3D Printing/ Process Parameters

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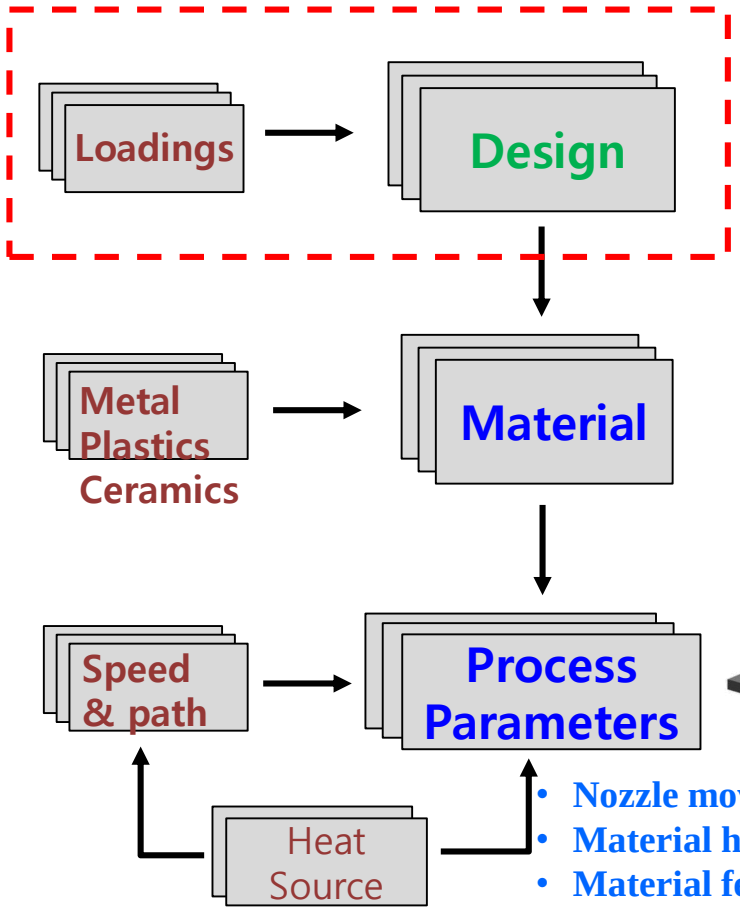
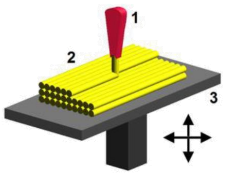
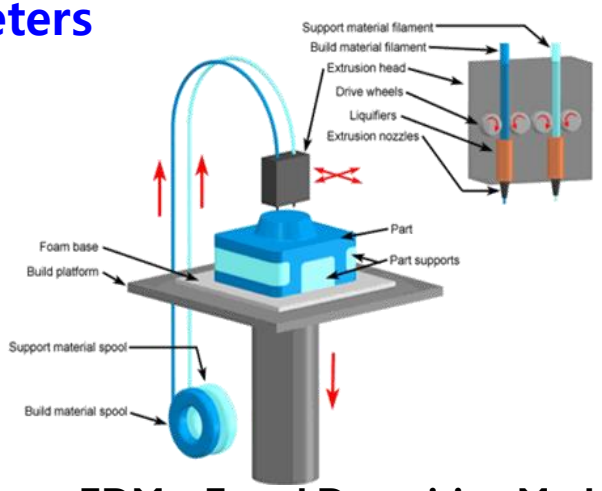
3D Printing Technology

Design, Material & Process Parameters

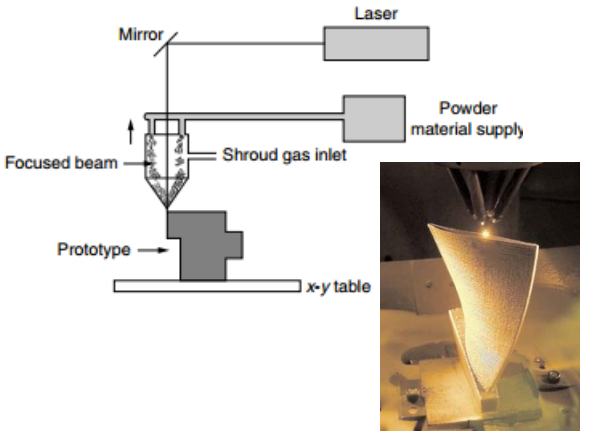




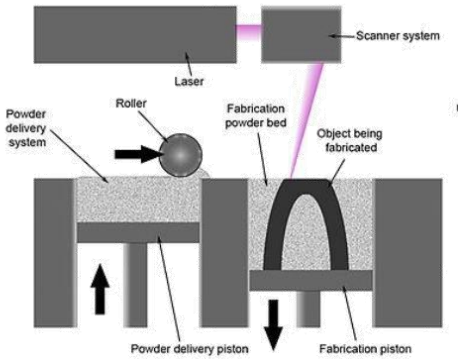
- Nozzle movement system
- Material heating system
- Material feeding process



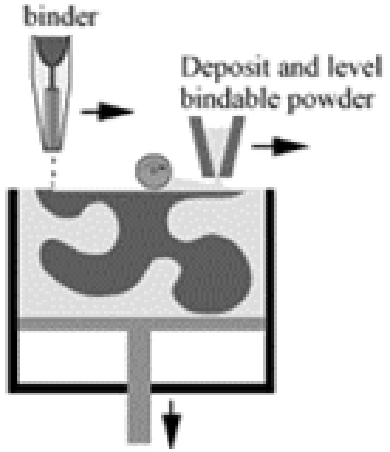
FDM – Fused Deposition Modeling
(thermoplastics, ABS and Nylon)



LENS-Laser Engineering Net Shaping (metal)

