3D Printing/ Process Parameters

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3D Printing Technology

Design, Material & Process Parameters

- Loadings
- Design
  - Material
    - Metal, Plastics, Ceramics
  - Process Parameters
    - Speed & path
    - Heat Source
    - Nozzle movement system
    - Material heating system
    - Material feeding process

FDM – Fused Deposition Modeling
(thermoplastics, ABS and Nylon)

SLS - Selective laser sintering
(thermoplastics, metals, Ceramics)

LENS - Laser Engineering Net Shaping
(metal)

3D Ink Jet Printing
Optimal Design of Automotive Lower Arm, for 3D-Printing

Conventional design
Constrained by manufacturing Process,
100 % volume

Topology optimization
60 % volume
Conventional Process vs 3D Printing

**Design, Material & Process Parameters**

- **Automotive Lower Arm**
  - Conventional Process
  - 3D Printing

<table>
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<tr>
<th>Design</th>
<th>Material</th>
<th>Process Parameters</th>
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<tr>
<td>Loadings</td>
<td>Metal, Plastics, Ceramics</td>
<td>Speed &amp; path</td>
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- **Heat Source**

- **100 %** vs. **60 %**

- **100 %** waste vs. **60 %** waste

- Two aspects in saving materials in 3D printing:
  1. In the design process;
  2. In the printing process.

- For 3D printing, redesign to save more material.
The 3D in the 3D printing is 2D by 1D...

3D printing

- FDM, SLS, SLA, LENS, EBM, InkJet, ...
- Enable to escape the constraints of traditional production process...

However, 3D in the 3D printing is achieved by 2D multiplied by 1D.

May cause slow process and weak materials → Need to Optimize PROCESS PARAMETERS
Process parameters and **Key Performance Indicators (KPI)**

- **Loadings** → **Design** → **Material** → **Process Parameters** → **Parts**
  - **Material** includes **Metal**, **Plastics**, and **Ceramics**
  - **Process Parameters** include **Speed & path**, **Heat Source**, and **Nozzle path and speed**
  - **Key Performance Indicators** include **Quality of Product**, **Production Rates**, **Dimensional Precision**, and **Waste & Scraps**

- **Key Performance Indicators**:
  - **Quality of Product**: Stiff & strong
  - **Production Rates**: Cycle time
  - **Dimensional Precision**: High precision
  - **Waste & Scraps**: Zero waste

**Balance Process parameters To achieve the best KPI**
FUSED DEPOSITION MODELING (FDM)

KEY METRICS
- Maximum build size: 20” x 20” x 20”
- Speed: Slow
- Cost: Medium
- Available materials: Thermoplastics ABS, PC, ULTEM

KEY PARAMETERS

KEY APPLICATION AREAS
- Conceptual Models
- Engineering Models
- Functional Testing Prototypes
Overall Process Parameters in FDM 3D printing

Cause and Effect Diagram

Concept Models
- Topology Optimization
- STL File

Materials
- Melt & Cool
- Density
- Color

Part Build Orientation
- X-direction
- Y-direction
- Z-direction

Part Build Parameters
- Part interior Style
- Part fill style
- Raster angle
- Raster width & gap
- Layer thickness
- Contour width & gap
- Part shrinkage

Working Parameters
- Model build temp
- Envelope temp
- Machine calibration
- Nozzle diameter

FDM Machine
- Temperature
- Humidity

Environmental Factors

KEY PERFORMANCE INDICATOR (KPI)

ref: Optimization of fused deposition modeling process parameters, 2015, Advances in Manufacturing
Effects of Print Speed and Layer thickness on Coalescence

- Influences of **Print Speed** and **Layer Thickness** on **Coalescence** in FDM

- The formation of bonds in the FDM process is driven by the thermal energy of the semi-molten materials.

