BITS Pilani
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M.Tech
Digital Manufacturing

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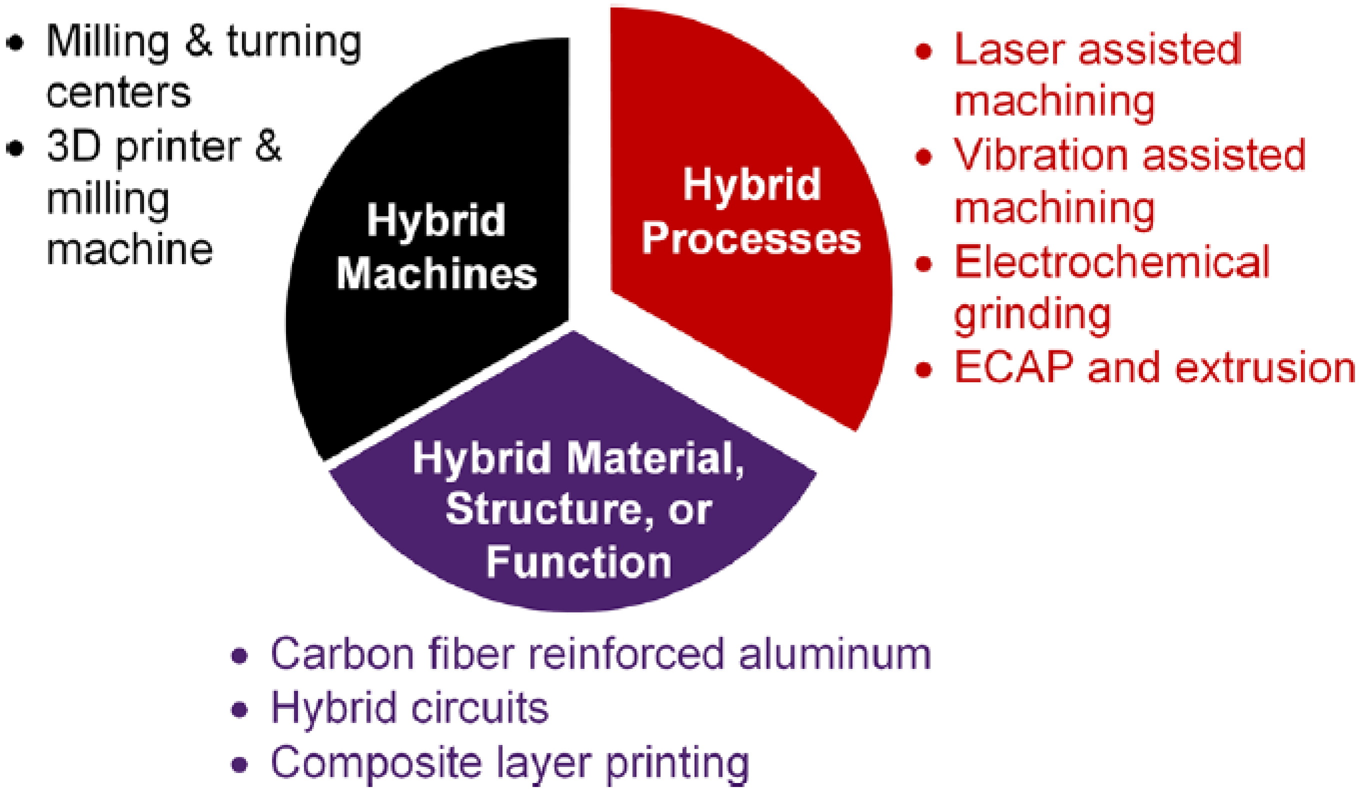
DMZG521- Design for Additive Manufacturing
Session 9 & Lecture 17-18

Todays Lecture Overview

- Hybrid Methodologies
- Hybrid Manufacturing
- Hybrid AM
- Process planning for HAM
- Challenges in HAM

Hybrid Methodologies



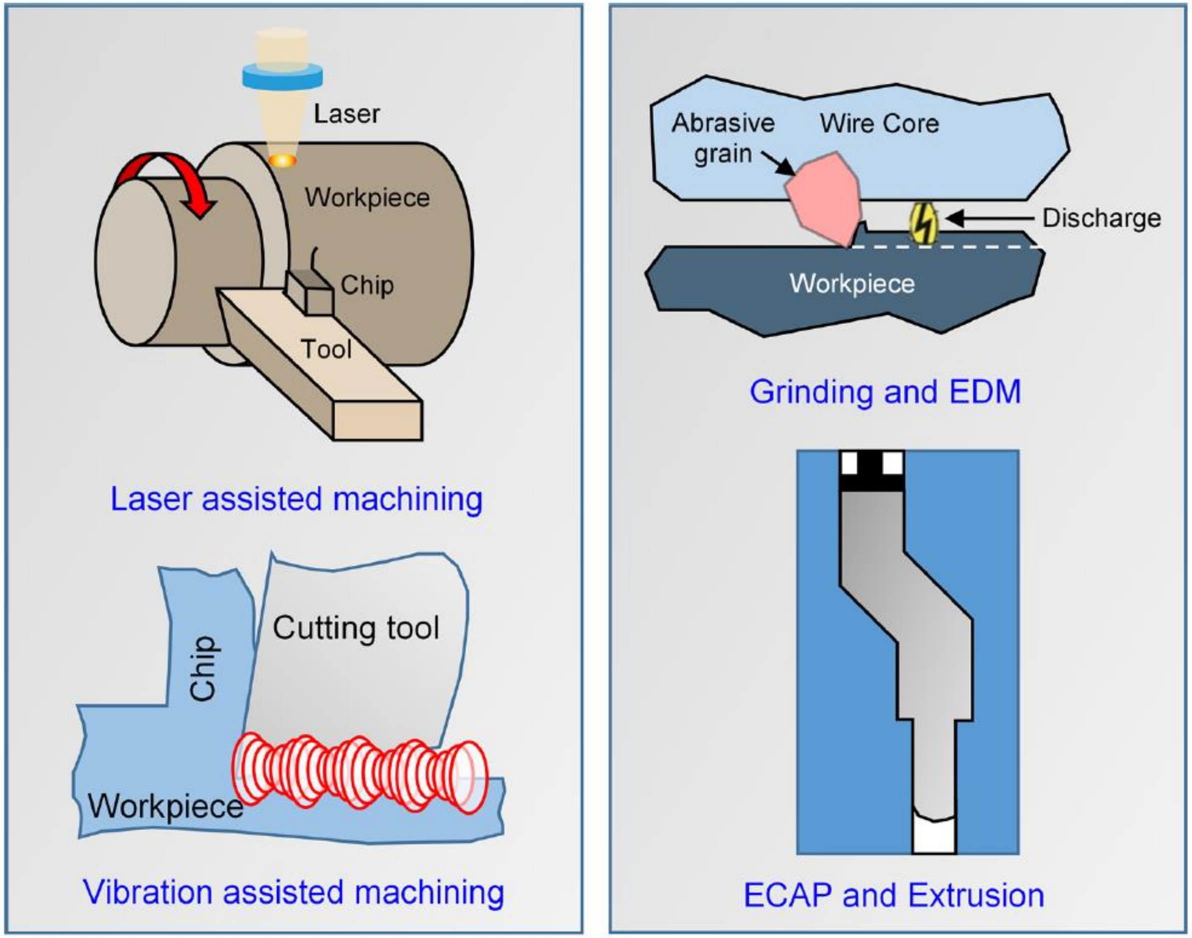
Source: Sealy, Michael P., et al. "Hybrid processes in additive manufacturing." *Journal of Manufacturing Science and Engineering* 140.6 (2018).

How Does Hybrid Manufacturing Work?

- One of the most common methods of hybrid manufacturing is to apply additive and subtractive processes in sequence.
- It is also typically possible to alternate between additive and subtractive in-process.

This scaled-down turbine casing made on DMG MORI's Lasertec 65 3D was built up from Inconel 718 and bronze, and then machined only where necessary.

HM Processes



Source: Sealy, Michael P., et al. "Hybrid processes in additive manufacturing." *Journal of Manufacturing Science and Engineering* 140.6 (2018).

Hybrid Additive Manufacturing

- Combination of subtractive and additive manufacturing
- Hybrid systems most often consist of a machine tool such as a mill or lathe, or a robot arm, that is equipped with a directed energy deposition (DED) head for depositing metal powder or wire

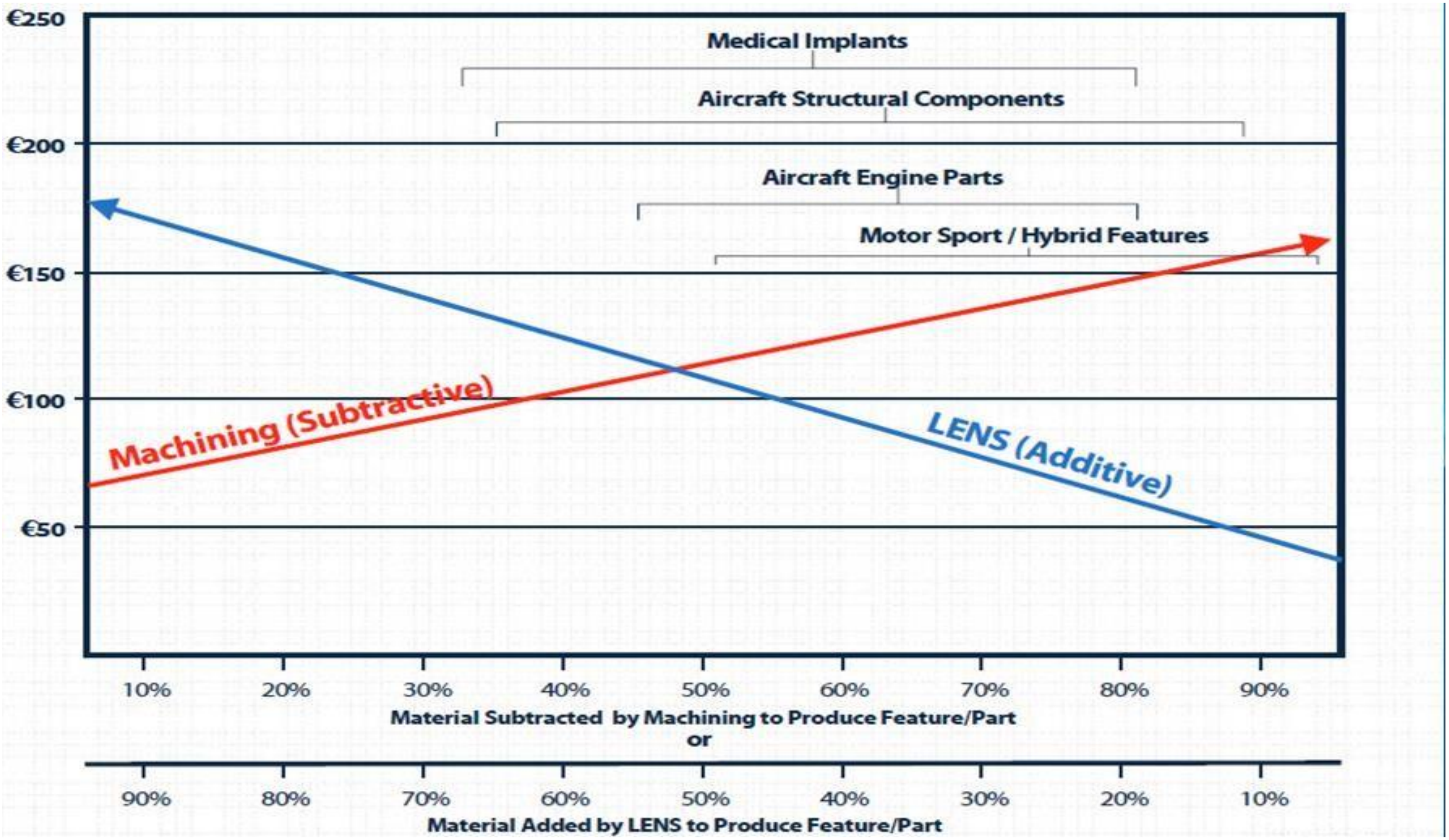
Hybrid Additive Manufacturing	=	**Additive Manufacturing (AM)**	+	**Subtractive Manufacturing (SM)**