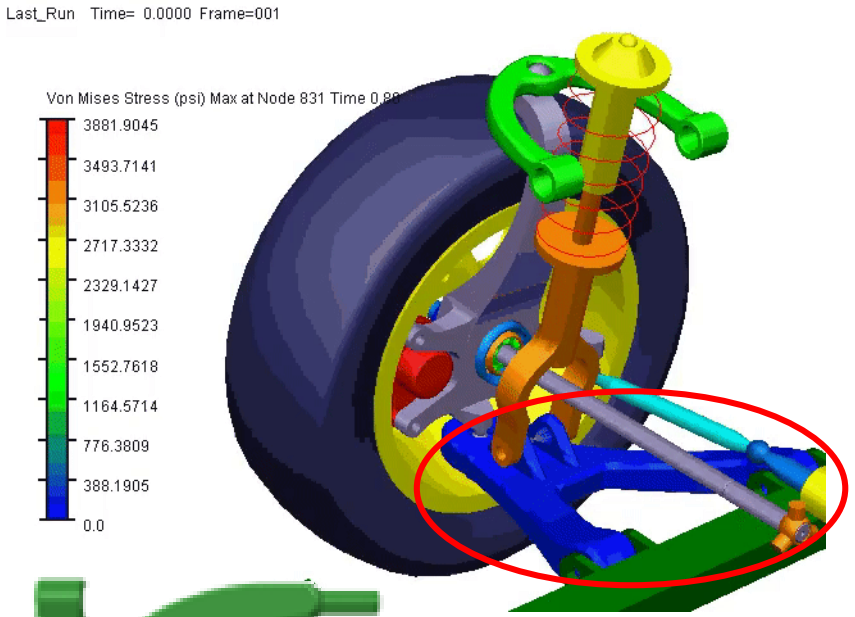


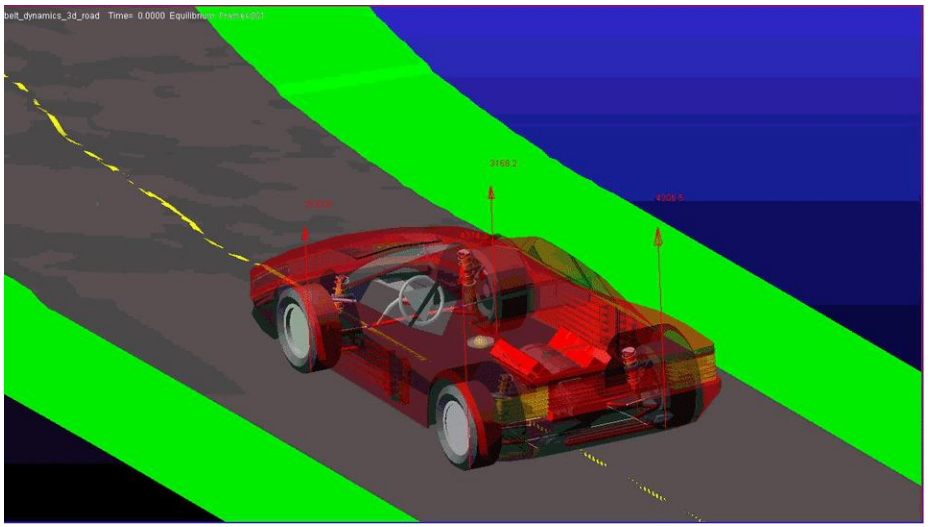
SLS - Selective laser sintering
(thermoplastics, metals, Ceramics)

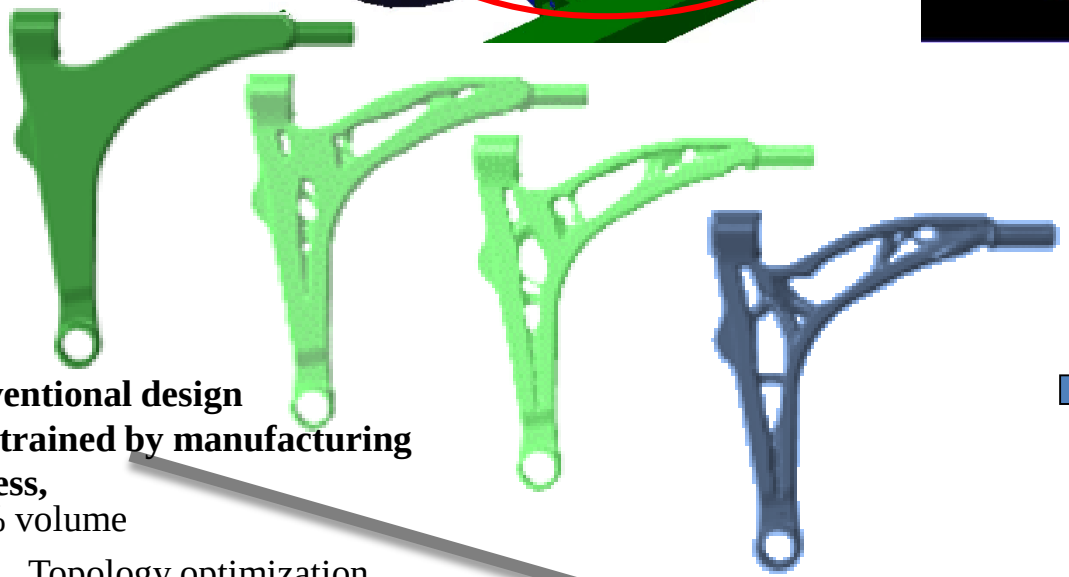


3D Ink Jet Printing

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



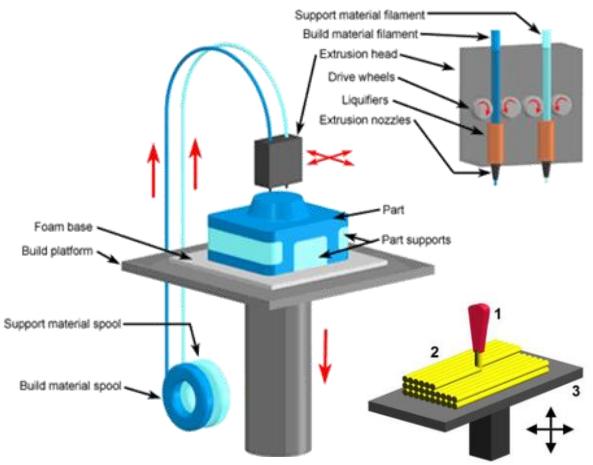




Conventional design
Constrained by manufacturing Process,
100 % volume

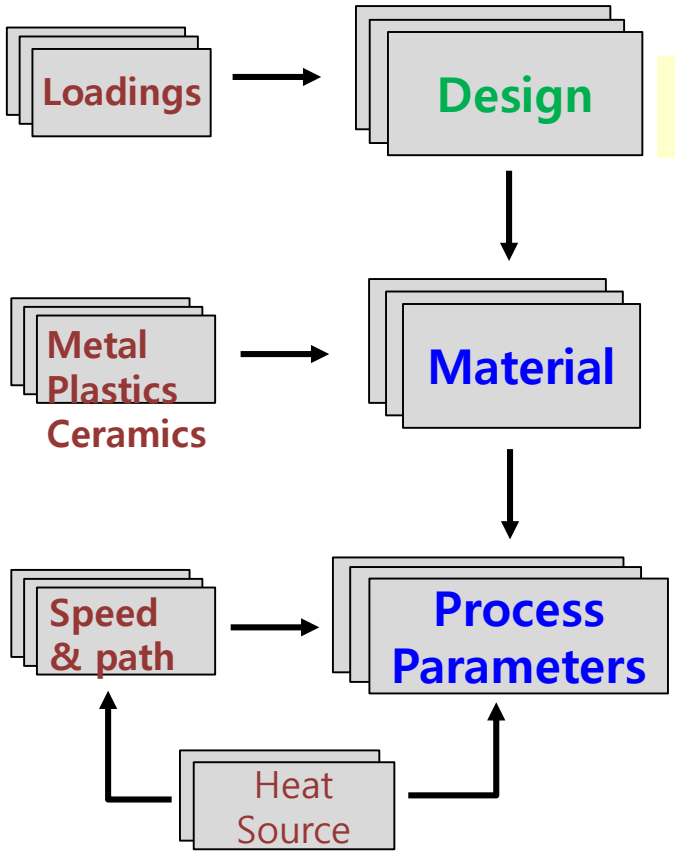
Topology optimization

60 % volume



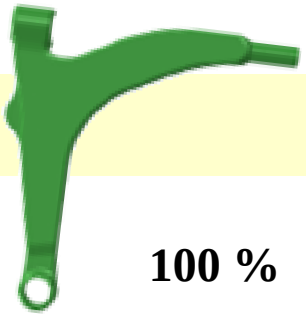
Conventional Process vs 3D Printing

Design, Material & Process Parameters

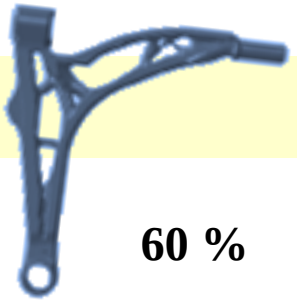


❖ Automotive Lower Arm

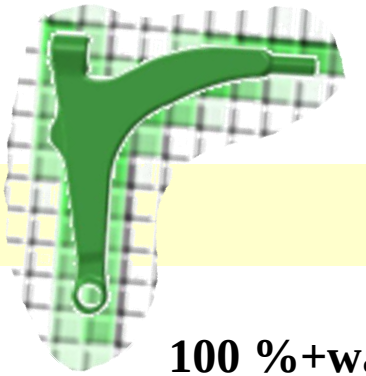
- **Conventional Process**
- **3D Printing**



