Session 5: Technologies and Processes

Role of Post-Build Processes in Additive Manufacturing

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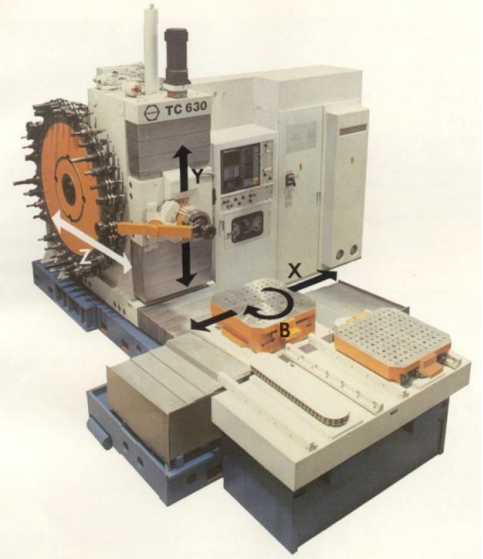
Outline

- Introduction
- Significant Benefits & Applications
- Challenges in Additive Manufacturing
- Remedies through interlayer and post-processes
- Conclusions

Introduction

Sign Change in Manufacturing



- → +: Till 1987, manufacturing was dominated by subtraction - not only machining but also the formative processes such as forming and casting. The sign change in manufacturing with the advent of Additive Manufacturing by 3D Systems led to total automation in converting art-to-part (design-to-manufacturing or virtual-to-physical). So, it is faster and hence called Rapid Prototyping. It is as easy as printing. So, many prefer to call it as 3D Printing.

AM revolutionized the way products are designed and manufactured today. It is an effective tool to compress product development time and hence gives an edge over the competitors.

Introduction
Analogy with 2D printing

Totally automated 2D printing
(Lithography)

Totally automated 3D printing
(Stereo-lithography)

Benefits & Applications

High Bandwidth Communication Tool: Gas Turbine (Video)

- Rs. 19,80,000 (30,000 Euro)
- 3 Weeks (Time-bound delivery through extensive outsourcing)
- High bandwidth communication tools
- 1:1 working model (1.1m long)

Significant Benefits & Applications

Features difficult/impossible by other means

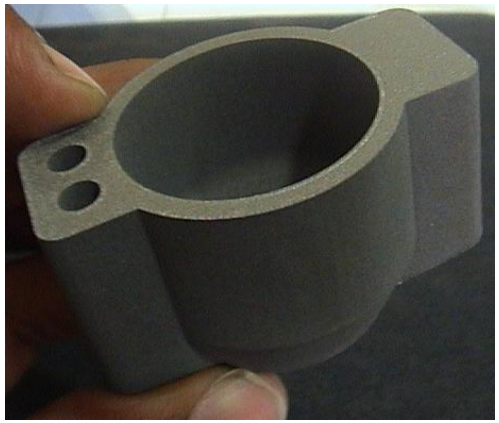
Design used to be constrained by the manufacturing limitations in the past. Additive Manufacturing has made the following possible giving designers greater freedom:

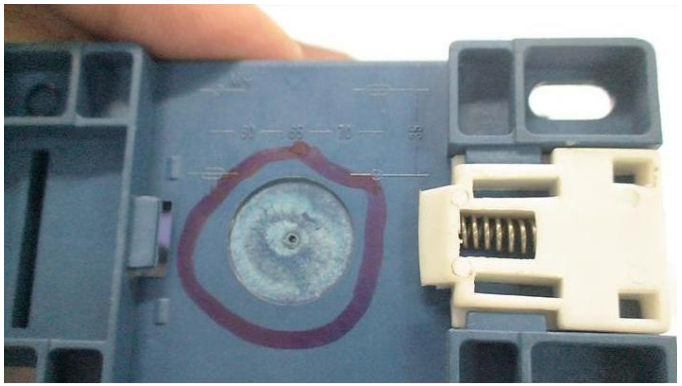
1. Conformal cooling channels
2. Assemblies without joints
3. Gradient Materials
4. Non-equilibrium Objects
5. Difficult or Impossible Shapes
6. Customized solutions …