Additive

+

Subtractive

Why do we go for Hybrid Manufacturing?



Why HAM?

CNC Machining

- High Productivity (+)
- Good surface finish (+)
- High accuracy (+)
- Repeatability (+)
- Waste material (-)
- Tooling required (-)

Additive Manufacturing

- Less material wastage (+)
- Customization (+)
- Geometrical freedom (+)
- Less accuracy (-)
- Low productivity (-)
- Poor surface finish

Hybrid Additive Manufacturing

- Customization and geometric freedom
- High productivity
- High accuracy and surface finish
- Functional material property
- Less material wastage

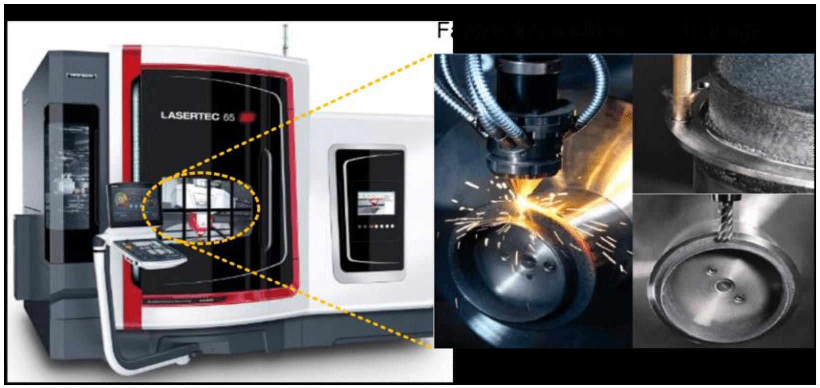
Source: Aamer Nazir and Jeng-Ywan Jeng (2019)

Material Efficiency

Buy-to-Fly ratio is the weight ratio between the raw material used for a component and the weight of the component itself.

Source: BDLI – German Aerospace Industries Association

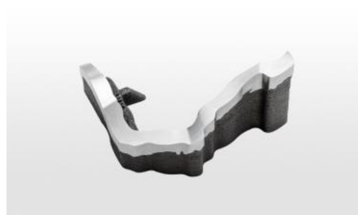
Quality



Blade – Aerospace

Cooled injection – Die & mould

Distribution tube – Aerospace



Cutting knife– Automotive

Drill bit – Oil & gas

Turbine housing – Aerospace

Source: DMG MORI

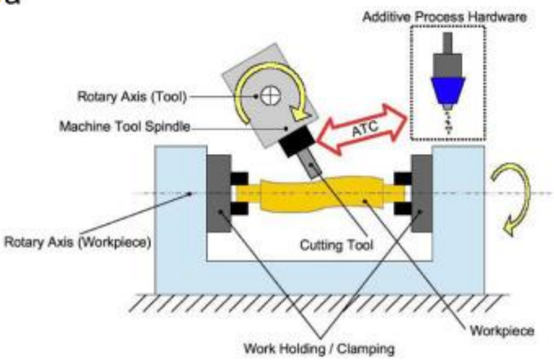
Classification of hybrid-AM machining processes

	AM Process category	Material feedstock	Types of material	Material distribution
Laser				
Laser Welding + Machining	DED	Powder	Metal	Deposition Nozzle
Laser Cladding + Milling	DED	Powder	Metal	Deposition Nozzle
Laser Deposition + Milling	DED	Powder	Metal	Deposition Nozzle
Selective Laser Sintering + Milling	PBF	Powder	Metal	Powder Bed
Plasma Arc				
3D Welding + Milling	DED	Wire	Metal	Deposition Nozzle
Plasma Deposition + Milling	DED	Powder	Metal	Deposition Nozzle
Microcasting + Milling + Shot Peening	DED	Powder	Metal	Deposition Nozzle
Solid State Fusion				
Ultrasonic Welding + Milling	Sheet Lamination	Sheet	Metal	Sheet Stock
Layered Compaction Manufacturing + Milling + Sintering	PBF	Powder	Ceramic	High Density Green Compact

DED- Direct Energy Deposition, PBF- Powder Bed Fusion

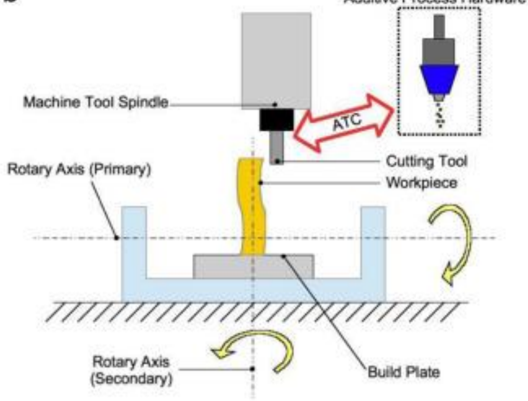
Machine tool configuration in HAM

a



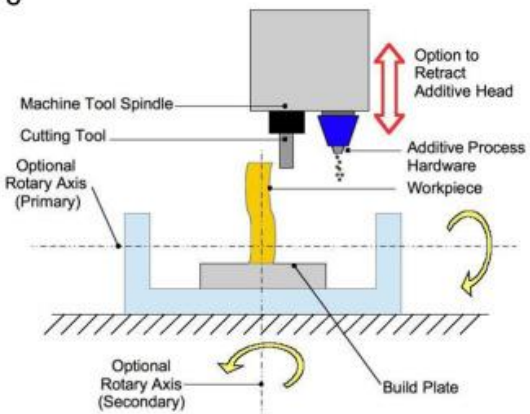
Turn-Mill

b



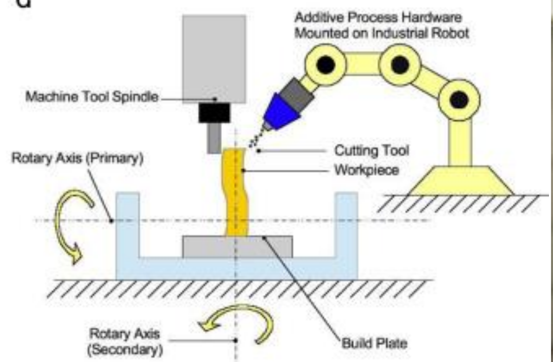
5-Axis with ATC

c



3/5-Axis with Permanent Mounting

d



3/5-Axis with Industrial Robot

Source: Flynn et. al (2015) & Hybrid Manufacturing technologies

Commercial HAM

- **<u>DMG MORI</u>**
  (i) LASERTEC 65 3D hybrid
  (ii) LASERTEC 4300 3D hybrid

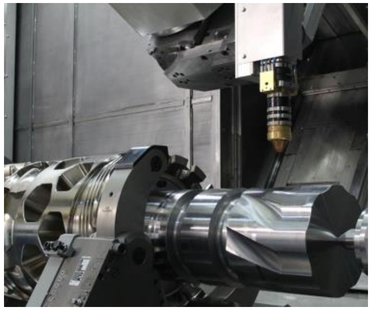
- **<u>MAZAK</u>**
  (i) INTEGREX i-400 AM
  (ii) VC-500 AM
  (iii) INTEGREX i-200S AM
  (iv) INTEGREX i-300S AM
  (v) VARIAXIS j-600/5X AM

Source: DMG MORI, MAZAK

Commercial HAM

- **<u>OKUMA + TRUMPF</u>**
  (i) LASER EX series
  (ii) MU – V LASER EX
  (iii) MULTUS U LASER EX

- **<u>WFL – WORLDWIDE MANUFACTURER</u>**
  M80 MILLTURN



Source: OKUMA, TRUMPF, WFL

Commercial HAM

- **<u>HERMLE</u>**

- **<u>MITSUI SEIKI</u>**
  (I) VERTEX 55X - H

Source: HERMLE, MITSUI SEIKI

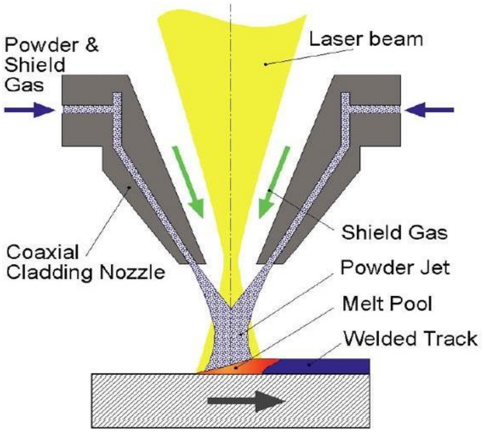
Sodick OPM250ML

Technical Specification	
Max size of molding object (W x D x H)	250×250×250mm
X axis stroke	260mm
Y axis stroke	260mm
U axis stroke	260mm
Molding tank inner dimensions (W x D)	290×290mm
Spindle Z-axis stroke	100mm
Max powder supply weight	90kg (Maraging steel)
Nitrogen supply capacity	32NL/min
Machine dimensions (Peripheral equipment not included)	1870×2230×2055mm
Machine weight (Peripheral equipment not included)	4500kg
Laser method	Yb fiber laser
Laser wavelength	1070nm
Max laser output	500W
Laser scan	Galvano method
Max main spindle rotation speed	45000min-1
Max main spindle torque	0.8Nm
Number of tools	0.8Nm
Number of tools	16
Tool holder method	Dual face contact holder HSK-E25

https://www.sodick.org/products/additive-manufacturing/opm250l.html

AM processes

1. Vat photo polymerization
2. Material jetting
3. Binder jetting
4. Material extrusion
5. Powder bed fusion
6. Sheet Lamination
7. Directed Energy Deposition