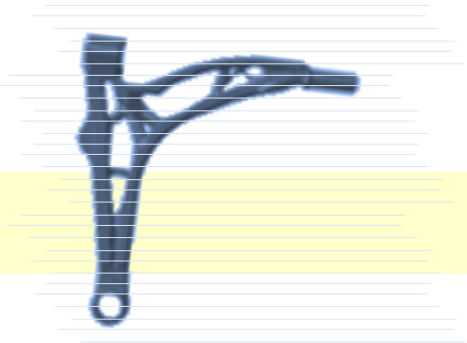
100 %



60 %



100 %+waste



60 %+0

- 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.

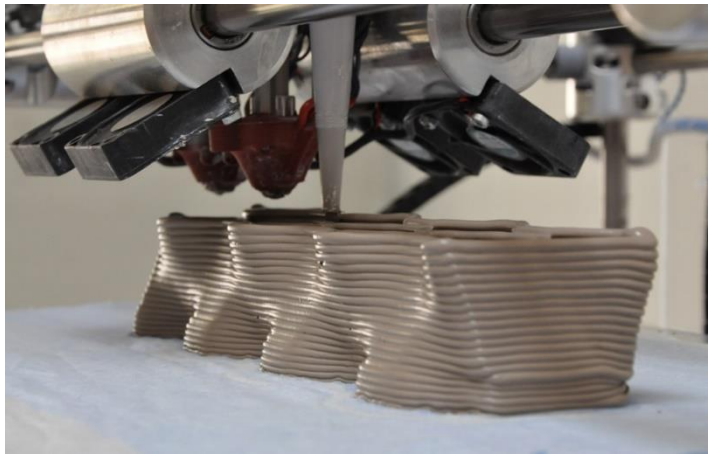
The 3D in the 3D printing is 2D by 1D...

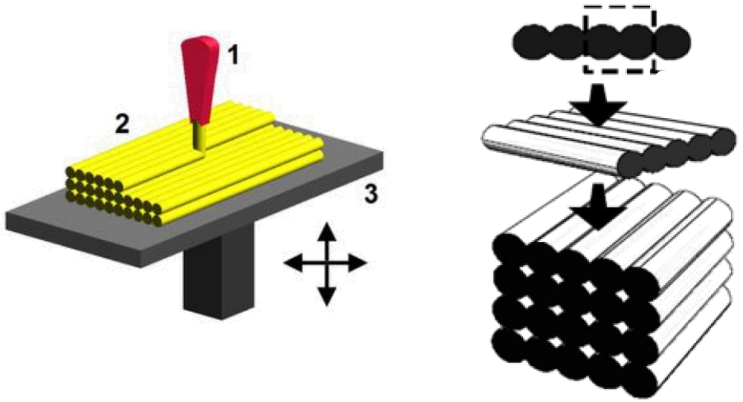
❑ 3D printing

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

courtesy of APWorks, 2016

- **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

Metal
Plastics
Ceramics

Speed
& path

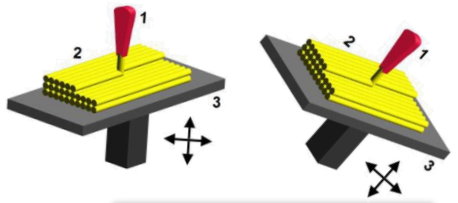
Heat
Source

Design

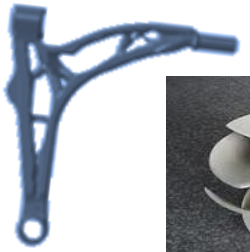
Material

Process
Parameters

- Nozzle path and speed
- Thermal heating & cooling
- Layering direction



Parts



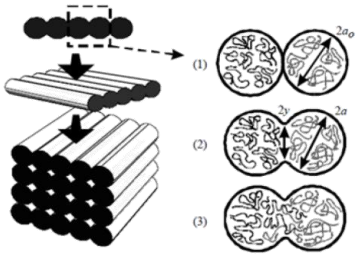
Key Performance Indicators

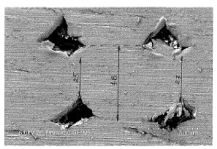
Quality of Product — Stiff & strong

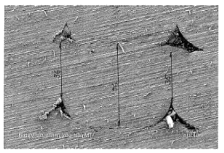
Production Rates — Cycle time

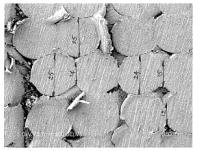
Dimensional Precision — High precision

Waste & Scraps — Zero waste









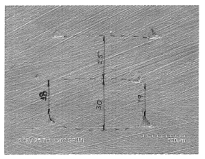


Figure A1.3 Meso structure of FDM test part of 15mm/s print speed (Average coalescence: 0.64)

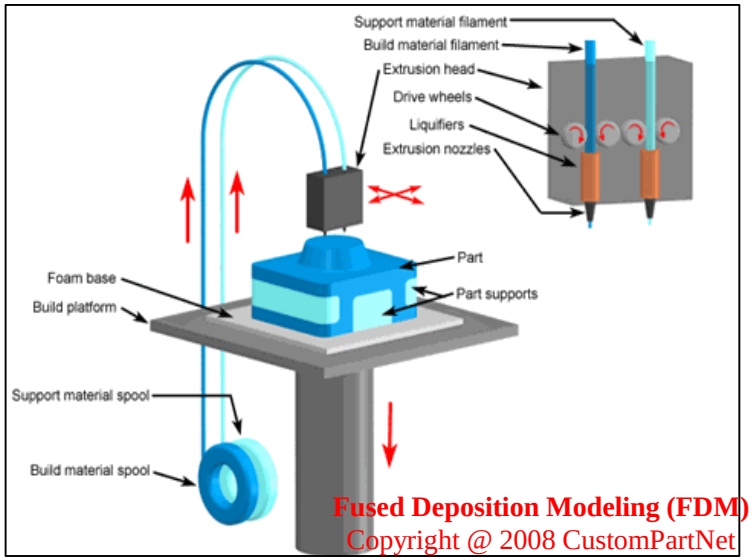
Figure A1.3 Meso structure of FDM test part of 13mm/s print speed (Average coalescence: 0.64)

Figure A1.4 Meso structure of FDM test part of 60mm/s print speed (Average coalescence: 0.65)

Figure A1.4 Meso structure of FDM test part of 35mm/s print speed (Average coalescence: 0.68)

Balance Process parameters
To achieve the best KPI

FUSED DEPOSITION MODELING (FDM)

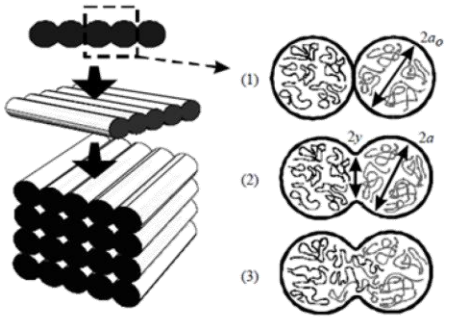


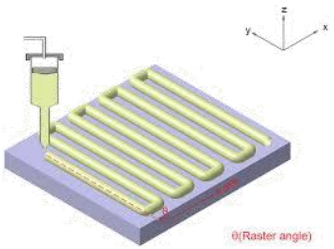
Fused Deposition Modeling (FDM)
Copyright @ 2008 CustomPartNet

