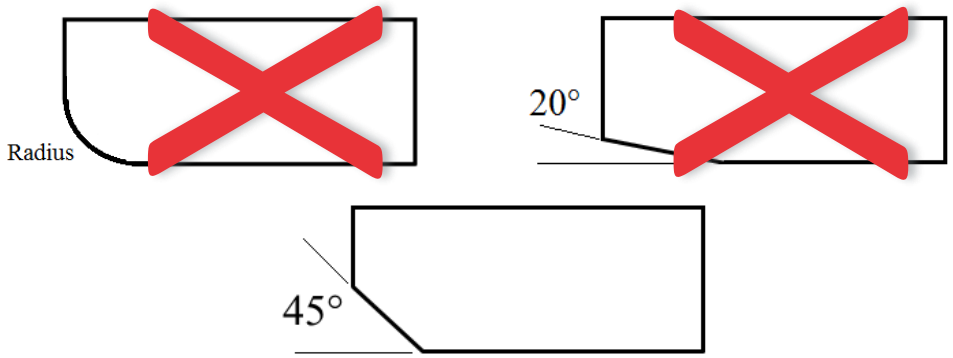
- Test settings on a section of the part
- Adjust **1 setting** at a time
  - Layer height, extrusion width, temperature, etc.
- Run simulations on the full part to analyze print times





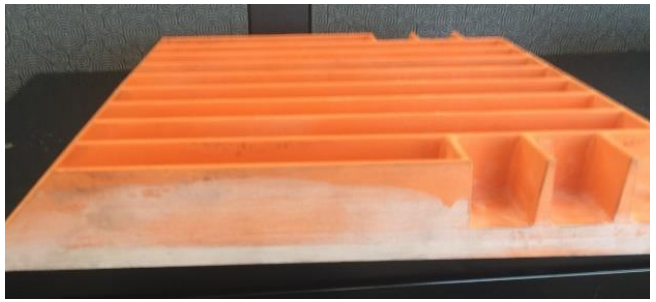
Design the Part for FFF 3D Printing

- Vertical surfaces produce best surface finish
- Change curves or shallow angles to 45° when possible
- Eliminate support material and minimize scarring printing at 45°



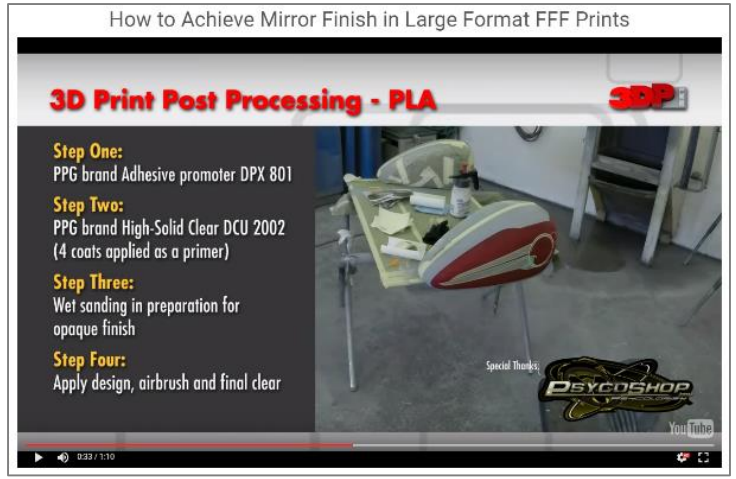
Ways to Use Post-Processing

- Fill and sanding



- Material smoothing
  - ABS with acetone vapor
  - Smooth-On treatment
    - www.smooth-on.com

- Automotive techniques / High-build primer



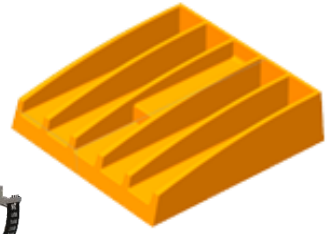
Video Links:

How to Achieve Mirror Finish in Large Format FFF Prints: https://www.youtube.com/watch?v=UA42OFMo-SU