Schematic representation of DED

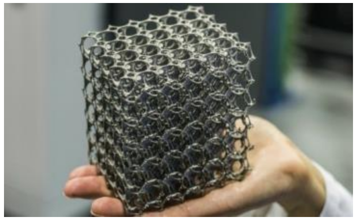
Materials Used in DED:

•Metals (Ti, Co, Cr etc.,)
•Powder or wire (Metals)

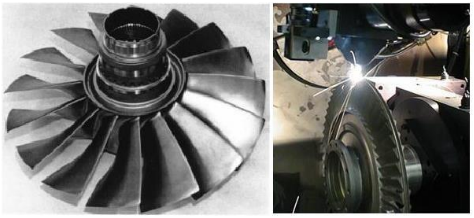
Limitations

•Accuracy, surface finish
• Difficult to process complex parts (Due to support structures)

Parts made by DED:



Source: STRATOSMITH technologies



Source: Dragonfly S.R.L

Example usage:

•Re- work of articles
•3D objects
•End use parts

DED process schematics

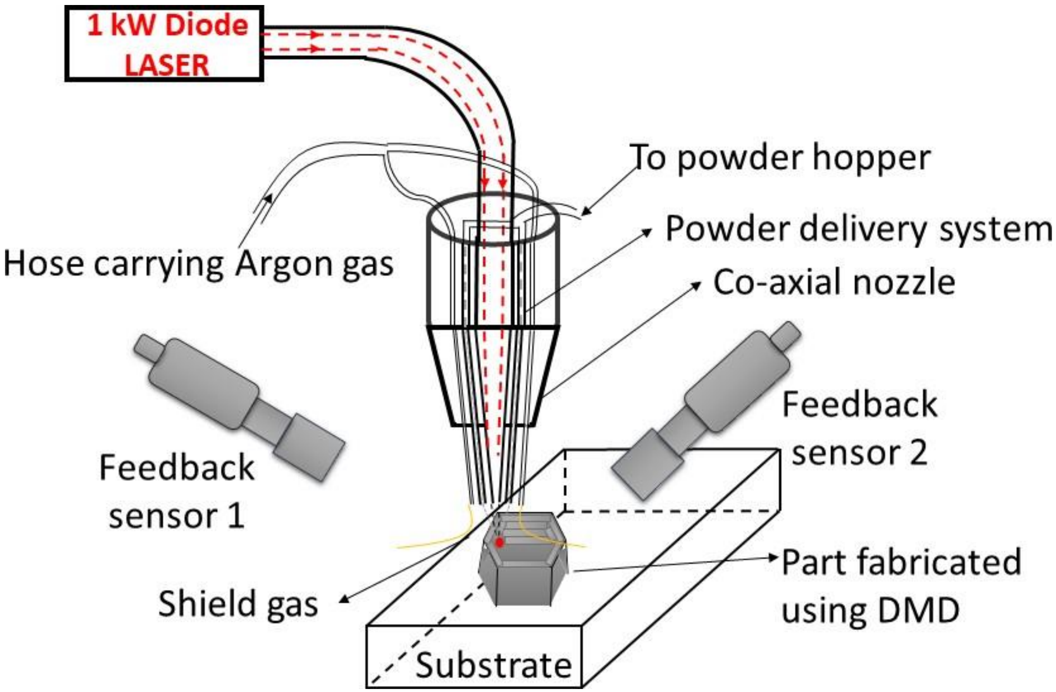


Fig. 4 Schematic representation of DMD process

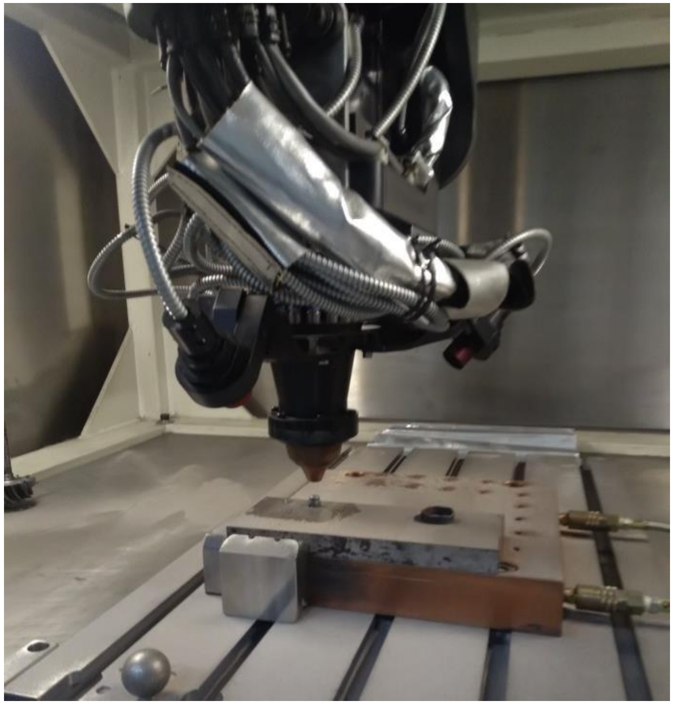
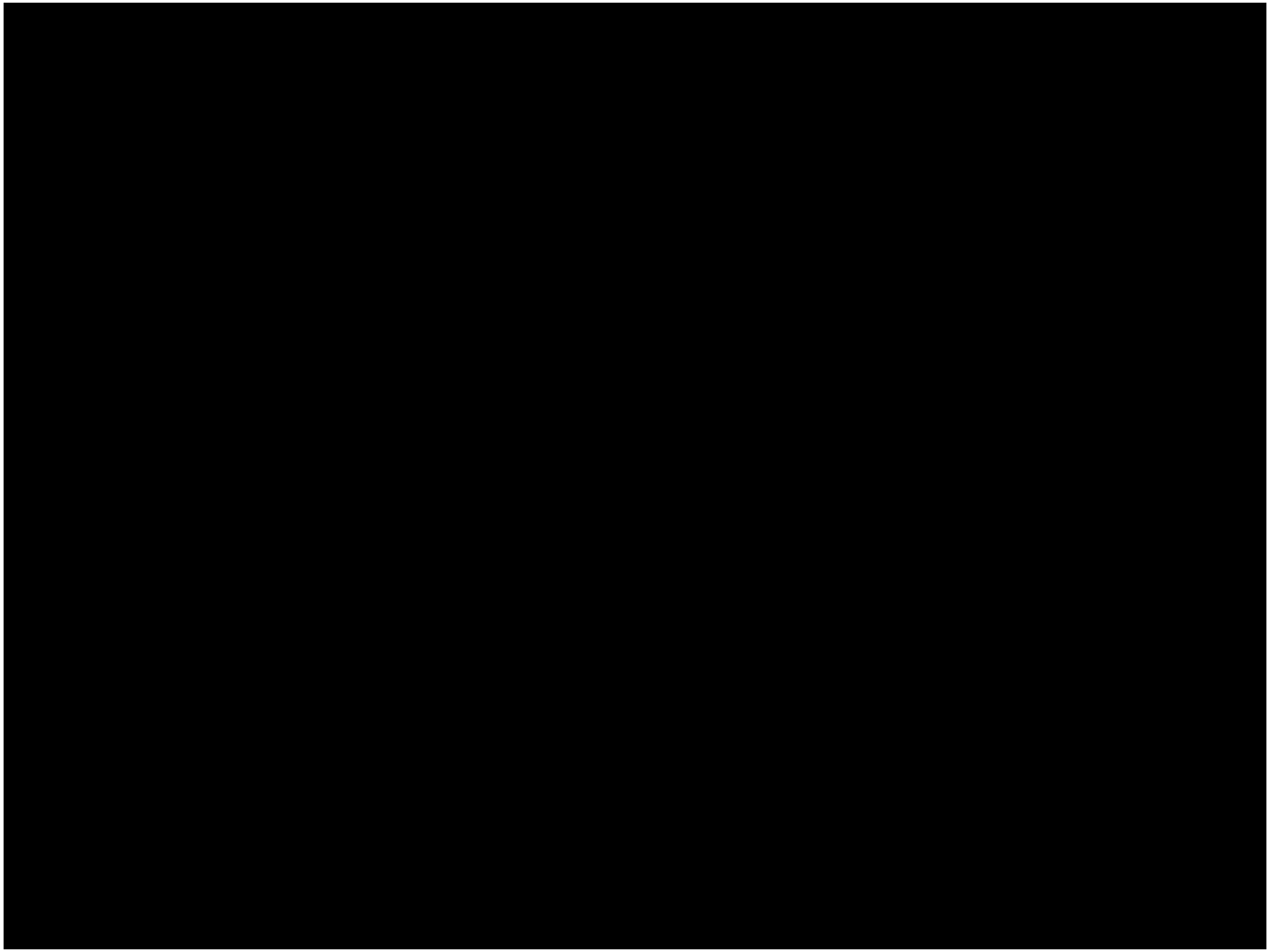
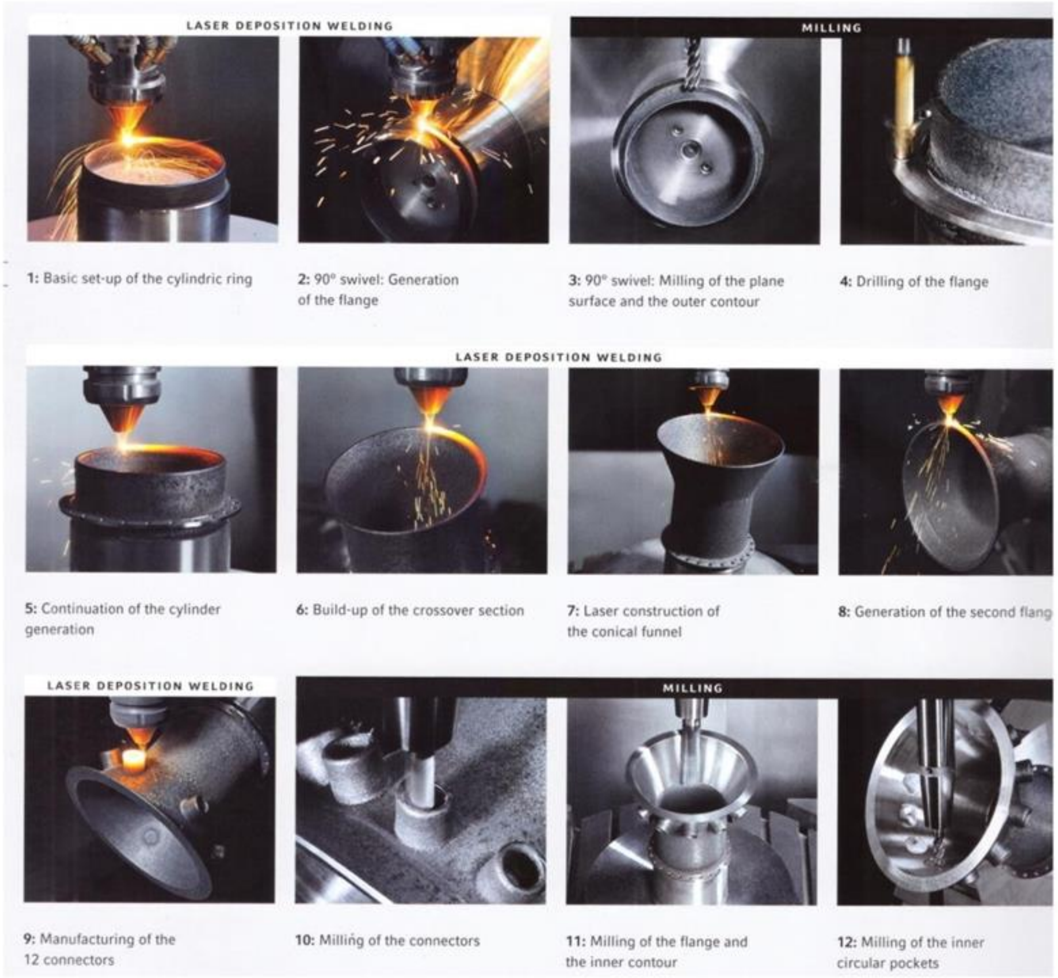