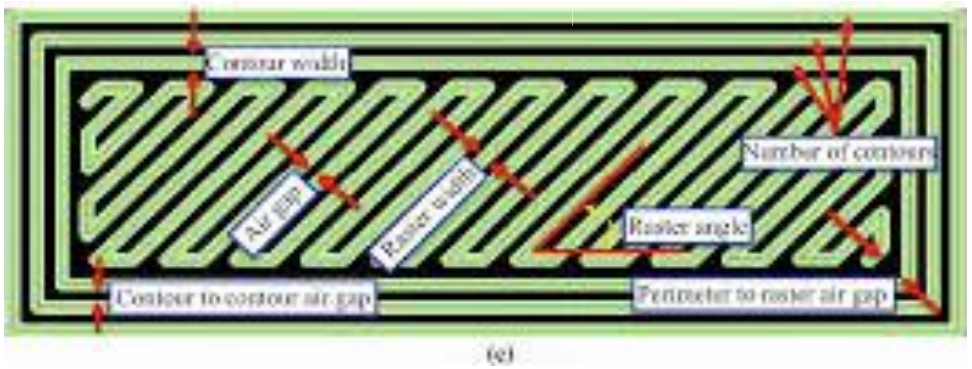
KEY METRICS

• Maximum build size	• 20” x 20” x 20”
• Speed	• Slow
• Cost	• Medium
• Available materials	• Thermoplastics ABS, PC, ULTEM

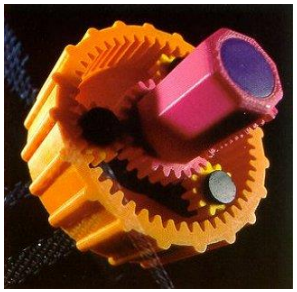
KEY PARAMETERS







(e)



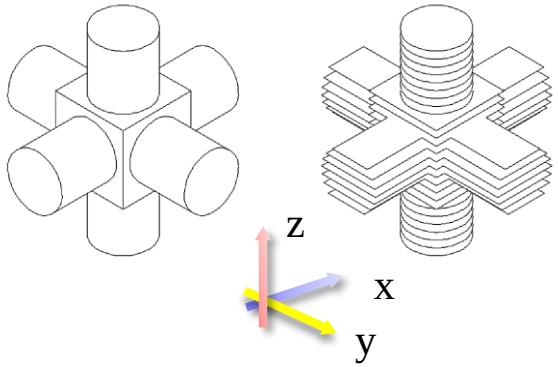
Courtesy, Dr. Robin Richards, University College London, UK

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

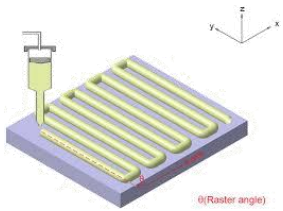
Part Build Orientation
- X-direction
- Y-direction
- Z-direction

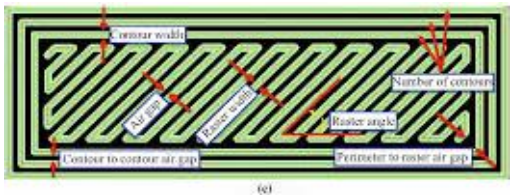
KEY PERFORMANCE INDICATOR (KPI)

Environmental Factors
- Temperature
- Humidity

FDM Machine
- Model build temp
- Envelope temp
- Machine calibration
- Nozzle diameter

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

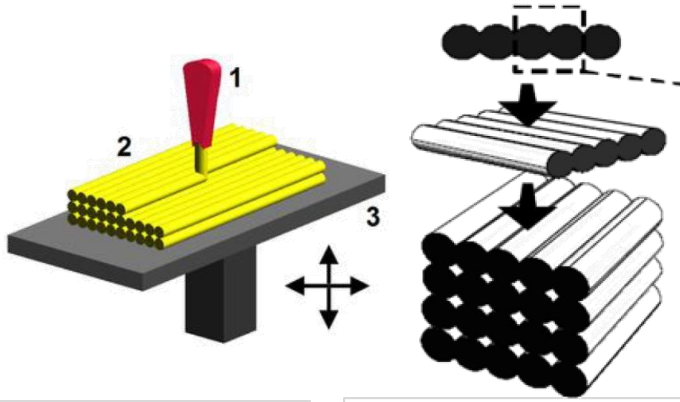


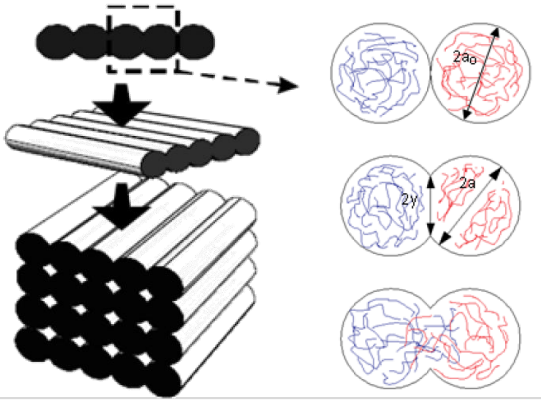


ref: Optimization of fused deposition modeling process parameters, 2015, Advances in Manufacturing

