Factors Affecting the Adoption of 3D Printing Technologies (SLS) as Manufacturing Platforms – Role of Standards for Adoption

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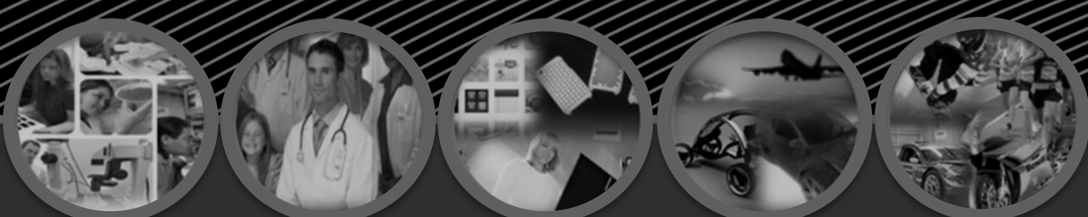
2016-06-10



SLS Print Technology

SLS:

- Uses thermoplastic semi-crystalline polymers as print materials
- Print material in powder form
- Powder material is pre-heated to 10 degrees below the melt point for every layer and a Laser is used to provide additional energy for melting
- Process is repeated layer after layer until the print is complete
- Capable of producing robust, durable & functional parts

Factors Affecting Adoption for Additive Manufacturing

1. Print Speed
2. Part Cost
3. Part Performance, Quality & Accuracy
4. Thermal Process Limitations - Thermal Distribution, Rate of Heating, Rate of Cooling
5. Intelligent Machine Controls – Closed-loop Feedback Controls, In-process Calibration, Smart Software, Measure & Record Process
6. Challenges Imposed by Material Form Requirements
7. Orientation of Parts & Orientation of Fillers in Composites
8. Quality & Reliability Standards; EH&S Standards
9. Lack of Studies concerning Part Performance over Time
10. Applications Development – White Papers, Process Guides

Print Speed

	0.1 mm Layers	0.125 mm Layers
Total Build Height (mm)	300	300
Weight of Parts (Kg)	2.0	1.9
Total Build Time	**23:28**	**18:34**
Warm Up Time	1:19	58:23
Build Time	20:04	15:35
Cool Down Time	2:04	2:04
Scan Time	**6:58**	**4:50**
Add Powder Layer Time	**12:38**	**10:11**
Wait for Tempreature Time	**1:43**	**1:26**
Minimum Layer Compensation Time	**0:13**	**0:11**
Pause & Misc. Times (Mostly during cooldown)	**1:54**	**1:50**
Layer Thickness (mm)	**0.100**	**0.125**
Fill Laser Power, output value (W)	63 - 66	93 - 97
Outline Laser Power, output value (W)	20	30
Scan Spacing (mm)	0.20	0.25
Tensile Strength (MPa)	**46.0**	**38.0**
Elongation At Break (%)	**22.0**	**15.0**
Tensile Modulus (MPa)	**1775**	**1460**
Density (g/cc)	**0.948**	**0.910**