Post Processing in 3D Printing: https://www.youtube.com/watch?v=Bc-zTKs4_1Y

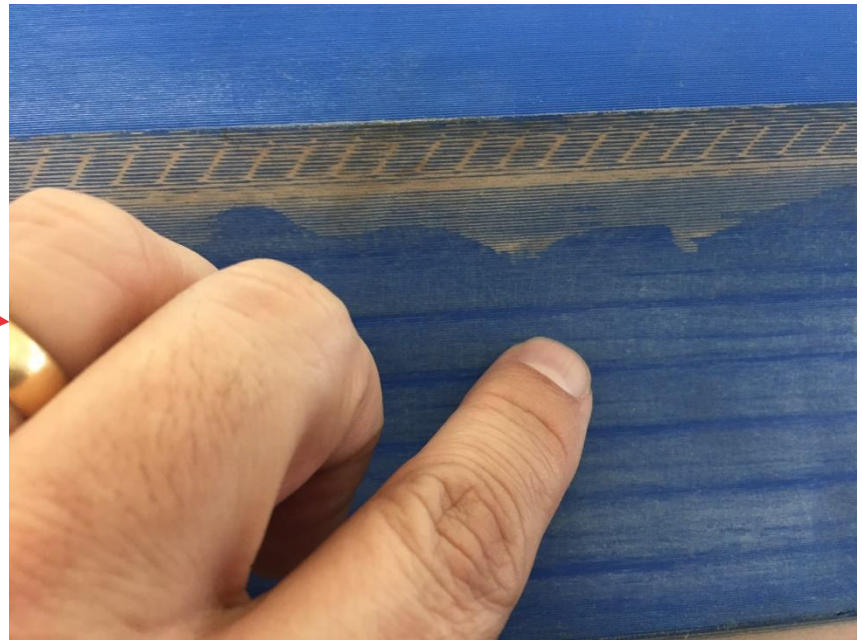
Casting Example

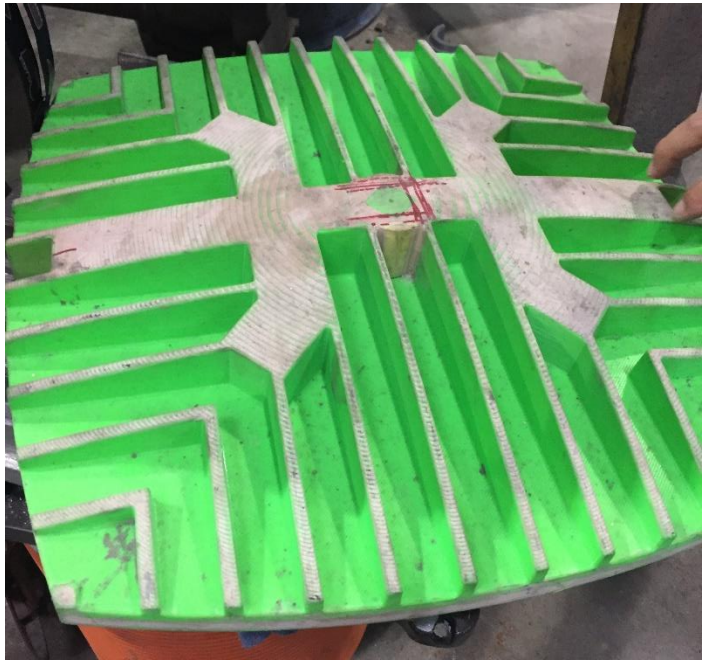
U.S. ARCHITECTURAL LIGHTING
CONTEMPORARY RELEVANCE



3D Printed Master

Fill and sand lightly as needed



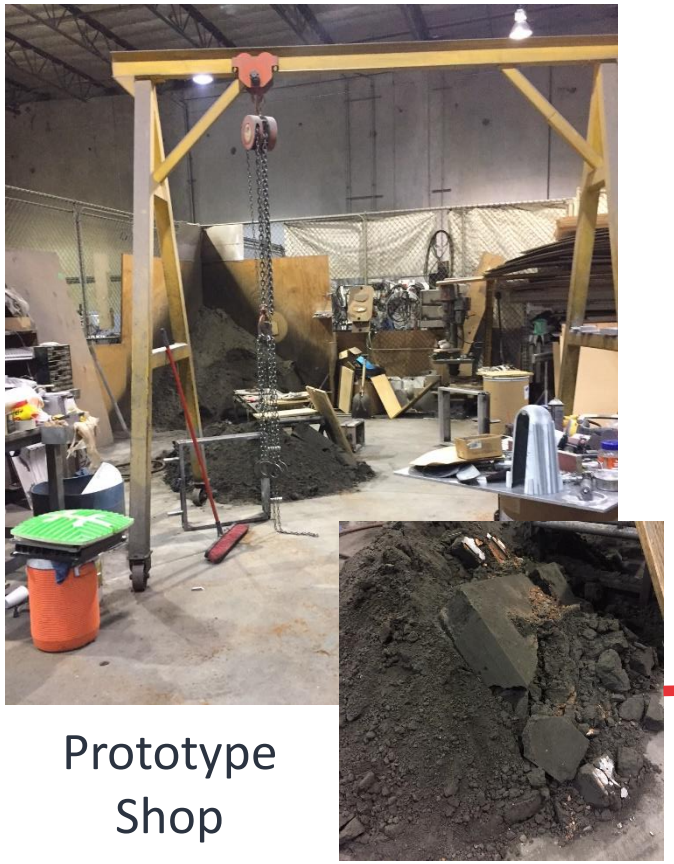


Printed part ready for prototype shop

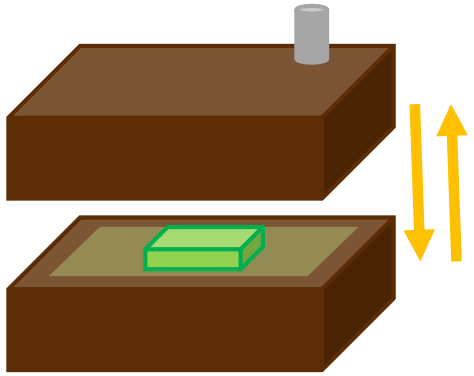
3DP 3D PLATFORM

Casting Example

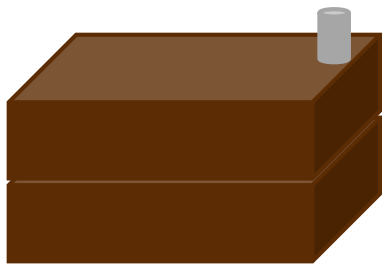
U.S. ARCHITECTURAL LIGHTING
CONTEMPORARY RELEVANCE



Prototype Shop



Sand placed in a temporary core box, the 3D printed master pressed into sand, and removed manually