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.**

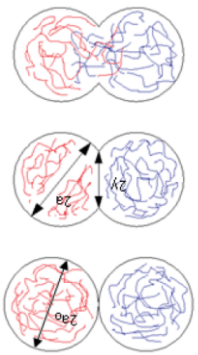


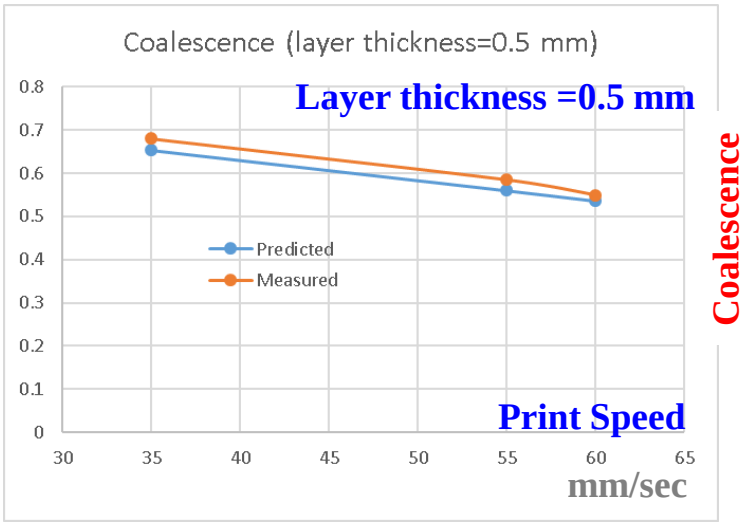


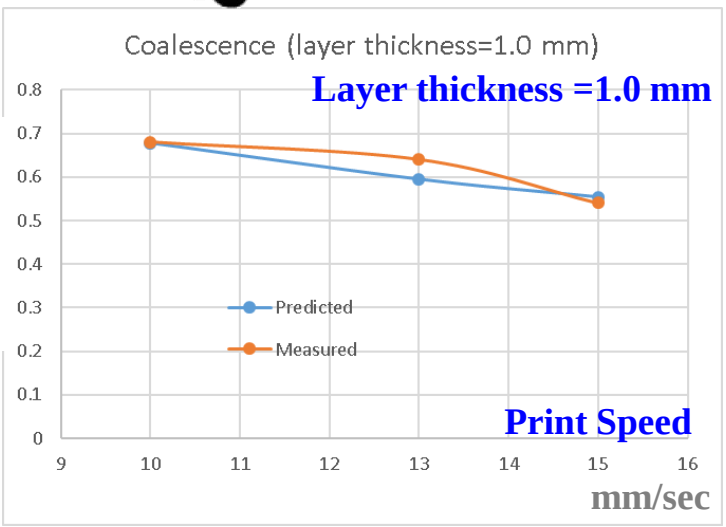
(1) Surface contacting

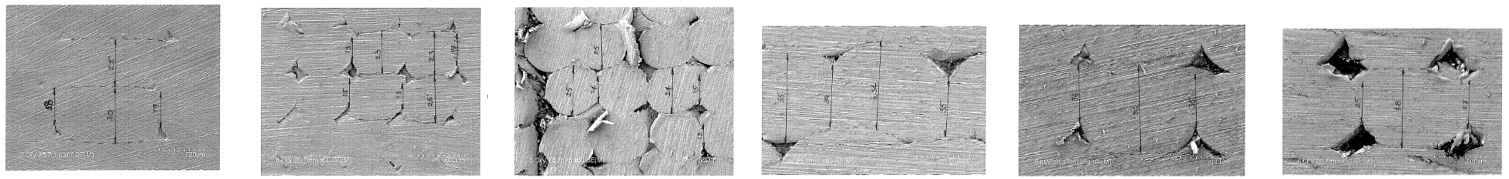
(2) Neck growth

(3) Diffusion and Randomization



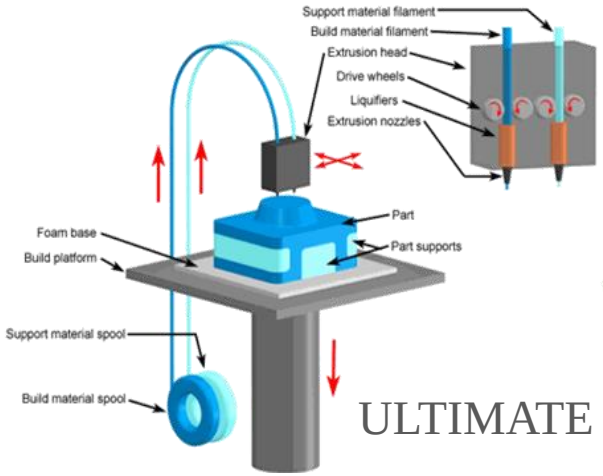




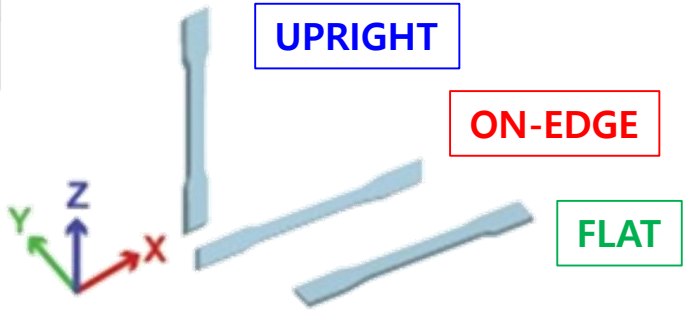


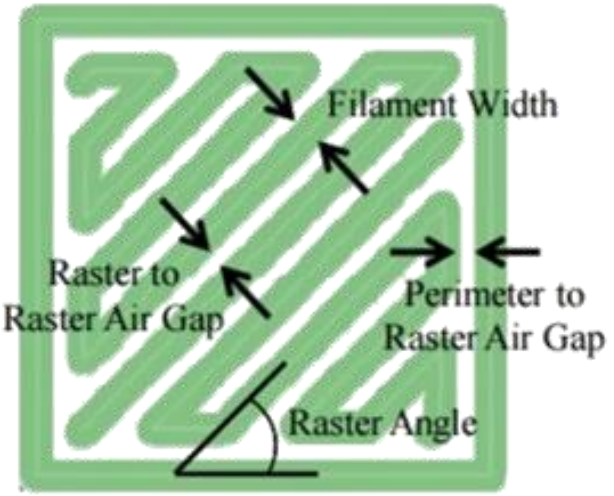
ref: alternate slicing and deposition strategies for FDM-Huang thesis

Effects of Build Orientation on Tensile Strength in FDM

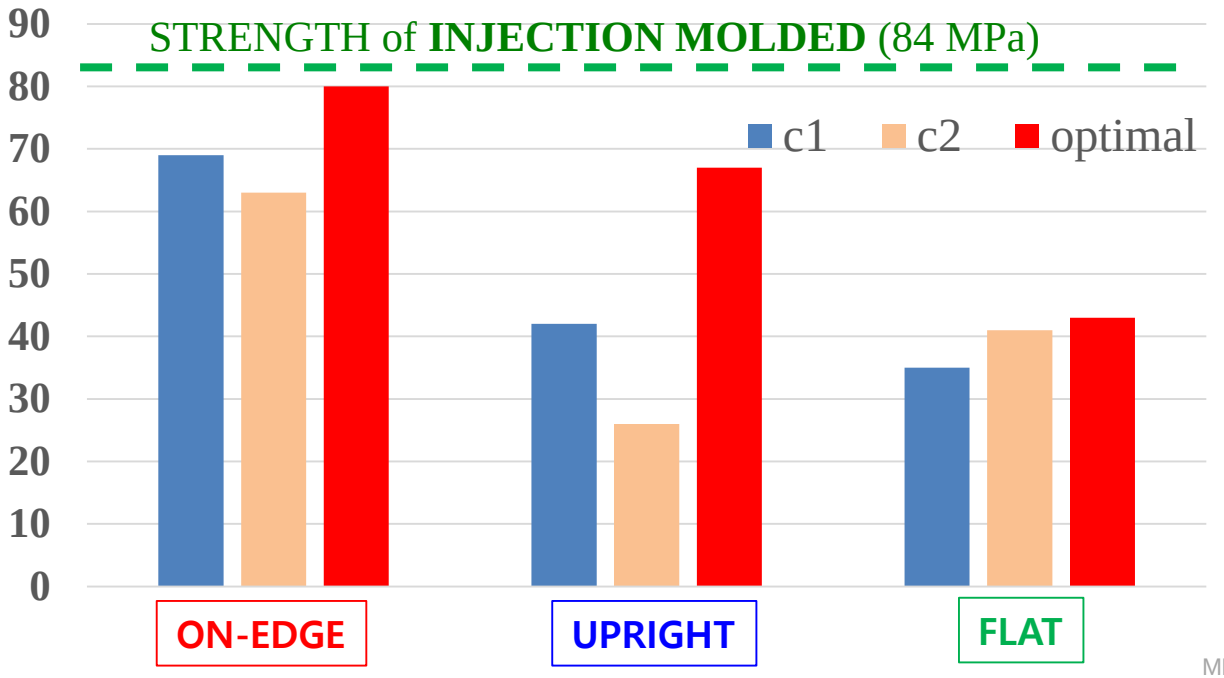


Material: ULTEM 9085





ULTIMATE TENSILE STRENGTH (MPa)