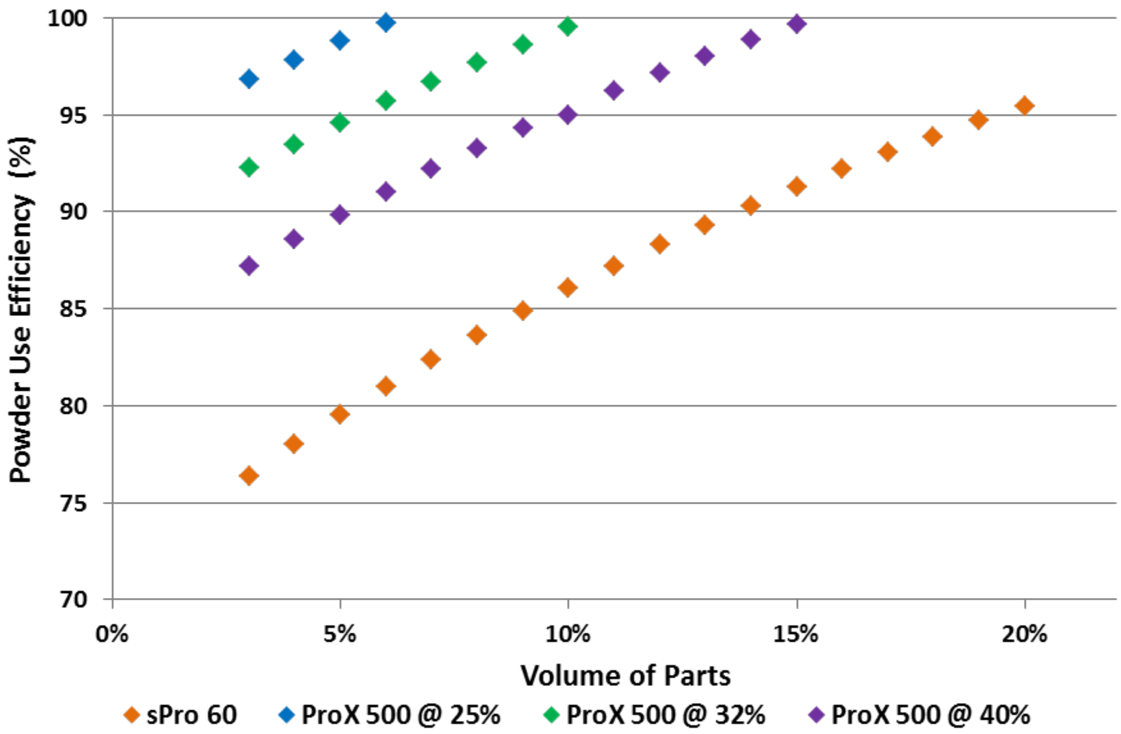
Part Cost; Part Performance, Quality & Accuracy