Fig. 5 Part fabrication using DMD process
(*Courtesy* : **CMTI, Bangalore**)

Video: Direct Energy Deposition



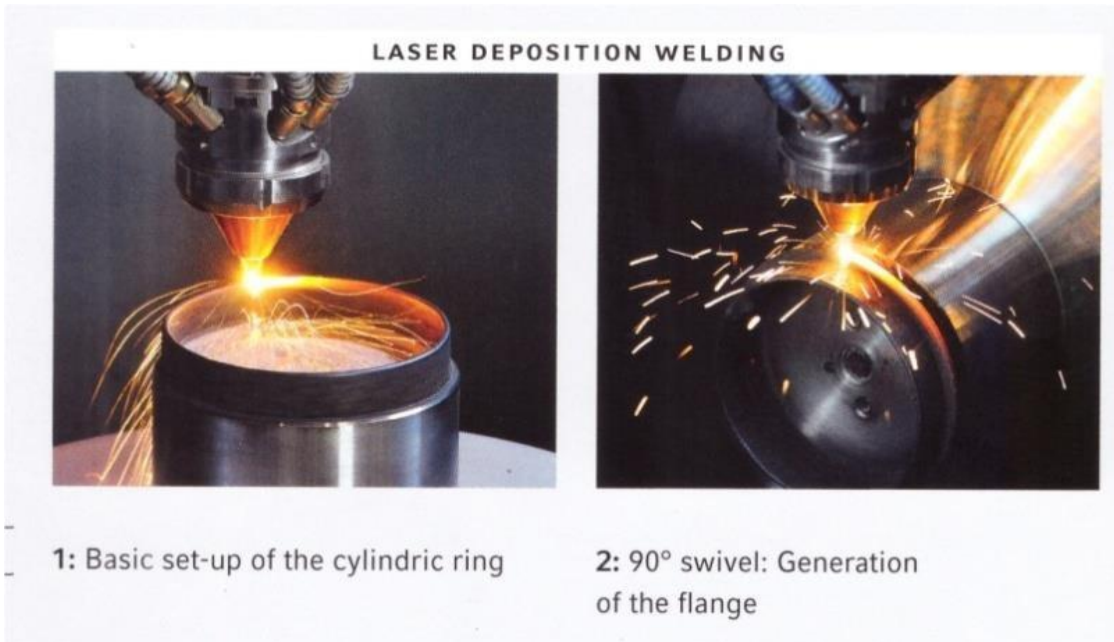
Hybrid Manufacturing Process



Hybrid Manufacturing Process (Courtesy: DMG MORI)

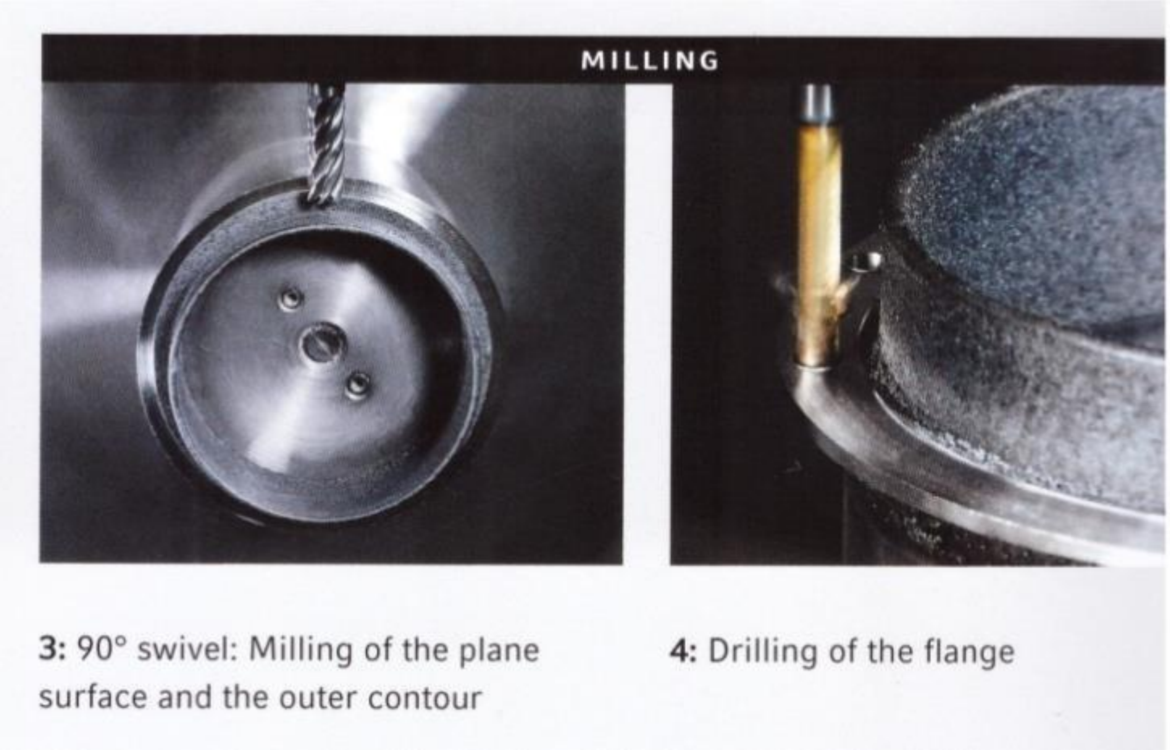
Laser deposition involving DED with milling

Laser Deposition Welding



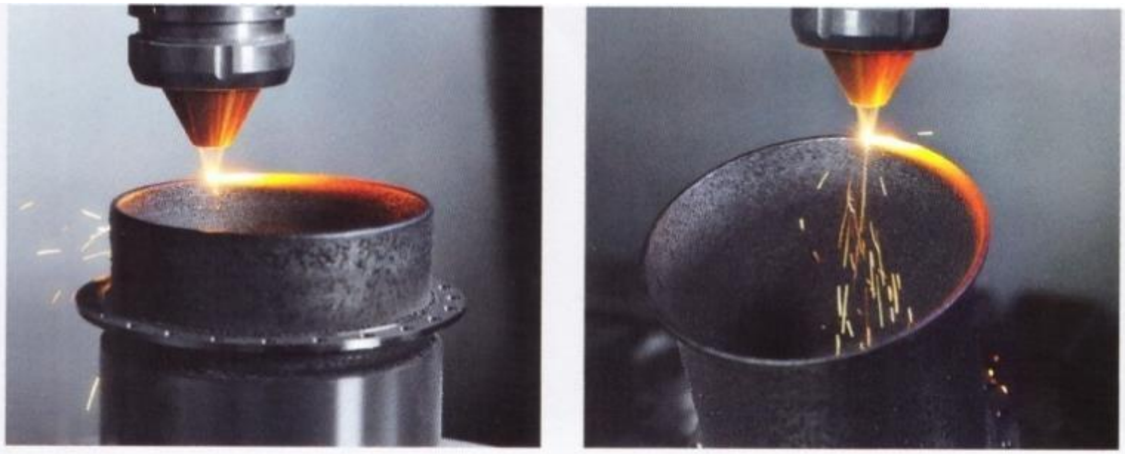
(Courtesy: DMG MORI)

Milling



(Courtesy: DMG MORI)

Laser Deposition Welding

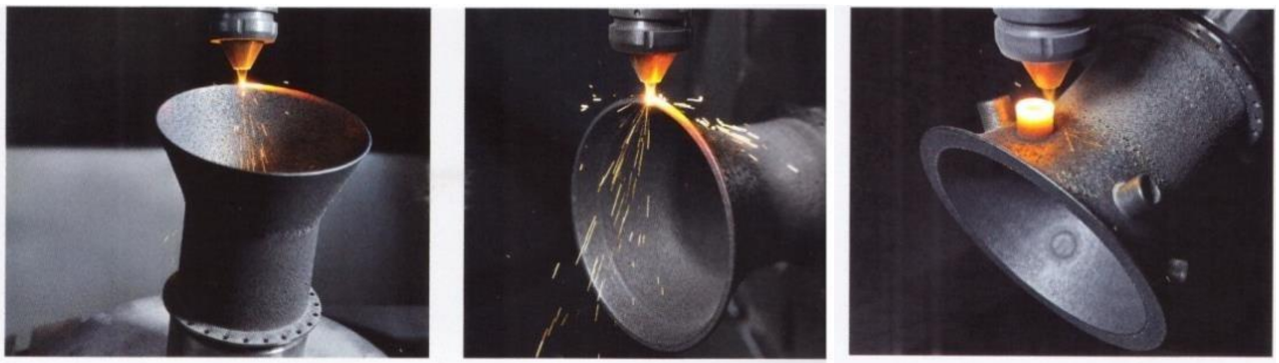


5: Continuation of the cylinder generation

6: Build-up of the crossover section

(Courtesy: DMG MORI)