Machine settings

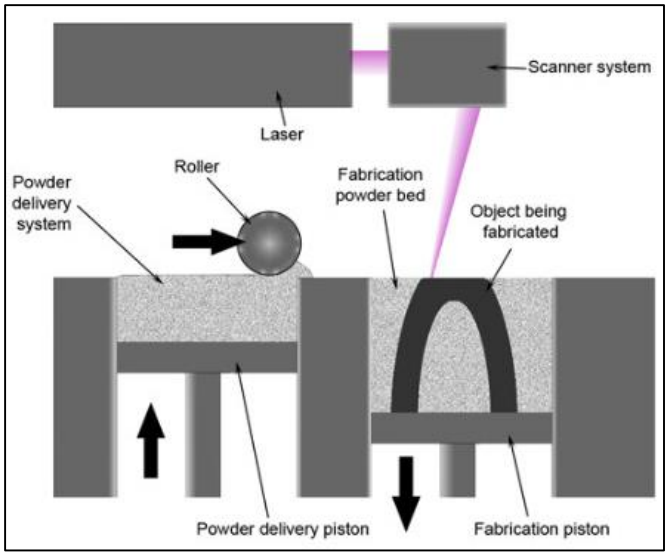
default 1

default 2

Optimal

MECHANICAL PROPERTIES OF FUSED DEPOSITION MODELING PARTS MANUFACTURED WITH ULTEM*9085, ANTEC 2011, Boston

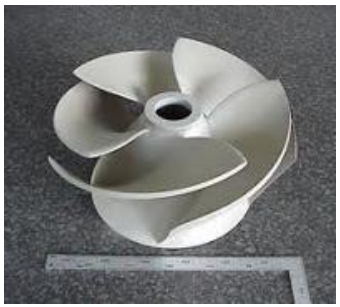
SELECTIVE LASER SINTERING (SLS)



KEY METRICS

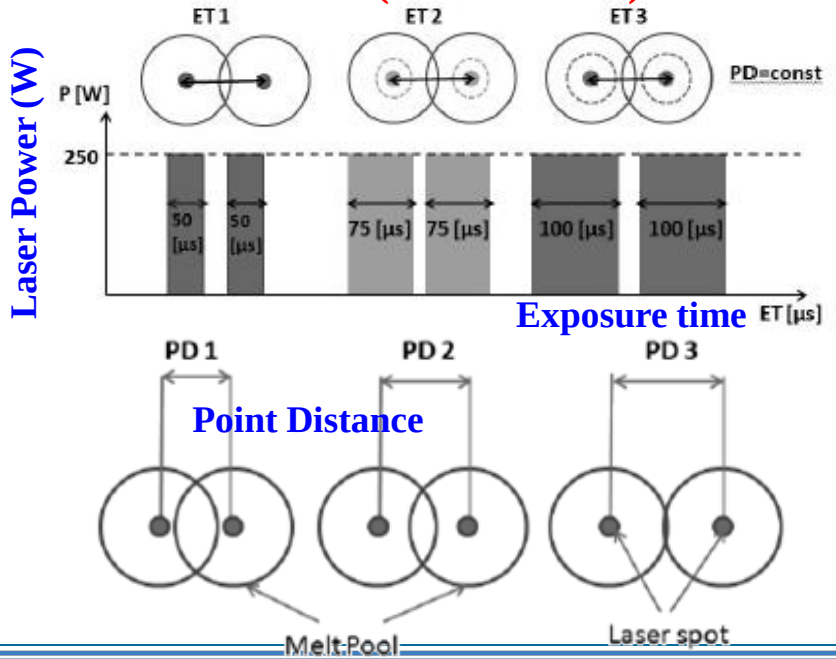
Maximum build size	700 mm x 380 mm x 560 mm
Speed	Medium
Cost	Medium
Available materials	Powdered plastics (nylon), metals (steel, titanium, tungsten), ceramics (silicon carbide) and fiber-reinforced PMCs

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



Metal Technology Co

KEY PARAMETERS (Laser Source)