Part Cost:
- Cost of Print Material
- Recyclability of Print Material

Part Performance:
- Physical, Mechanical & Thermal properties

Part Quality:
- Sidewalls, Top & Bottom Surfaces, Warpage

Part Accuracy:
- Definition, Smallest Feature



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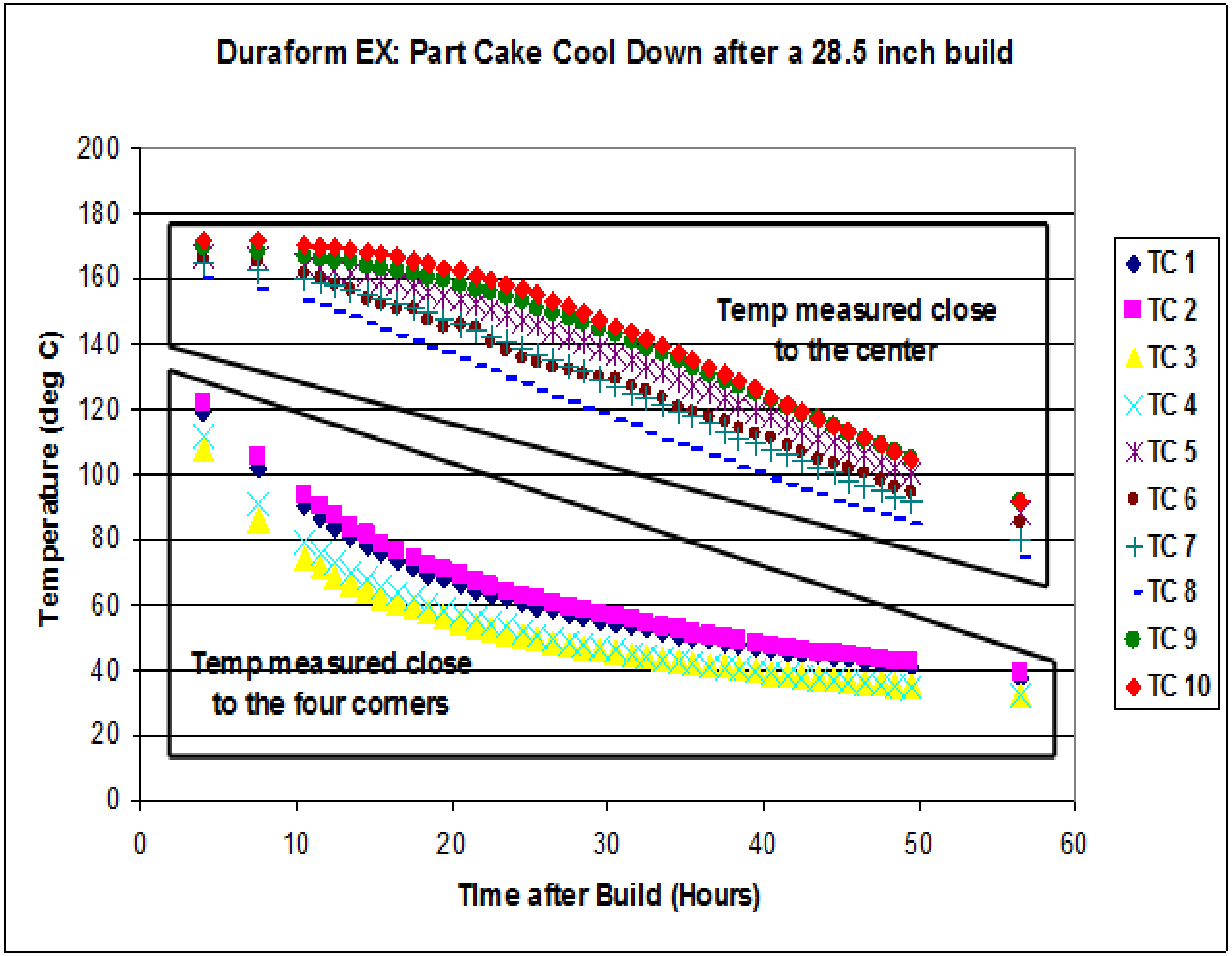
Thermal Process Limitations – Rate of Cooling