Molten metal poured into mold

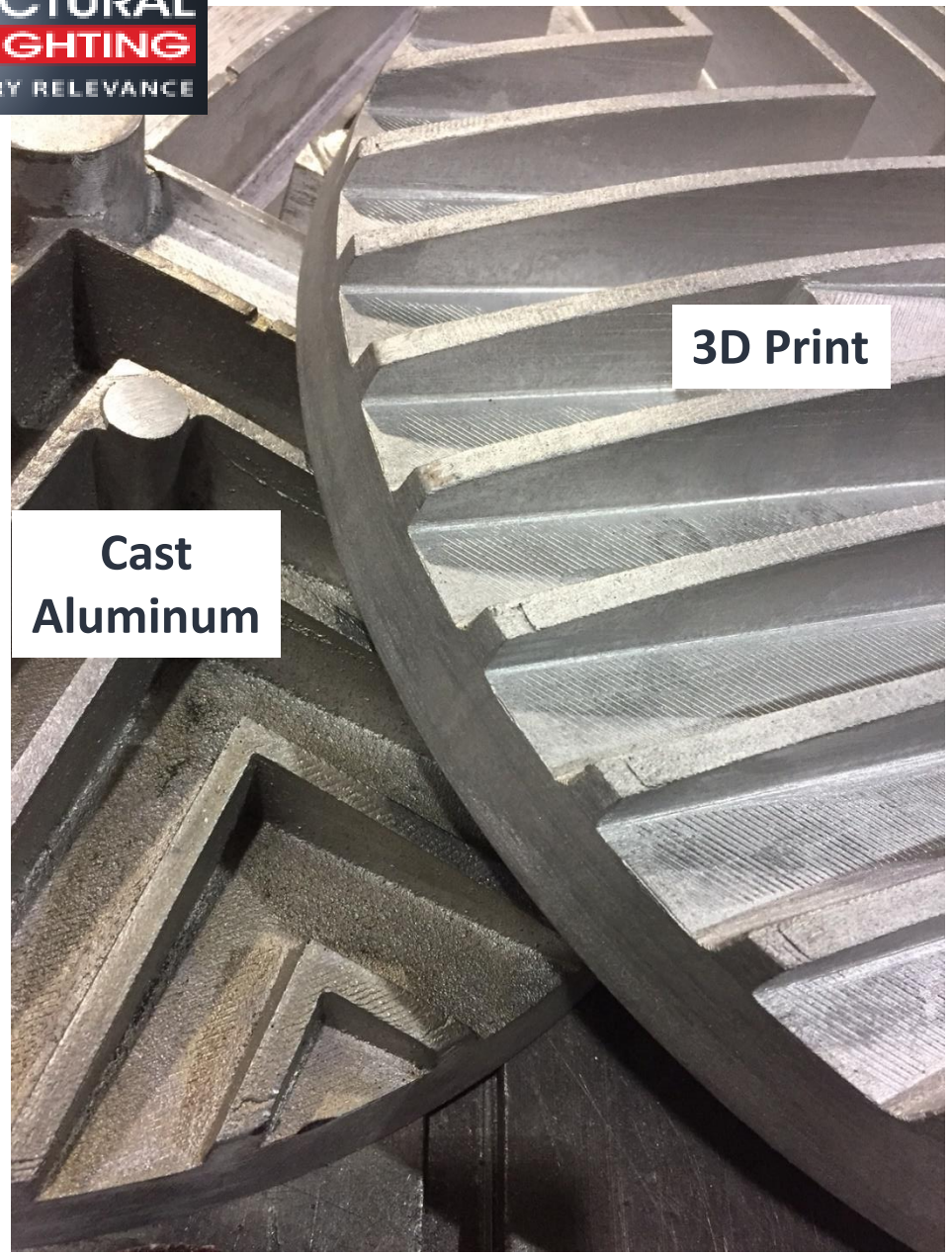
Aluminum Cast Prototype

3DP 3D PLATFORM

Casting Example

U.S. ARCHITECTURAL LIGHTING
CONTEMPORARY RELEVANCE

- Final sanding on metal cast piece before final mold created for high volume production
- Metal allows for easier use of tools
  - Die grinder
  - Power sander
  - Plays to metal working skills



3DP 3D PLATFORM

The Bottom Line

U.S. ARCHITECTURAL LIGHTING
CONTEMPORARY RELEVANCE

- Old Way
  - Outside service bureau
  - Fragile SLA parts
  - 2-3 week lead time
  - Avg. cost - $3,000 per part

- ***NEW** Way*
  - 3D print strong PLA parts in house
  - Lead time cut to 2-3 days
  - 40+ projects completed in year one
  - Savings - ***$50,000 annually***
  - Decreased lead time for customer
  - Gained competitive advantage

"In what we saved versus going outside to have things printed, the machine paid for itself within six months."