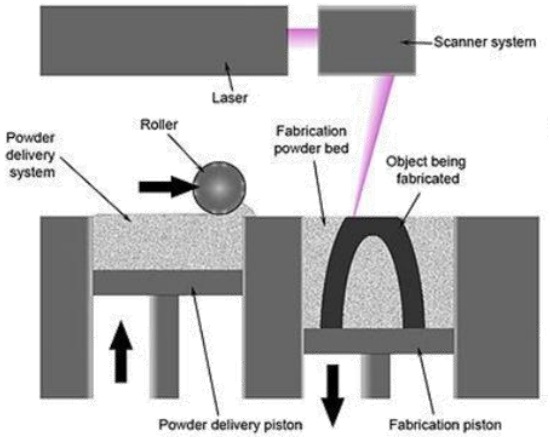


KEY APPLICATION AREAS

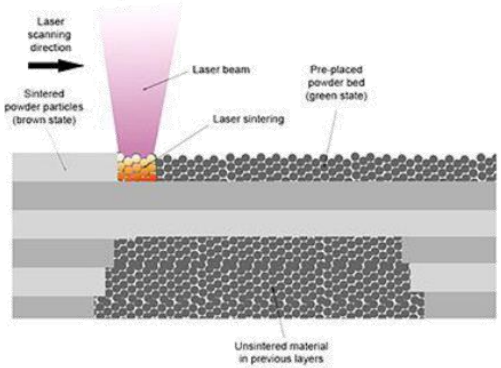
- Structural components

Process parameters in SLS

Materials: TP, metal, Ceramics



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



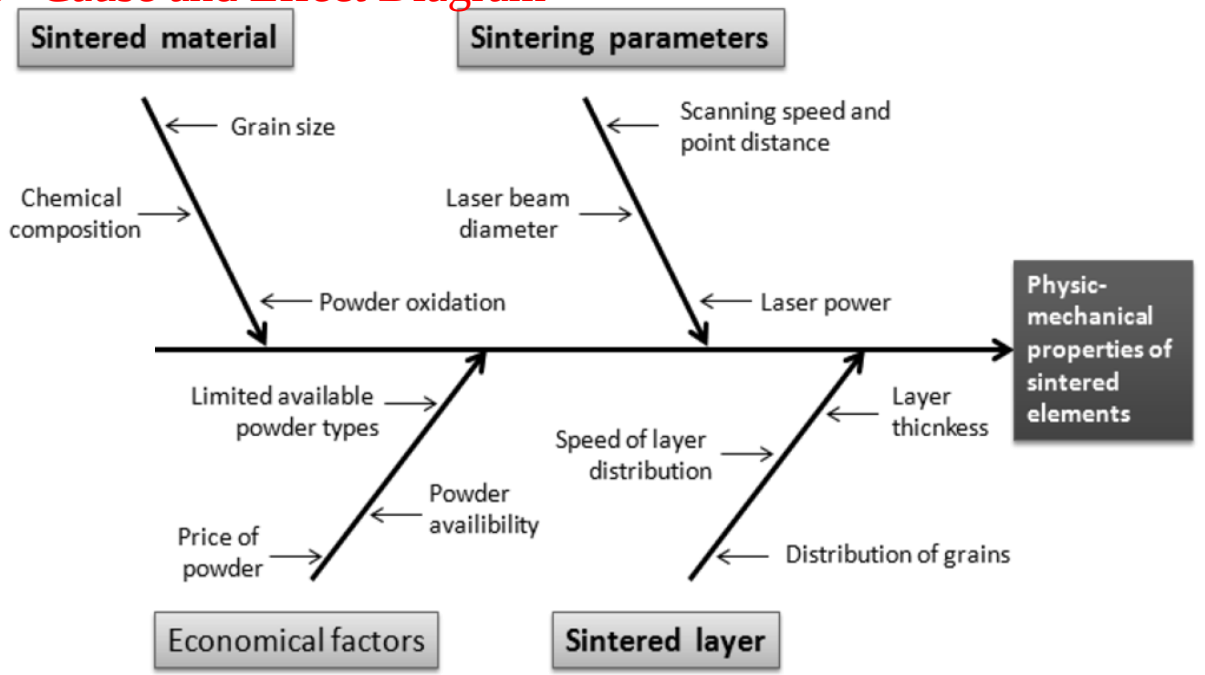
❑ Laser Parameters

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

❑ Geometric Parameters

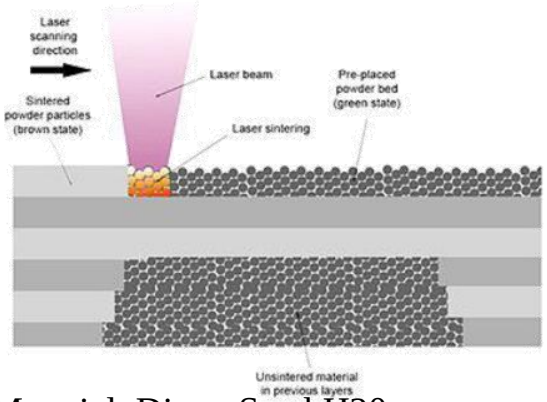
- Hatch Spacing
- Scan Pattern
- Layer Thickness
- Building Direction
- Part Orientation
- Point Distance

❖ Cause and Effect Diagram



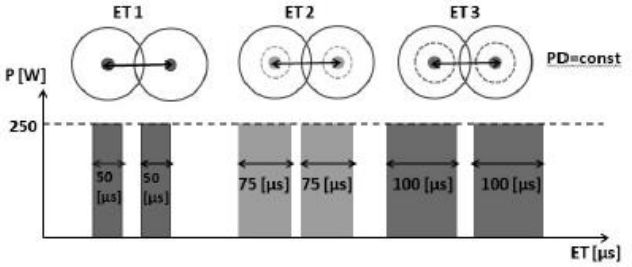
Effects of SLS PROCESS PARAMETERS on Strength & Density

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

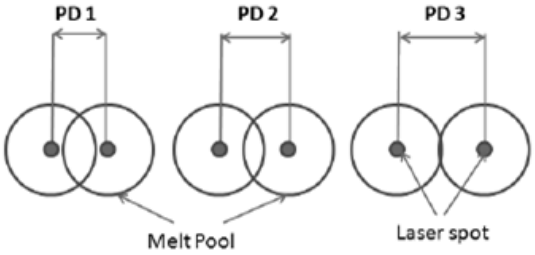


Material: Direct Steel H20

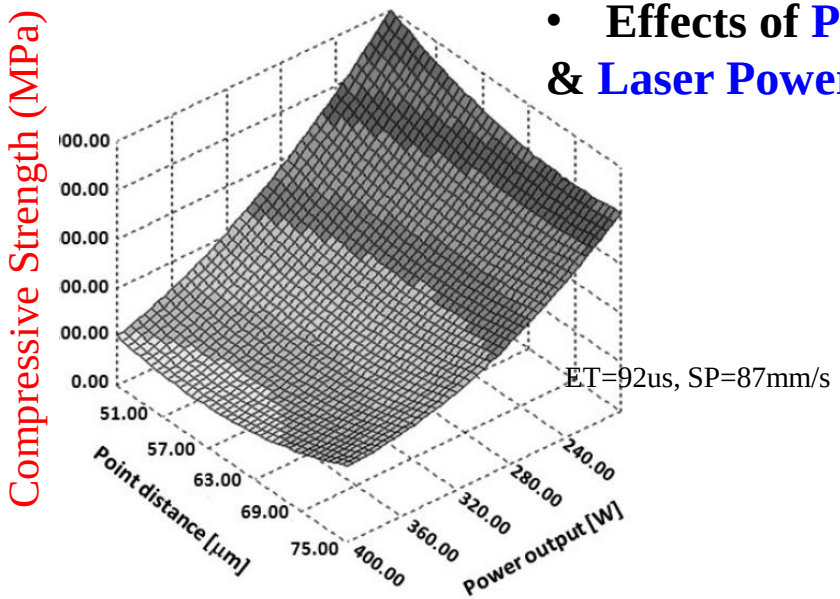
Exposure Time, length of time when laser spots in one point



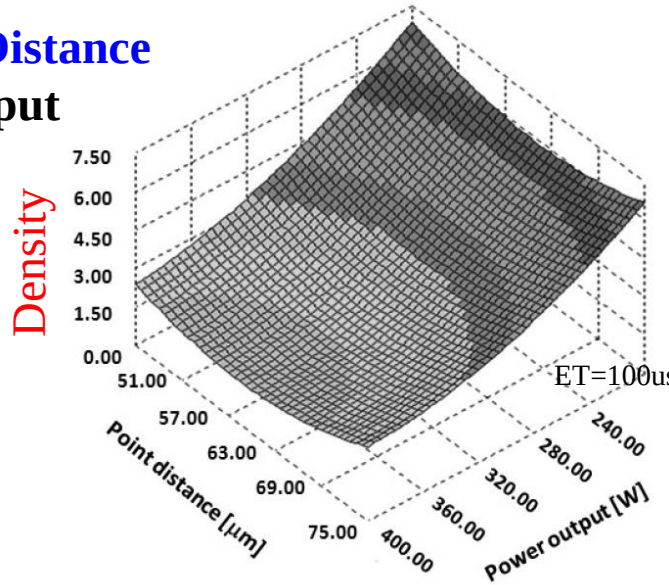
Point Distance, distance between laser spots



- **Effects of Point Distance & Laser Power Output**



ET=92us, SP=87mm/s

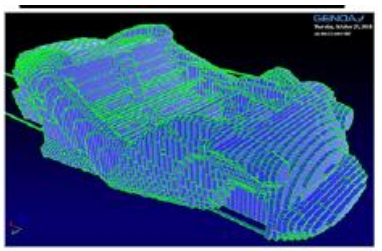


ET=100us, SP=84.5mm/s

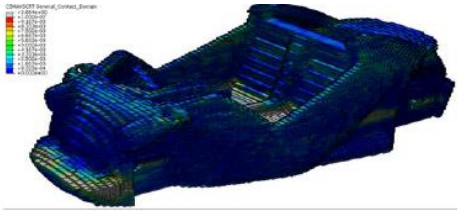
A. Stwora, G. Skrabalak, Influence of selected parameters of Selective Laser Sintering process on properties of sintered materials, Journal of Achievements in Materials and Manufacturing Engineering 61/2 (2013) 375-380.