Laser Deposition Welding



7: Laser construction of the conical funnel

8: Generation of the second flang

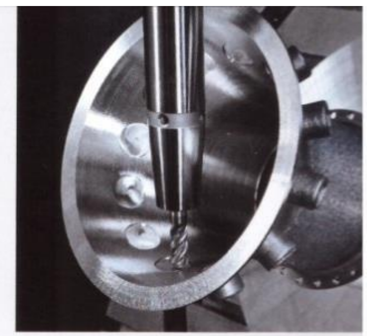
9: Manufacturing of the 12 connectors

(Courtesy: DMG MORI)

Milling

10: Milling of the connectors

11: Milling of the flange and the inner contour

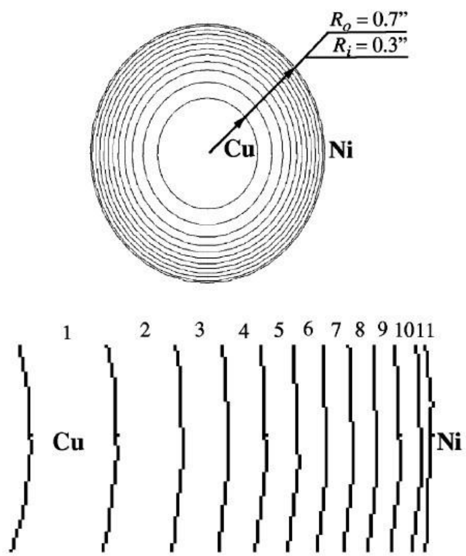


12: Milling of the inner circular pockets

(Courtesy: DMG MORI)

Material Complexity

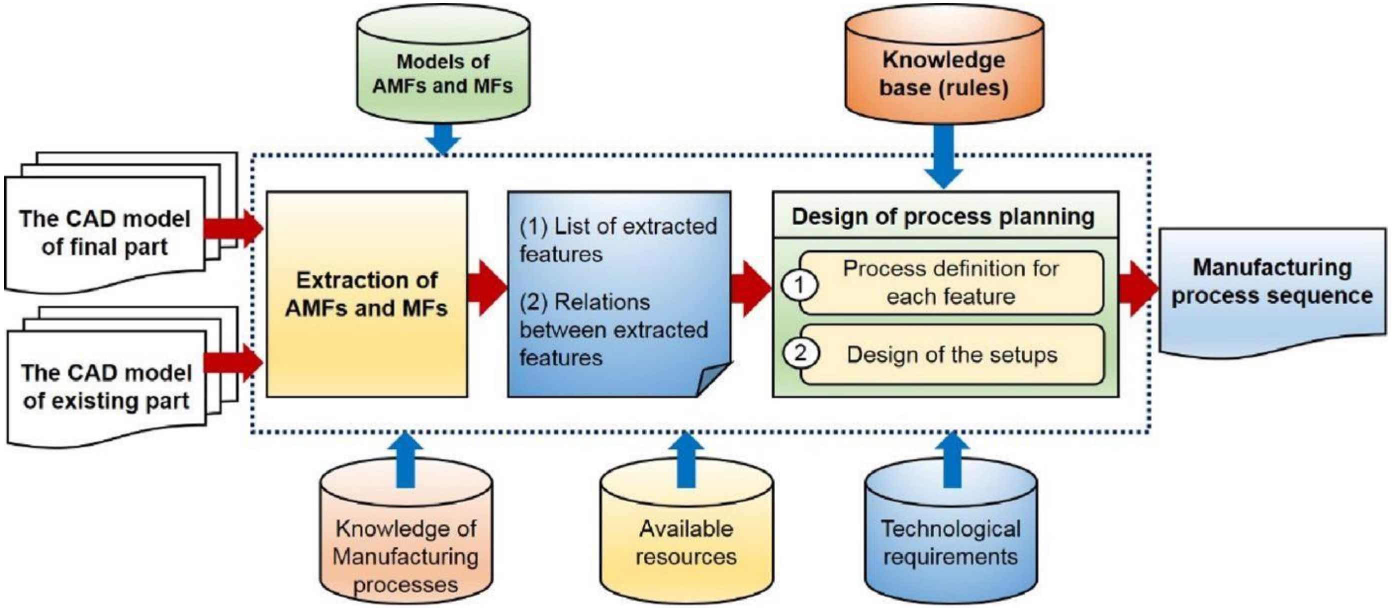
Material complexity: Material can be processed one point, or one layer, at a time as a single material or as a combination of materials



Material compostion	Radius
1: 100 % Cu	0.39"
2: 90% Cu + 10% Ni	0.45"
3: 80% Cu + 20 % Ni	0.50"
4: 70% Cu + 30% Ni	0.54"
5: 60% Cu + 40% Ni	0.57"
6: 50% Cu + 50% Ni	0.60"
7: 40% Cu + 60% Ni	0.62"
8: 30% Cu + 70% Ni	0.64"
9: 20% Cu + 80% Ni	0.66"
10: 10% Cu + 90% Ni	0.68"
11: 100% Ni	0.70"

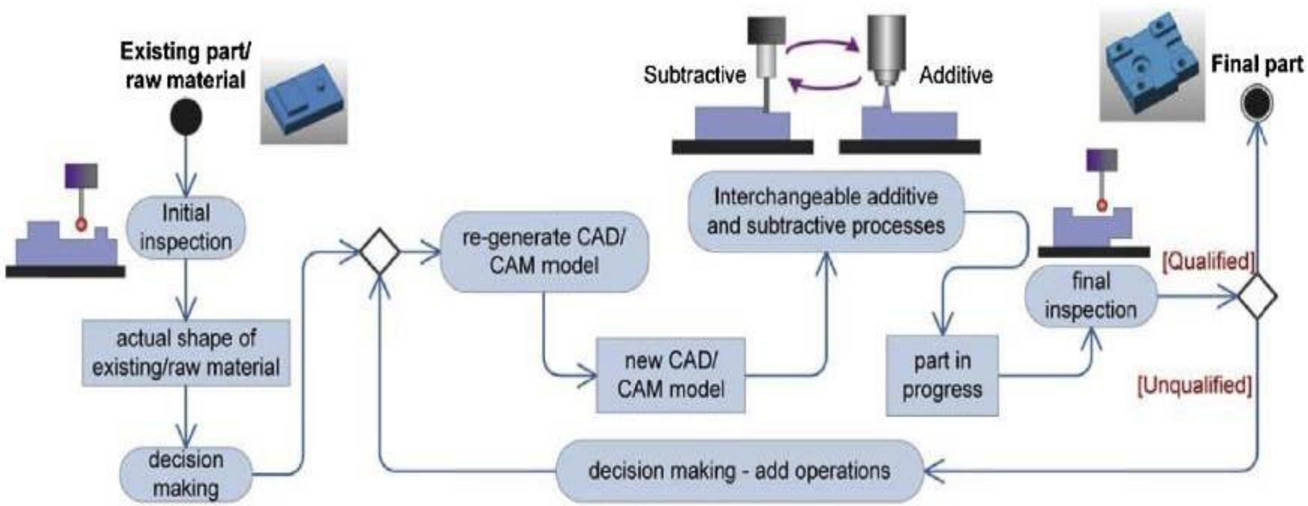
Material composition in different areas of Functionally Graded Material (Cu-Ni)

Design for AM



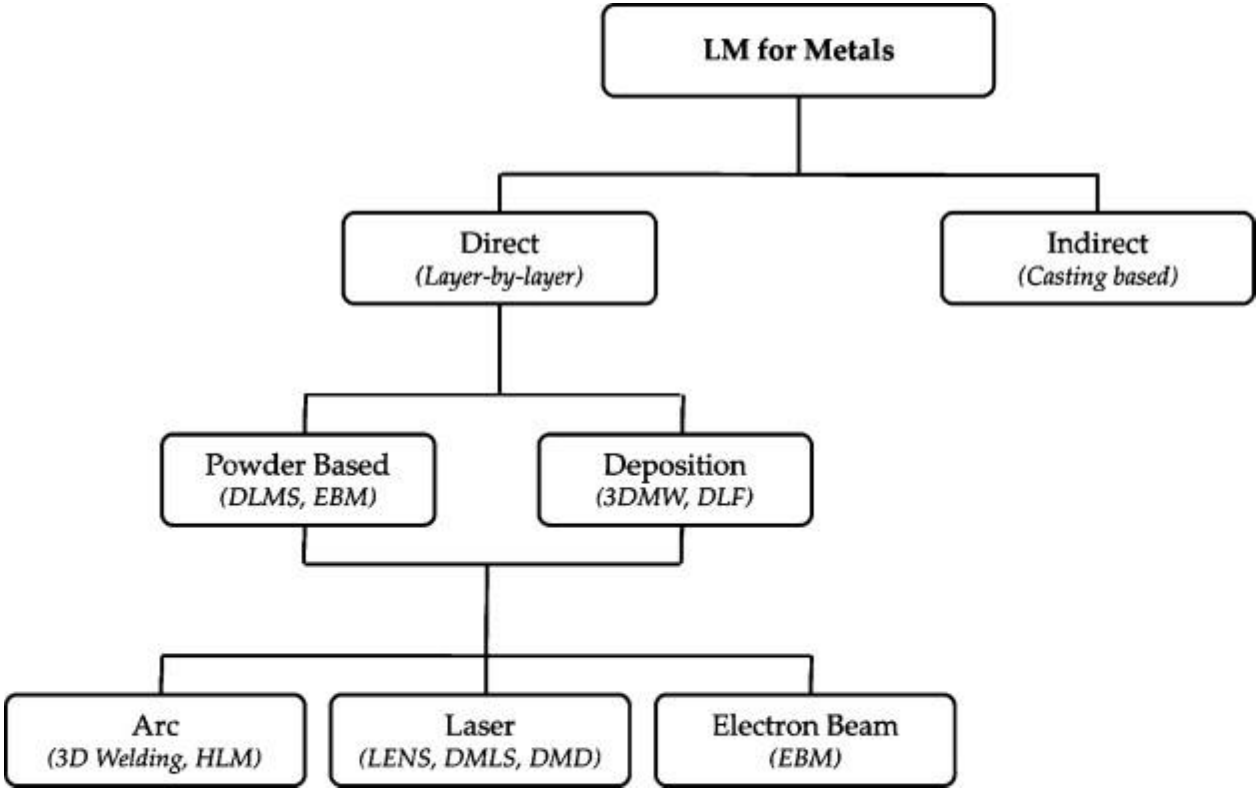
The developed methodology for the design of AM and machining process sequence *(source: Le et al. (2017))*