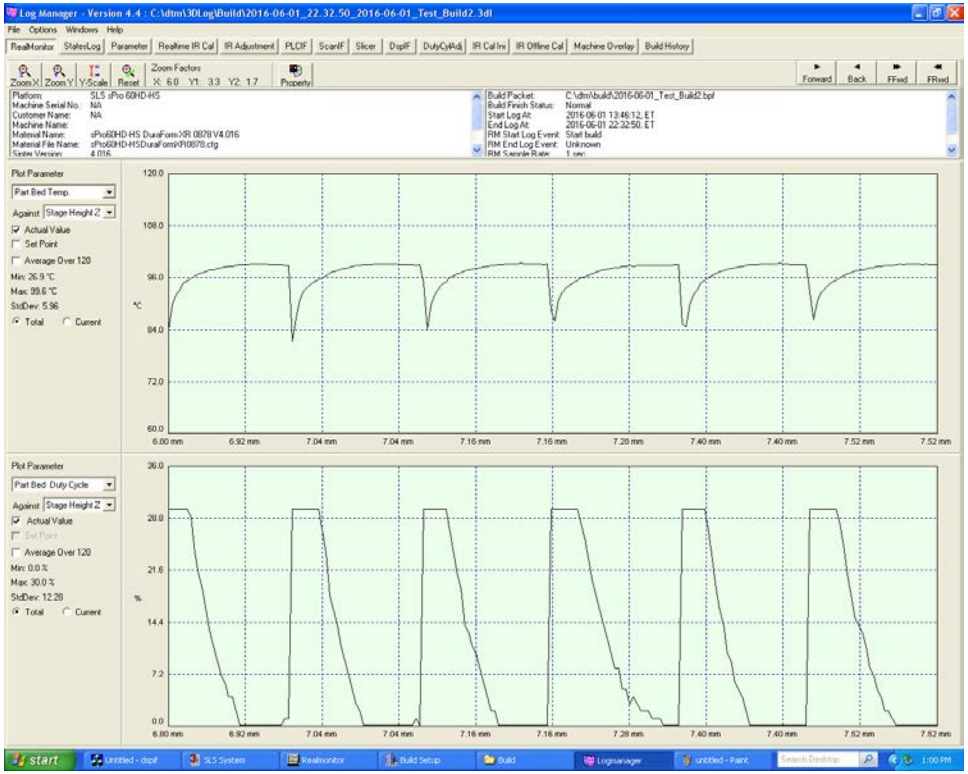
Temp Set Point: 185C



PA12 Material	Top of Build	Bottom of Build
Tensile Modulus, MPa	1850	2020
Tensile Strength, MPa	48	50
Elongation to Break, %	15	11

Intelligent Machine Controls

- **Closed-loop Feedback Controls:** Exists for most heaters but absent for Laser, Variation of beam shape and size center to the corners, Laser power variation in Z
- **In-process Calibration:** Exists for primary Temp sensor only
- **Smart Software:** Capable of suggesting orientation, process parameters, allow ease of design etc.
- **Measure & Record Process:** For validation, problem determination & solving



Print Material Challenges

- Semi-crystalline thermoplastic in powder form (precipitated, cryo-ground)
- Particle size distribution (powder flow, part resolution)
- Thermal characteristics (process latitude) - melt & re-crystallization (part distortion, part definition, heated powder cake hardness, powder recyclability)
- Powder flow characteristics (particle size, particle shape, static charges, change with temperature)
- Melt Viscosity & Surface energy (for coalescence and layer to layer adhesion)
- Powder recyclability (thermal characteristics, molecular weight change, agglomeration of heated powder)
- Excellent Thermal stability

Orientation of Parts & Orientation of Fillers

X vs Z; or at another angle to XY

Unfilled Material	X Direction	Z Direction
Tensile Modulus, MPa	1760	1600
Tensile Strength, MPa	46.0	45.5
Elongation at Break, %	19.0	9.5

Fiber Orientation in X, Y, Z

Fiber Filled Material	X Direction	Y Direction	Z Direction
Tensile Modulus, MPa	5640	3390	2940
Tensile Strength, MPa	49.8	43.3	32.6
Elongation at Break, %	4.5	3.5	2.7

Quality & Reliability Standards; EH&S Standards

Quality & Reliability Standards:
Compliance to ISO, TS16949 type of standards for Machine & Materials manufacturing
Machine performance over time – Preventive maintenance
SPC techniques for reliability – six lot data, six sigma process

EH&S Standards:
Air Quality/Environmental testing - VOC emissions (hazardous decomposition products)
Explosion Severity testing

Part Performance over Time; Applications Development

Part Performance over Time:

- Need to generate fatigue, creep, exposure, RTI type data

Applications Development:

- Advance through developing new applications for the AM processes, publish more white papers
- Generate better machine guides, material guides, process guides & troubleshooting guides

Adopt the Advantages

- **Hollow Parts using Fused Deposition print process for Speed**
- **Lower Density but Higher Strength to weight ratio**

Printed Part Density, g/cc	0.44
Tensile Strength, MPa	33
Strength-to-weight ratio, MPa/(g/cc)	**76**
Tensile Modulus, MPa	1710
Elongation at Break, %	22

- **Freedom of part placement, orientation**
- **Capability to apply different parameters to different parts**
- **Change settings on the fly**
- **Different hatch patters for different speeds & properties**

Acknowledgements

- **Khalil Moussa**
- **Jenny Reilly**
- **Christian Folgar**
- **Steven Goransson**

Thank you!!

May need to think outside the box to overcome these barriers