Research Areas to improve 3D printing

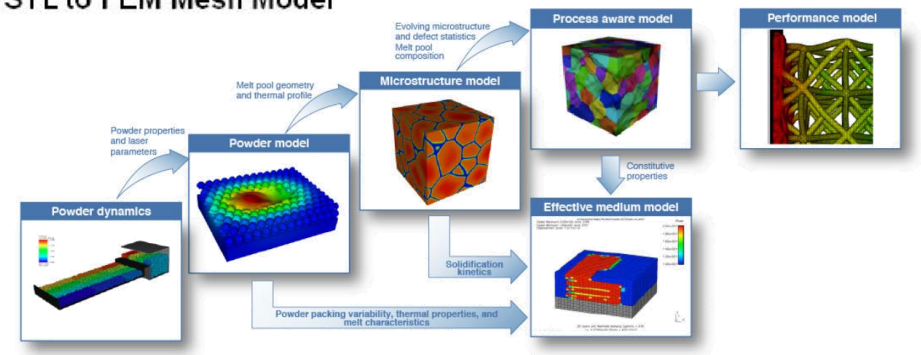
- **Need to develop Models for predicting the KPI in terms of Process Parameters**
- **Optimization of process parameters**: raster angles and gaps; laser power, scanning speed, exposure time, point distance, etc
  - Thermal-chemical-mechanical simulation of material melting and cooling process
  - Measurement 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

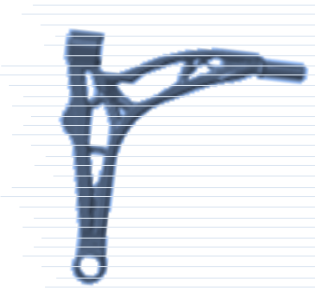


STL to FEM Mesh Model



Delamination initiation and damage contour plot





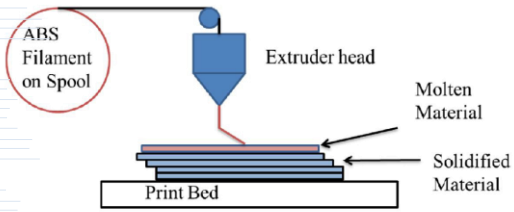
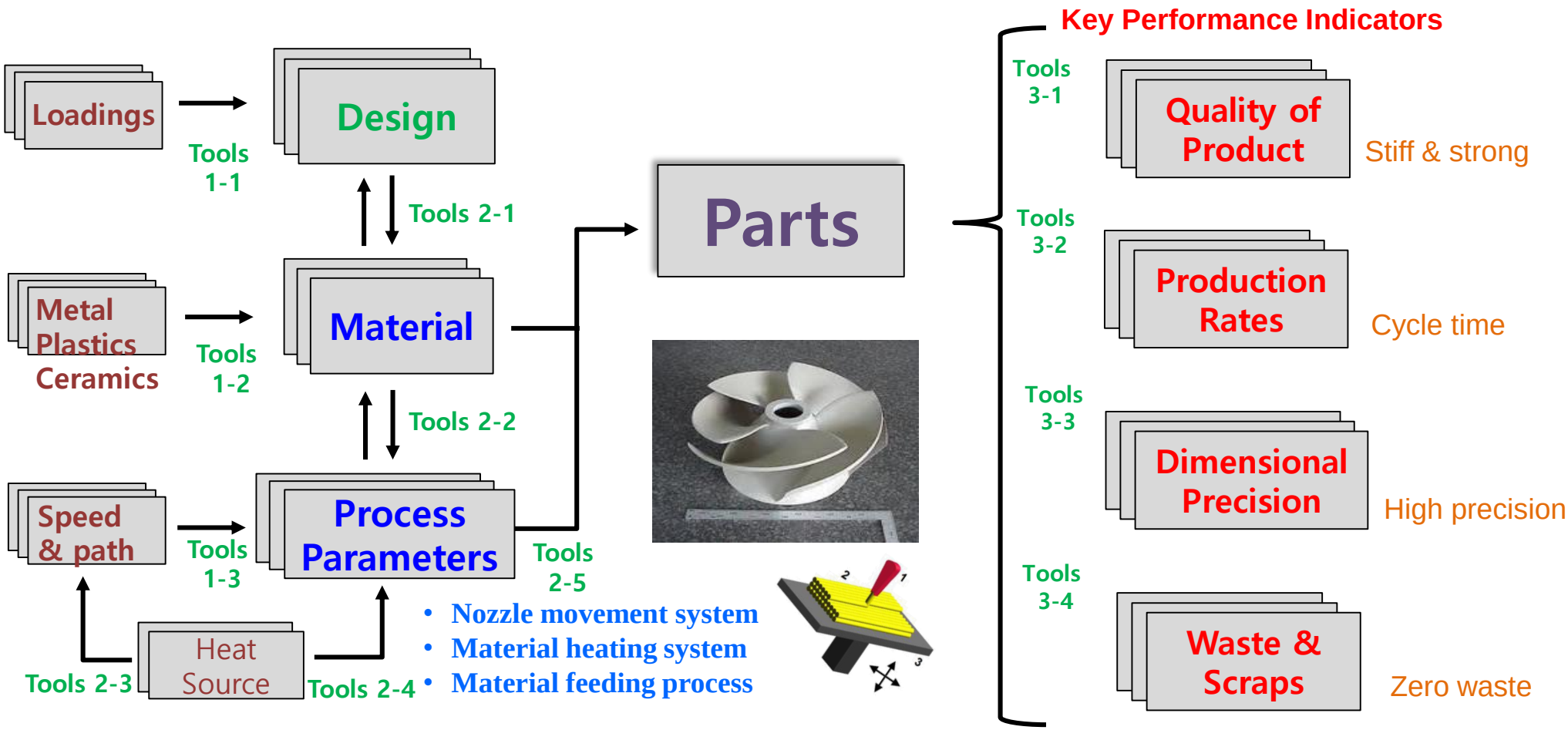


Figure 2: FDM-3D Printing Process

CONCLUSION: Integrated Processes to Achieve the best KPI

Design, Material & Process Parameters → Simulation Tools → KPI

Balance Process parameters To achieve the best KPI



- **Integration of Design and Process Parameters** Severity X Occurrence X Detection = RPN (Risk Priority Number)

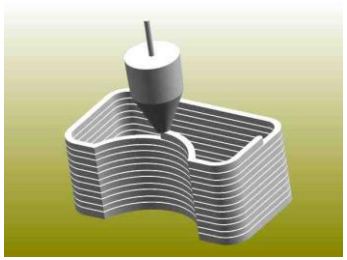
Composites for 3D-printing

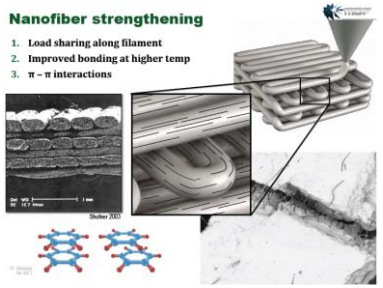
❖ To enhance material properties of 3D printing:
Develop a 3D printing of continuous-fiber composites

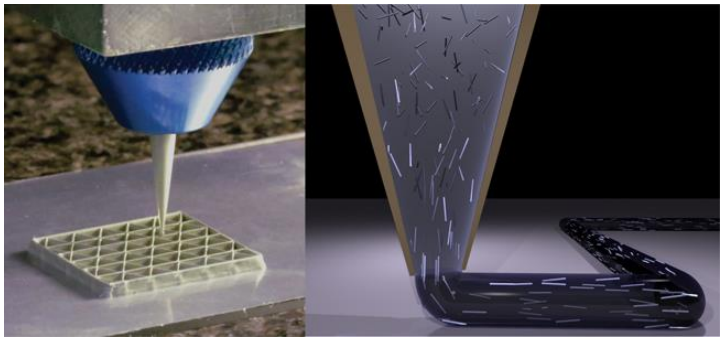
✓ Plastics

- Nanocomposites
- Short fibers
- Long fibers
- Continuous fiber

Nano fiber strengthen







- 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