Process planning in Hybrid Additive Manufacturing

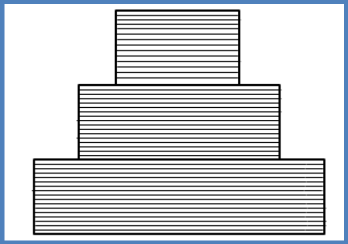
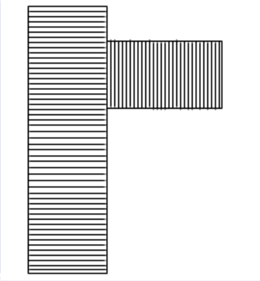
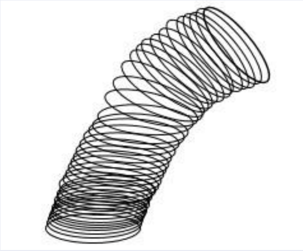


Process planning in Hybrid Additive Manufacturing *(source: Le et al. (2017))*

Layer manufacturing for metals

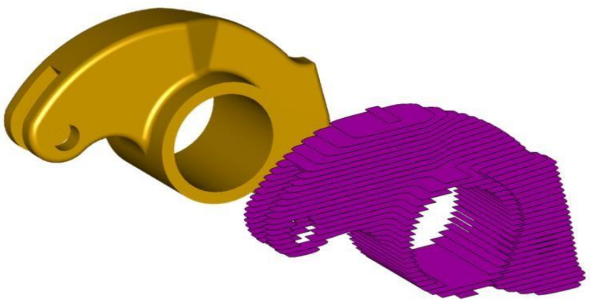


Various slicing techniques

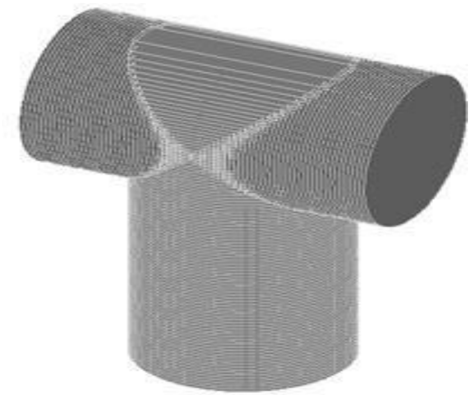
1.		**Uni-directional Slicing along Single build direction**
2.		Conformal slicing along multiple build directions
3.		Conformal slicing for continuously varying build directions

Slicing

"Process of converting the model into a series of thin layers"



Sliced model source: ITI techigroup



Multi directional slicing of overhang part [3]

Basic types of Slicing

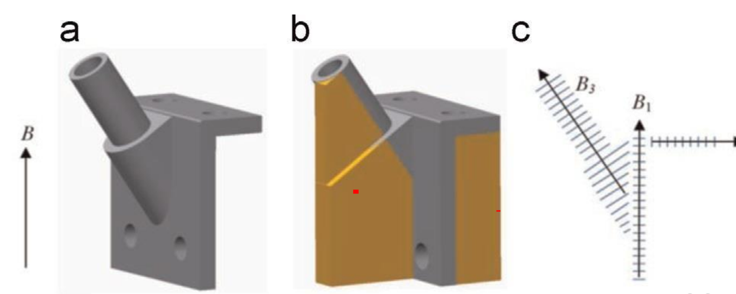
- 2.5D slicing
- Multi- directional Slicing

Factors to be consider in slicing

- Build time
- Surface quality
- Orientation of the part
- Minimum overhangs

Methods of Slicing

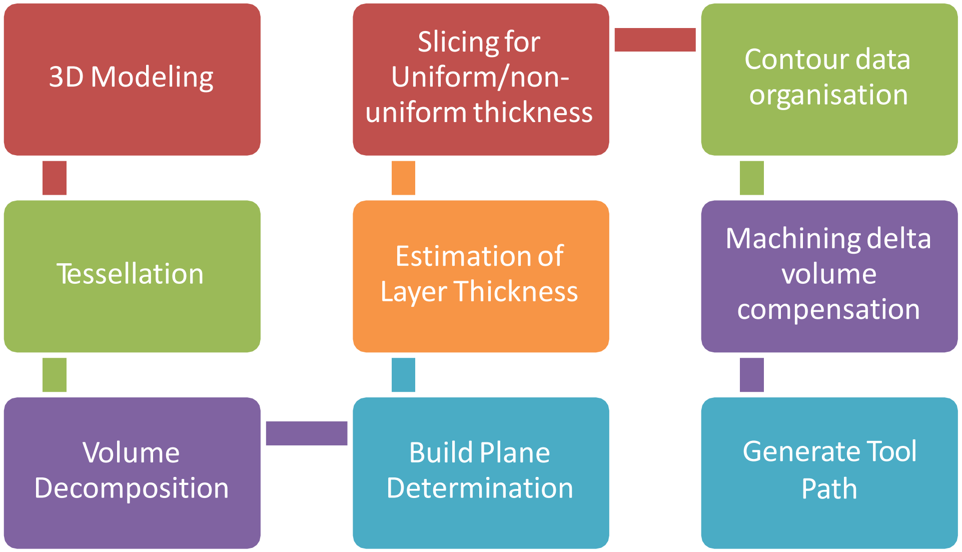
- Constant thickness slicing
- Adaptive slicing



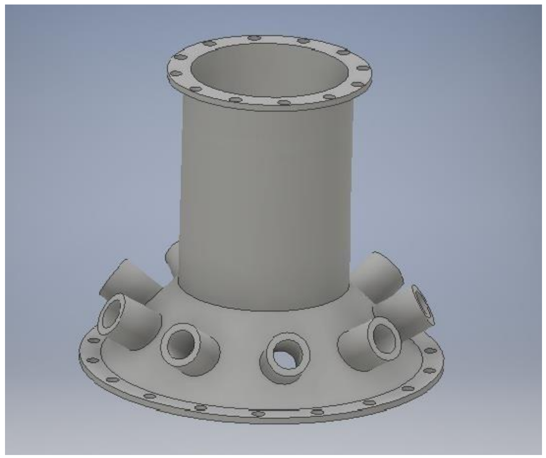
Part with different build direction with support structure[4]

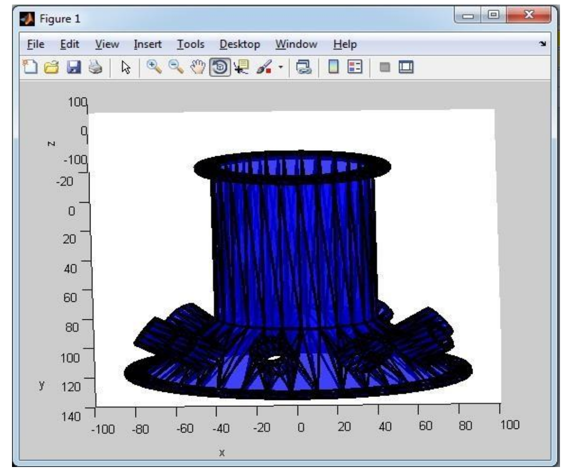
Multi-direction slicing

Developing a multi-direction slicing algorithm for hybrid additive manufacturing system, to add the material for complex geometric features is challenging"

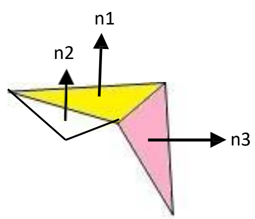


3D Modelling and Tessellation





Feature edges extraction



$$\theta = \arccos\left(n_i, n_j\right) \quad 1$$

Representation of triangular facets with different normal directions

If Θ = 0, both the triangles are in the same plane If Θ ≠ 0, it is a feature edge.

Give, $\Theta > \Theta_{threshold}$ as per the required threshold value. Threshold value is user defined.

For a given geometry two types of edges possible

1. Concave edges
2. Convex edges

Identification of concave and convex edges

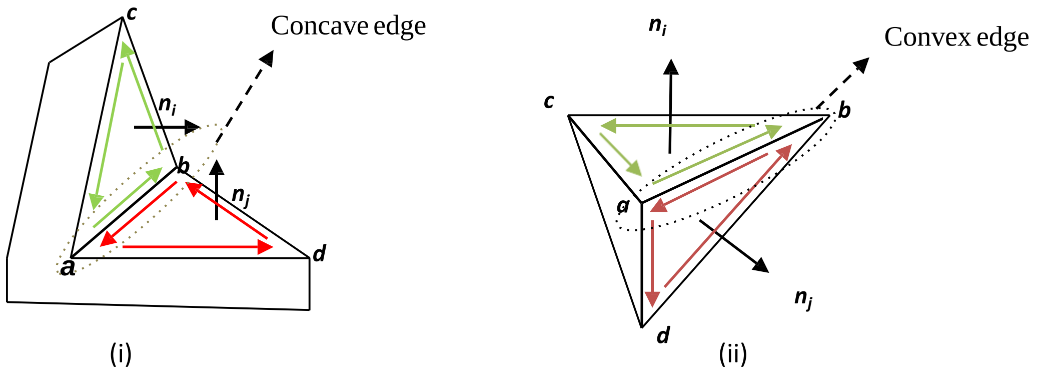


Fig. (i) Concave edge, (ii) Convex edge representation

$$\emptyset_{ab} = (n_i \times n_j).\overrightarrow{ab} \longrightarrow (2)$$

From the fig the value of ø represents the type of the edge it belongs to.

If $ø_{ab} > 0$, the edge represented is a concave edge. If $ø_{ab} < 0$, the edge represented is a convex edge.