![Diagram of FDM process with coalescence stages: 1. Surface contacting, 2. Neck growth, 3. Diffusion and Randomization](image

**Coalescence (layer thickness=0.5 mm)**

- Layer thickness =0.5 mm
- **Print Speed**
  - mm/sec
- **Coalescence**

**Coalescence (layer thickness=1.0 mm)**

- Layer thickness =1.0 mm
- **Print Speed**
  - mm/sec
- **Coalescence**

*ref: alternate slicing and deposition strategies for FDM-Huang thesis*
Effects of Build Orientation on Tensile Strength in FDM

Material: ULTEM 9085

ULTIMATE TENSILE STRENGTH (MPa)

STRENGTH of INJECTION MOLDED (84 MPa)

Machine settings
- default 1
- default 2
- Optimal

MECHANICAL PROPERTIES OF FUSED DEPOSITION MODELING PARTS MANUFACTURED WITH ULTEM*9085, ANTEC 2011, Boston
SELECTIVE LASER SINTERING (SLS)

KEY APPLICATION AREAS
- Structural components

KEY METRICS

<table>
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<tr>
<th>Application</th>
<th>Value</th>
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<tbody>
<tr>
<td>Maximum build size</td>
<td>700 mm x 380 mm x 560 mm</td>
</tr>
<tr>
<td>Speed</td>
<td>Medium</td>
</tr>
<tr>
<td>Cost</td>
<td>Medium</td>
</tr>
<tr>
<td>Available materials</td>
<td>Powdered plastics (nylon), metals (steel, titanium, tungsten), ceramics (silicon carbide) and fiber-reinforced PMCs</td>
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KEY PARAMETERS (Laser Source)

- A focused laser beam is used to fuse/sinter powder particles in a small volume within the layer.

Metal Technology Co

3D Systems
Process parameters in SLS

Materials: TP, metal, Ceramics

High-energy laser beam to fuse metal (plastics or ceramic) powder

- **Laser Parameters**
  - Laser Power / Laser Energy
  - Spot Size
  - Scanning Speed
  - Scanning Mode
  - Interval Time
  - Exposure Time
  - Part Bed Temperature

- **Geometric Parameters**
  - Hatch Spacing
  - Scan Pattern
  - Layer Thickness
  - Building Direction
  - Part Orientation
  - Point Distance

- **Cause and Effect Diagram**

[Diagram showing cause and effect relationships between sintered material, sintering parameters, and physical-mechanical properties of sintered elements.]
Effects of SLS PROCESS PARAMETERS on Strength & Density

- SLS process parameters: Laser Power, Scanning speed, Exposure Time, Point Distance, etc

Material: Direct Steel H20

- Effects of Point Distance & Laser Power Output

ET=92us, SP=87mm/s

ET=100us, SP=84.5mm/s

Research Areas to improve 3D printing

- Need to develop Models for predicting the KPI in terms of Process Parameters
- **Optimization of process parameters**: raster angles and gaps; laser power, scanning speed, exposure time, point distance, etc
  - Thermal-chemical-mechanical simulation of material melting and cooling process
  - Measurement of mechanical attributes for various process parameters
  - Multi-scale approach to select best process parameters
  - Need to perform Topology optimization considering material anisotropy, layer direction
  - Fiber reinforced composites
CONCLUSION: Integrated Processes to Achieve the best KPI

Design, Material & Process Parameters → Simulation Tools → KPI

- Integration of Design and Process Parameters
- Balance Process parameters

Key Performance Indicators

- Quality of Product
  - Stiff & strong
- Production Rates
  - Cycle time
- Dimensional Precision
  - High precision
- Waste & Scraps
  - Zero waste

\[ \text{RPN} = \text{Severity} \times \text{Occurrence} \times \text{Detection} \]
Composites for 3D-printing

- To enhance material properties of 3D printing:
  Develop a 3D printing of continuous-fiber composites

- Plastics
  - Nanocomposites
  - Short fibers
  - Long fibers
  - Continuous fiber

- Resin reinforced with chopped carbon fiber is placed layer by layer.
- Temperature difference and cohesion between the individual beads, resulting in asymmetric shrinkage and bending moments