Tim Carraher, Lead Engineer

3DP 3D PLATFORM

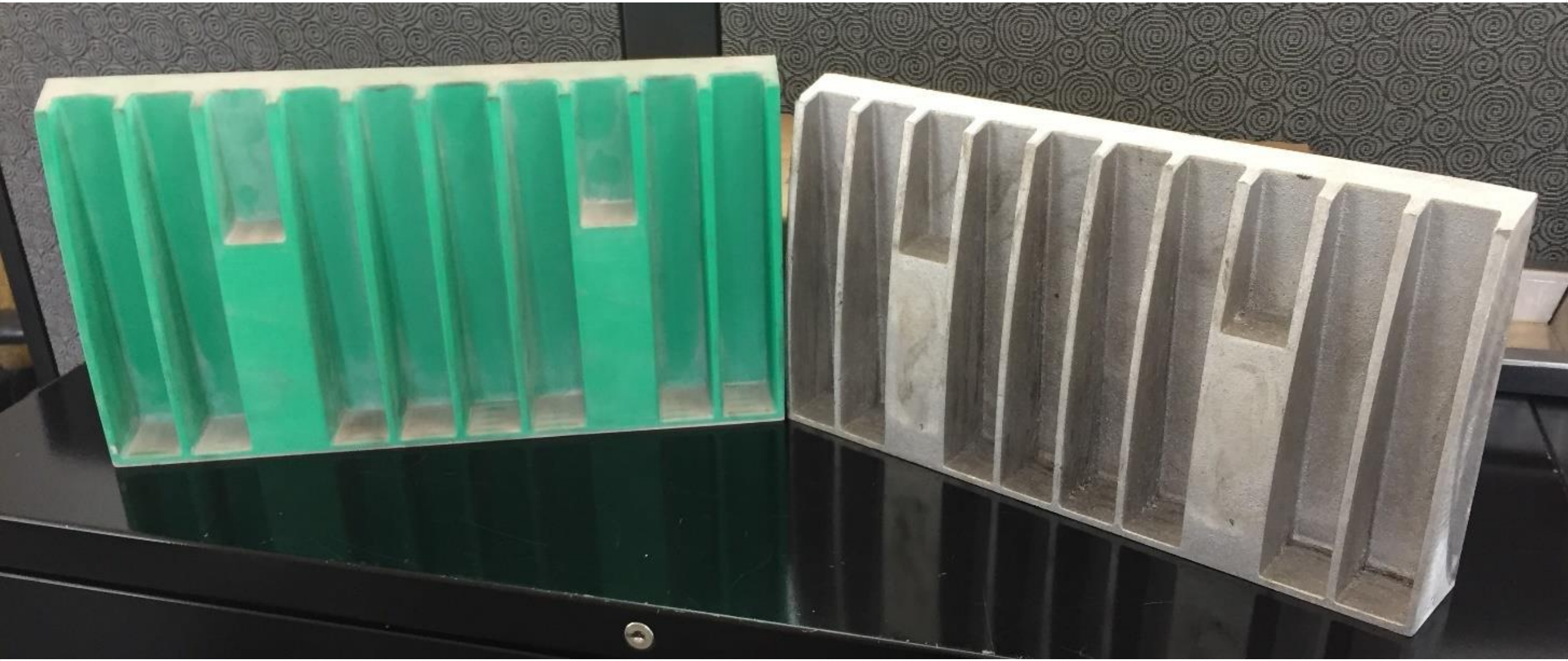
U.S. ARCHITECTURAL LIGHTING
CONTEMPORARY RELEVANCE