Illustration

Illustration with a model geometry

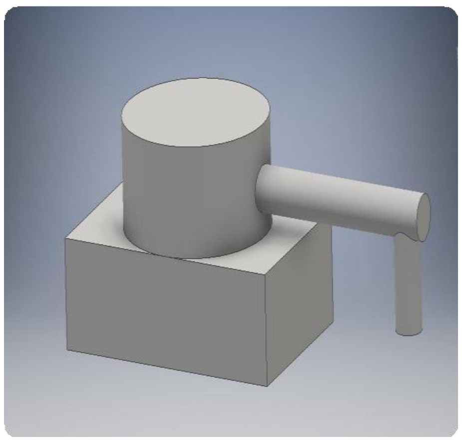
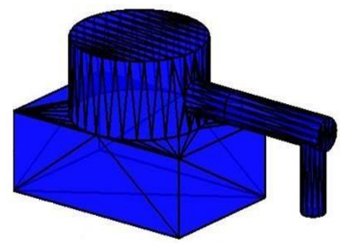
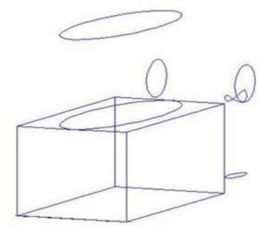


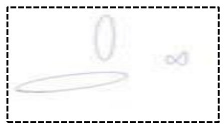
Fig. CAD model of overhang part



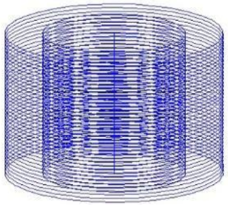
(a) Facet model



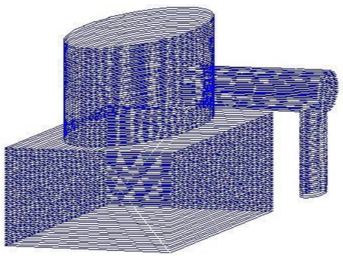
(b) Feature edge extraction



(c) Concave loop extraction



(d) Centroidal extraction



(e) Slicing

Validation results of overhang model

Illustration

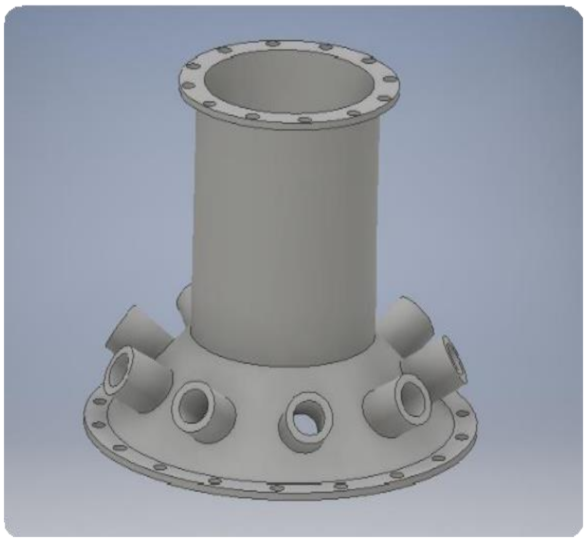
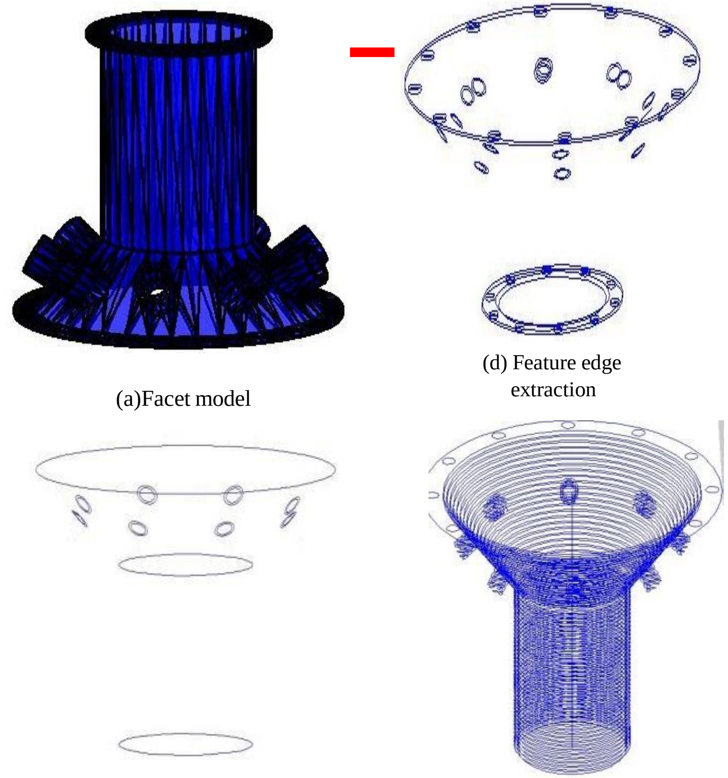


Fig. Thruster CAD model



(a)Facet model

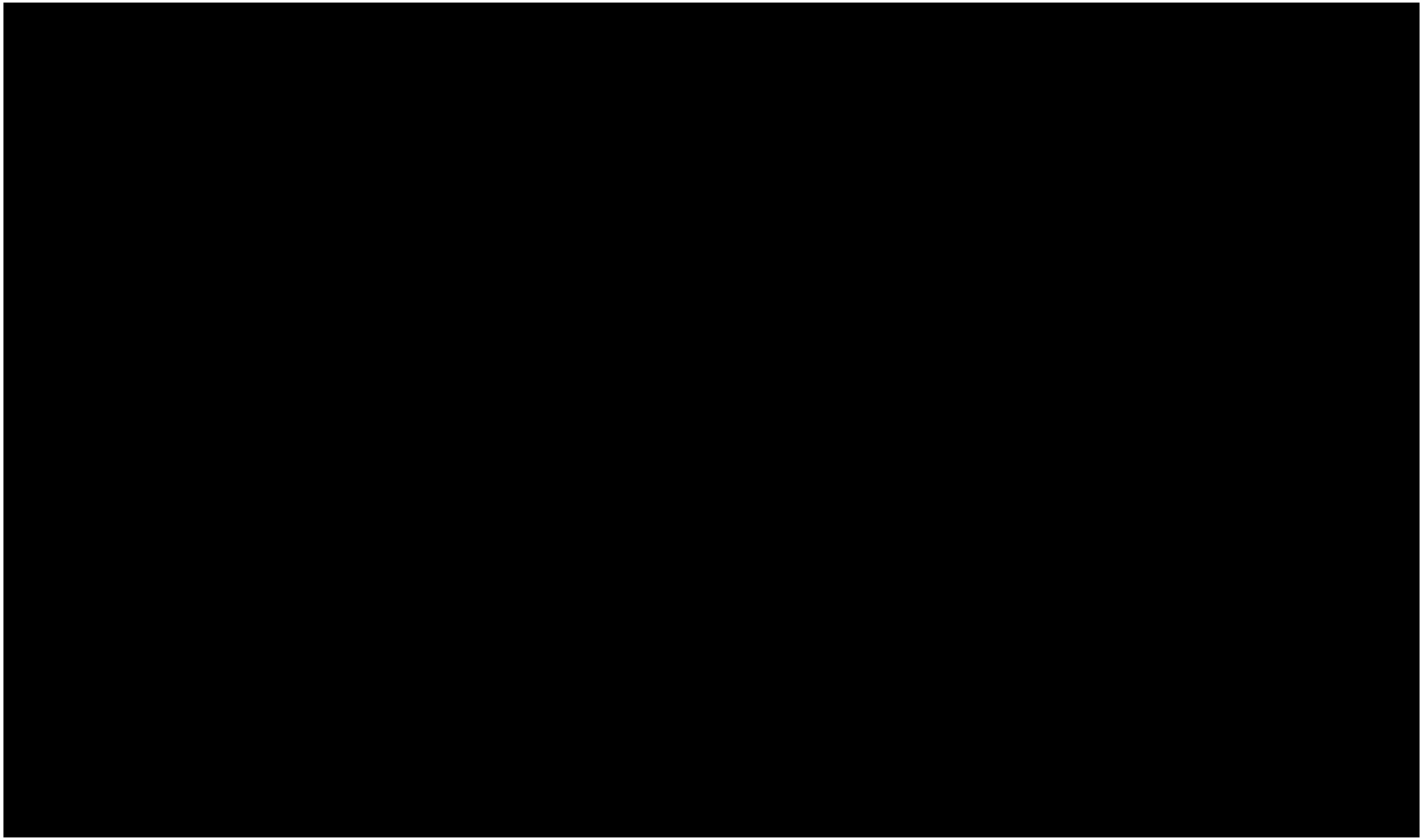
(d) Feature edge extraction

(e) Concave loop extraction

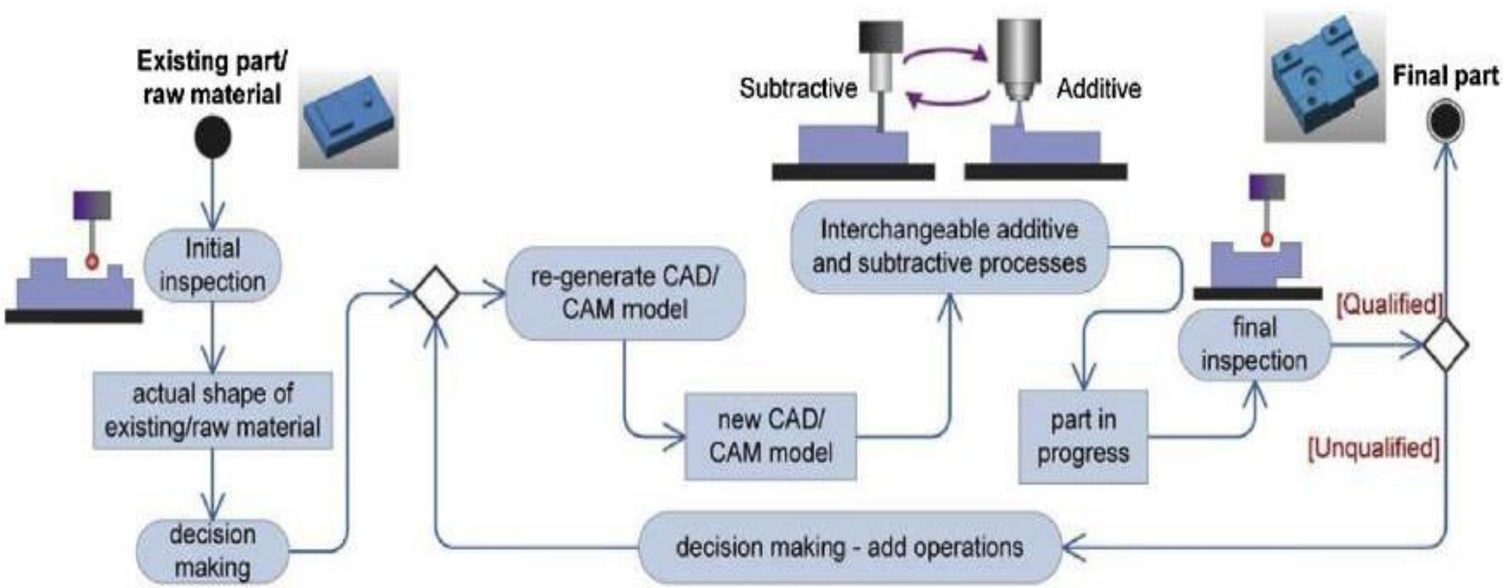
(c) Centroidal extraction and slicing

Fig. Validation results of Thruster model

Video: Hybrid Additive Manufacturing



Process planning system



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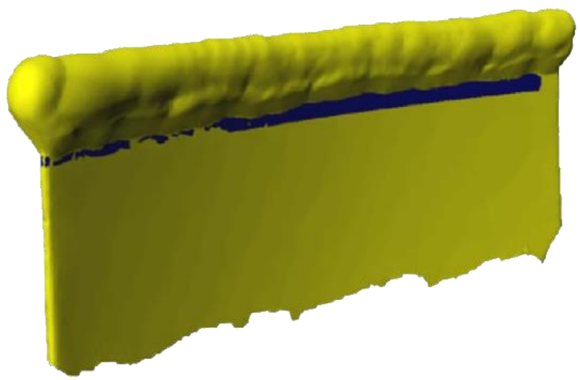
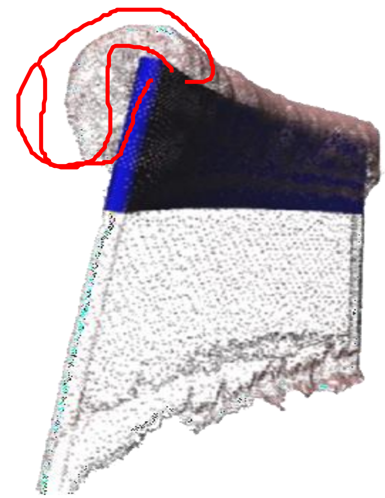
CONVENTIONAL TURBINE BLADE REPAIR

