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OMICS Group has organized 500 conferences, workshops and national symposiums across the major cities including San Francisco, Las Vegas, San Antonio, Omaha, Orlando, Raleigh, Santa Clara, Chicago, Philadelphia, Baltimore, United Kingdom, Valencia, Dubai, Beijing, Hyderabad, Bengaluru and Mumbai.

Effect of Individual Input Parameters on Development of Imperfections during Selective Laser Melting

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OUTLINE

- Motivation and Objective
- Methodology
- Results and Analysis
- Contributions/Concluding Remarks

Additive Manufacturing/3D Printing of Metals

- Additive Manufacturing (AM) –
  - a method of manufacturing that is represented by adding material to form a finished part usually through layered deposition

- Selective Laser Melting (SLM) –
  - a layered AM method in which a laser selectively heats a path on a 2D analog layer of powder, with subsequent layers forming a 3D object

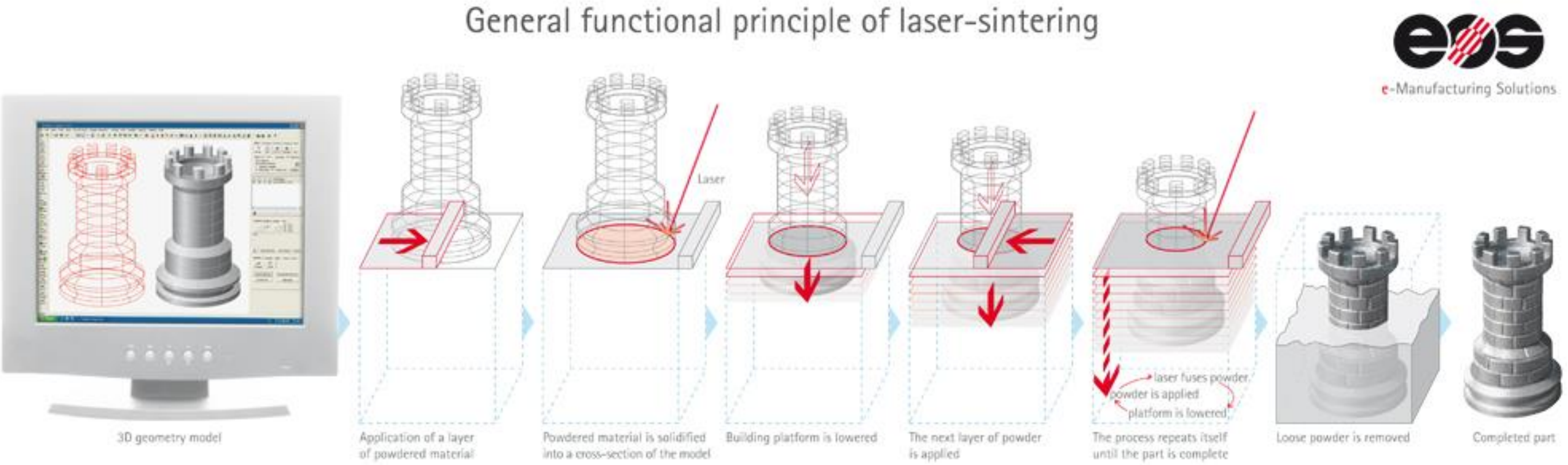


Fig. 1.1 - http://www.eos.info/additive_manufacturing/for_technology_interested

Adjustable Parameters

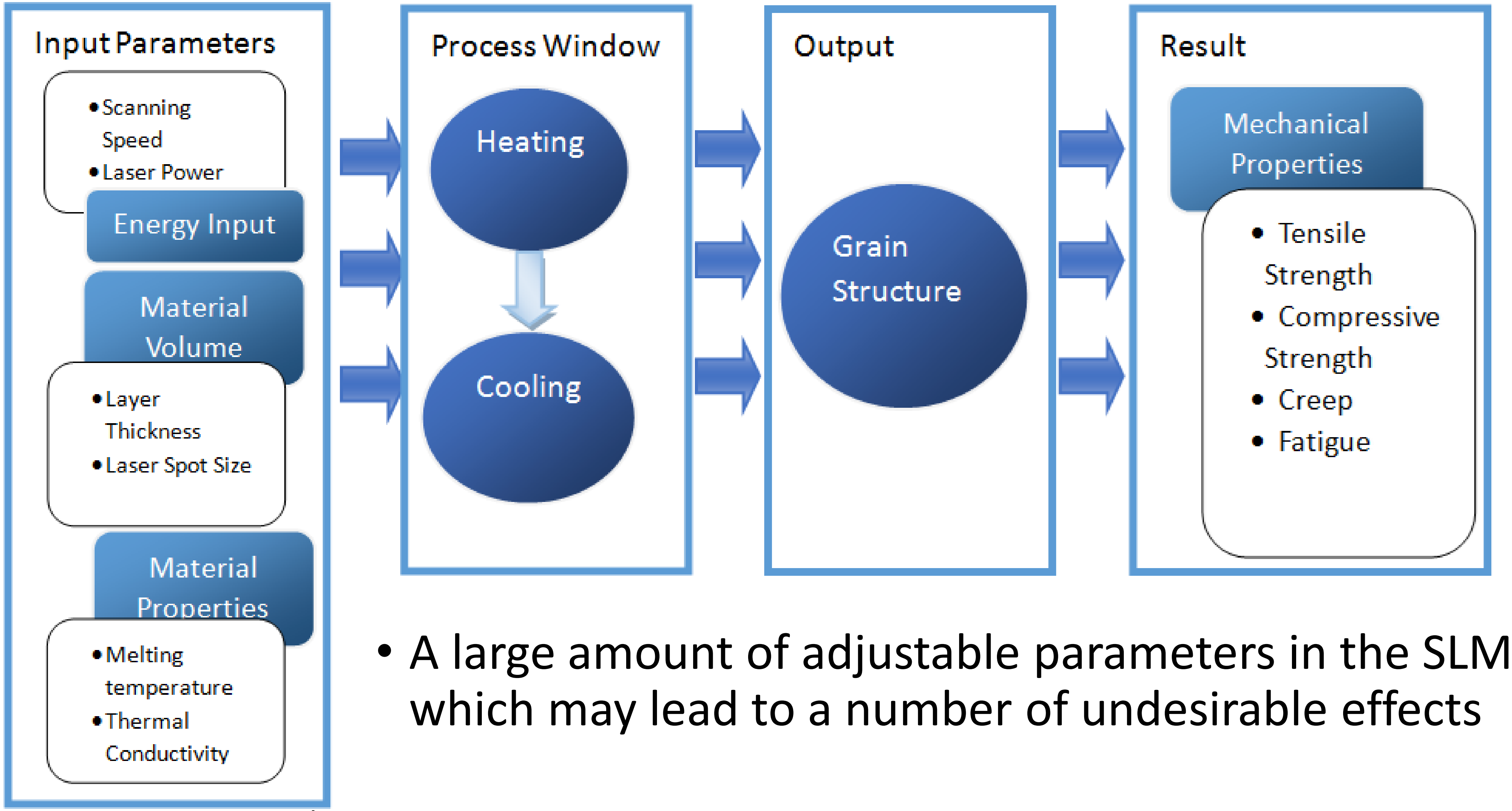
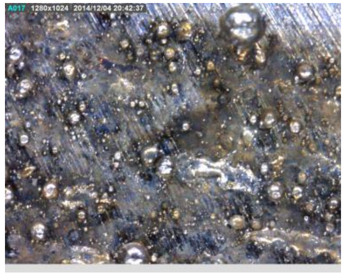


Figure 1.3. Process window

- A large amount of adjustable parameters in the SLM process which may lead to a number of undesirable effects

Possible Artifacts in the SLM Process

- **Relating to the successful manufacturing of components**
  - **Improper melting**
  - **Balling of molten metals**
  - **Surface Oxidation**



- Materials Aspect*
  - Anisotropy of properties
  - Poor ductility
  - Poor fatigue and fracture performance
  - etc.