3D Printed PLA Masters

Cast Aluminum Prototypes

3DP
3D PLATFORM

U.S. ARCHITECTURAL LIGHTING
CONTEMPORARY RELEVANCE

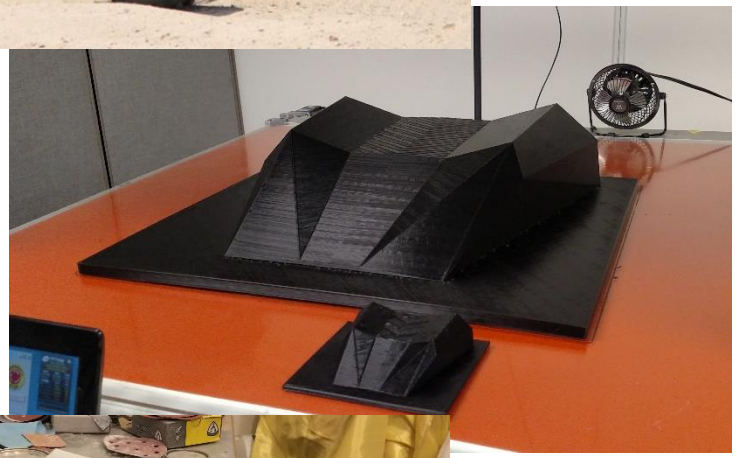


3DP
3D PLATFORM

UMBC Mold Application

University of Maryland, Baltimore County

- UMBC chapter of SAE Race Team
- Process used …
  - 3D printed mold master
  - Light fill and sanding
  - Sealed with spray gel coat
  - Layup carbon fiber reinforced hood
  - Remove from mold
  - Trim, sand and paint to finish



3DP 3D PLATFORM

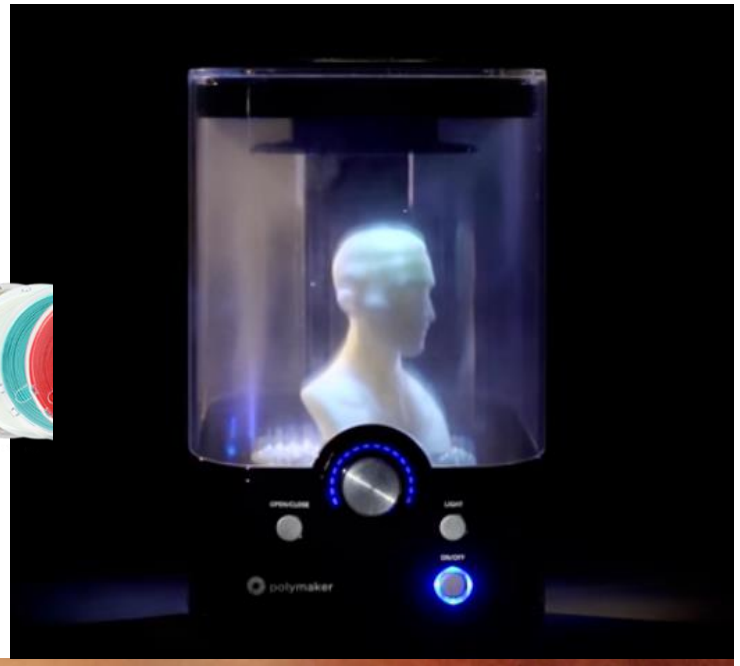
UMBC Mold Application

University of Maryland, Baltimore County

- Old Way
  - Shape master by hand with a variety of materials
  - Process would take weeks to months
  - Difficult to hold accuracy
- ***NEW** Way*
  - 3D print PLA part in 2 days
  - Had carbon fiber layup in less than 1 week
  - Highly accurate shape due to controlled print of master

New and Developing Materials

polymaker



- PolySmooth™ and Polysher™
  - Made smooth in alcohol mist / atomizer
  - http://www.polymaker.com/shop/polysmoothpolysher/

- PolyCast™
  - Can be smoothed with Polysher™
  - Complete clean burnout
  - http://www.polymaker.com/home/polycast-info/

3DP 3D PLATFORM

New and Developing Materials

- Graphene
  - Clean burnout with pure graphene
  - Testing with graphene blended materials such as Haydale enhanced PLA
  - http://www.haydale.com/solutions/3d-printing-solutions/
  - http://shop.3dfilaprint.com/graphene-enhanced-pla-285mm-3d-printer-filament-750gms-8527-p.asp

- Wax Filament from MachineableWax.com
  - Can be sculpted and shaped after printing
  - Clean burnout from mold
  - http://www.machinablewax.com/product.php?product=52

3DP 3D PLATFORM