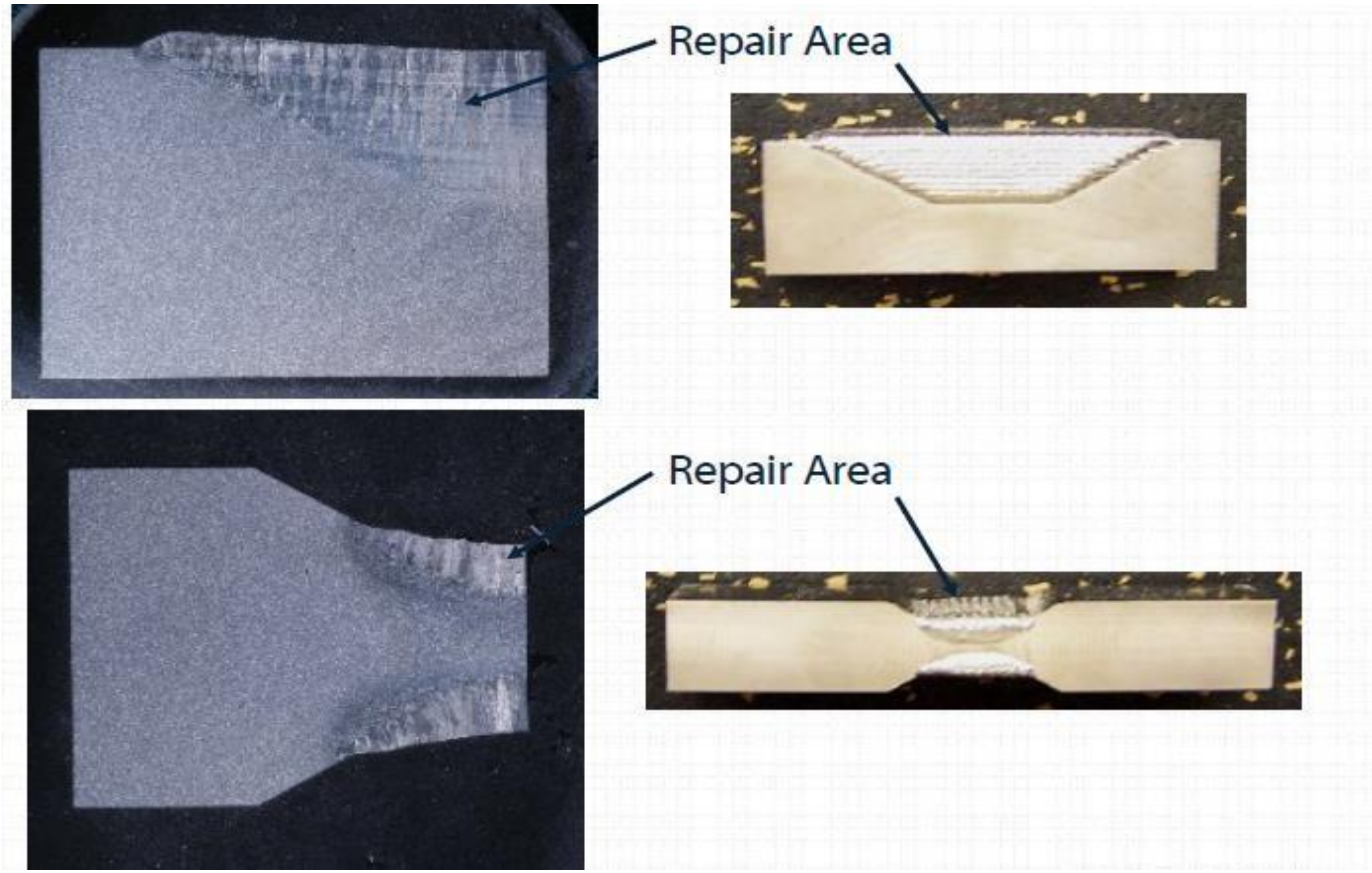


The defective turbine blade is initially deposited by a welding bead done by laser welding. The bead covers the more than the defective area

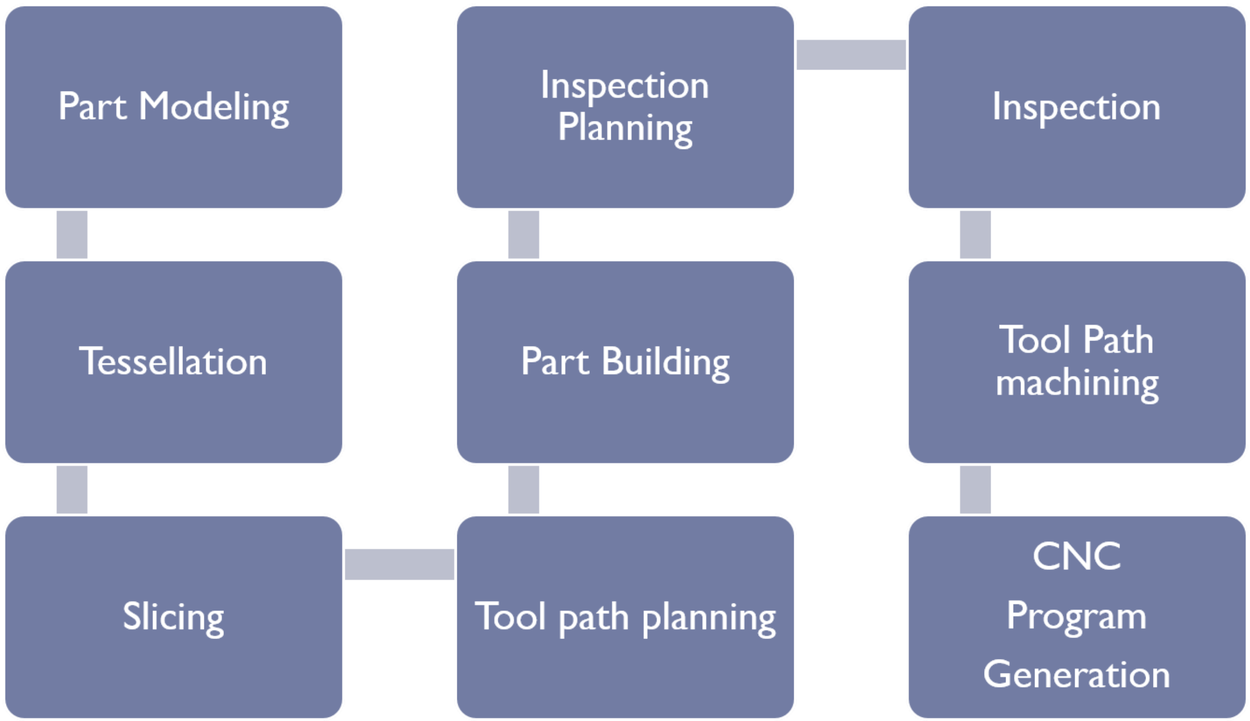


A digitized CAD represented is then generated and the actual turbine blade is then programmed into a CNC machine for subtractive process and finishing

DED PROCESS USED IN BLADE REPAIR



Tool Path Planning



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Software for HAM part preparation

- Siemens NX
- Vericut

Challenges in Process Planning for Hybrid Manufacturing

5- Axis configuration

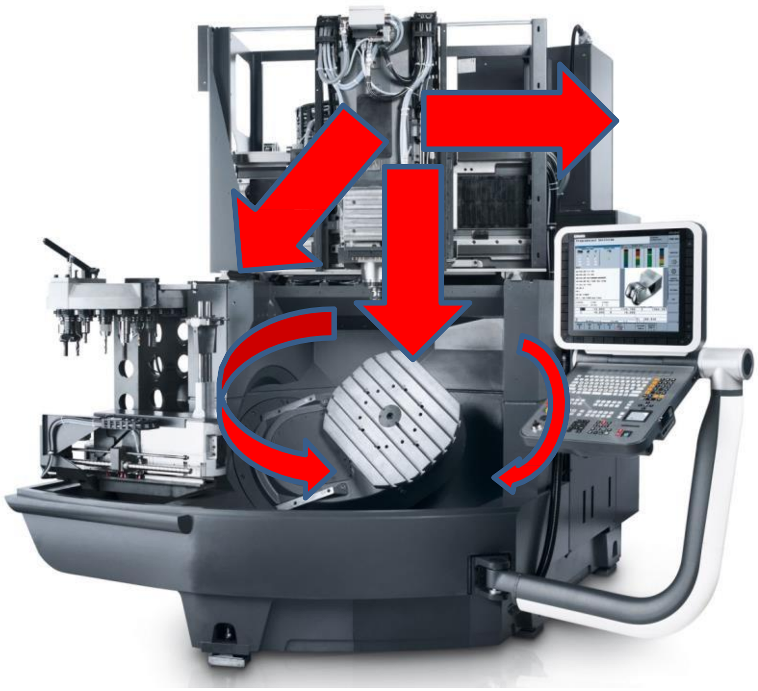
“ Three linear (X, Y & Z), one rotating (C), one tilting (B)

What is currently available in COTS tools?

- Decomposition of Features
- Merging of features
- Sub-dividing Volumes axially and radially

The additive manufacturing toolbar.

Courtesy: Siemens NX



Hybrid System Configuration:

Challenges in Slicing for Hybrid Manufacturing

What is needed?

- Overhang volume decomposition and slicing
- Complex internal cavity generation
- Machining delta volume compensation

innovate achieve lead

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End of Lecture17-18