OBJECTIVE

- **To de-convolute the effect each adjustable parameters on the formation of manufacturing relating parameters during the 3D printing of metals using SLM**

- Parameters of focus in this presentation:
  - Hatch Spacing
  - Scanning Speed
  - Laser Power
  - Laser Spot size - Fixed
  - Layer Thickness - Fixed

Focused on the parameters that are related to the Energy input

Methodology

- Attempt to de-convolute the effect of individual parameters using an ANOVA analysis

- To simplify matter, analysis was done based on the printing of 1 layer of powder

		Val 1	Val 2	Val 3
P1	Laser Power [W]	70	100	130
P2	Hatch Spacing [µm]	50	100	150
P3	Scanning Speed [m/min]	2	6	10
	Layer Thickness [µm]	100	100	100

Powder Material used:
304L SS – "-270" Mesh size

- Minimized the # of experiments using one of the Taguchi Methods
  - to optimize the effect of 3 parameters on 3 possible artifacts

Methodology – Quantification of Artifacts

- Measurements of artifacts are done using image analysis based on visible light (optical) microscopy

- Quantifying the artifacts present:
  - **Improper melting**: Measurement of area fraction with no observable deposition on the surface.
  - **Surface oxidation**: Measurement of surface area of the deposited metal or substrate covered in surface oxidation as percentage of full sample area
  - **Balling of molten metal**: Counting the frequency of spherical object observed on the sample surface.

ANOVA Analysis

Proper Melting (more is better)

Level	Power	Hatch	Speed
1	12.25	48.76	15.69
2	16.06	19.19	5.33
3	70.00	36.76	8.67
Mean	32.77	34.90	9.90
Sum of Sq	6258.90	1326.63	167.77
%Contr	**80.73**	**17.11**	**2.16**

Oxidation (Less is better)

Level	Power	Hatch	Speed
1	69.92	76.70	81.33
2	65.97	85.62	1.89
3	77.22	79.34	73.37
Mean	71.04	80.55	52.20
Sum of Sq	195.58	125.90	11484.88
%Contr	**1.66**	**1.07**	**97.28**

Balling (Less is better)

Level	Power	Hatch	Speed
1	6.33	0.67	3.00
2	9.00	15.50	5.33
3	1.67	6.00	8.67
Mean	5.67	7.39	5.67
Sum of Sq	82.67	338.72	48.67
%Contr	**17.59**	**72.06**	**10.35**

Averages, Variance, and Signal Noise

Melting SN	Oxidation SN	Balling SN
334.35	331.53	327.63
Average	Average	Average
32.77	71.04	5.67
Variance	Variance	Variance
0.00	0.00	0.00

Summary of ANOVA Analysis

	Contribution[%]		
Characteristic\Input Parameter	Power	Hatch Spacing	Scanning Speed
Melting area (More is Better)	**80.7**	17.1	2.2
Oxidation (Lesser is Better)	1.7	1.1	**97.2**
Balling (Lesser is Better)	17.6	**72.0**	10.4

- The trend seems to be that:
  - **Increasing Laser power improves proper melting**
  - **Increasing scanning speed reduces oxidation**
  - **Increasing hatch spacing can reduce balling**

- There are dominating parameters for each artifact, but there are still other contributions

VOLUMETRIC ENERGY DENSITY

- Since there remains some convolution of the effect of the parameters, seems like using **volumetric energy density** may be a better criterion to minimize artifacts

$$\epsilon = \frac{P}{vhd} \quad \left[\frac{J}{mm^3}\right]$$

P is the laser power used,
V is the scanning speed,
H is the hatch spacing, and
d is the layer thickness

- There exist an optimal range for each materials
  - For the present 304L, it is $\sim 240 \frac{J}{mm^3}$

Concluding Remarks

- **There seems to be a dominant parameters** for each of the three specific manufacturing artifacts
  - **Increasing Laser power improves proper melting**
  - **Increasing scanning speed reduces oxidation**
  - **Increasing hatch spacing can reduce balling**

- It seems that the use of ***volumetric energy density*** is a more suitable choice to minimize the appearance of artifacts in the 3D printing of metals

Thank you!

Q&A