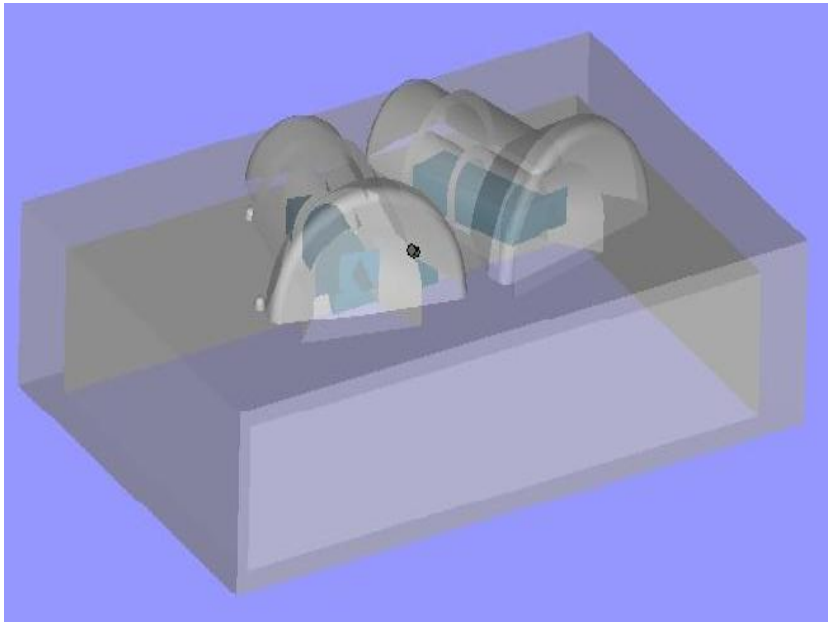
So, design innovation need not be limited by the manufacturing constraints. It should exploit these newer capabilities.

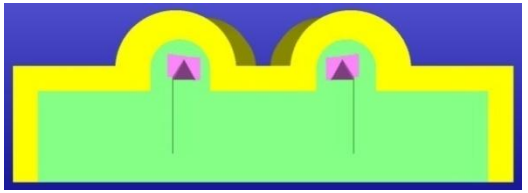
Significant Benefits & Applications

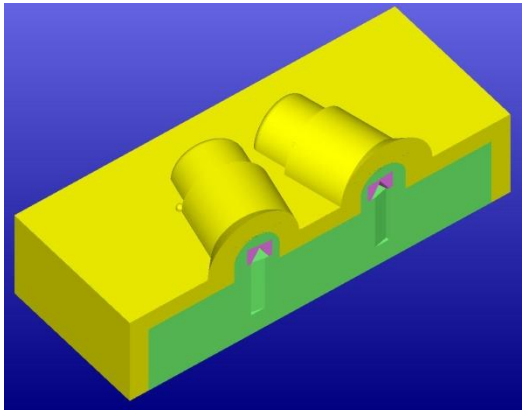
1. Conformal cooling channels











- Cycle time reduction
- Less distortion
- Good integrity

Significant Benefits & Applications

2. Assemblies without joints

Courtesy: Stratasys, USA

Courtesy: EoS, Germany

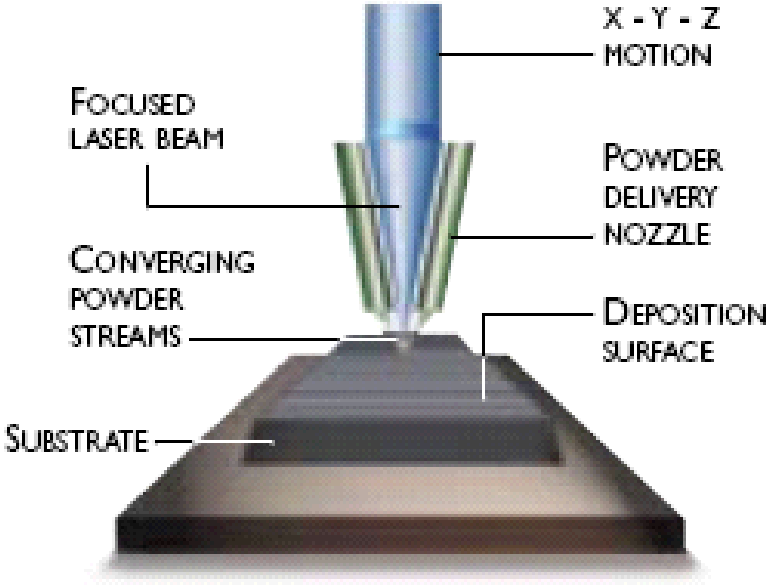
Thin walled turbine combustion chamber, produced on EOSINT M 270, material EOS Nickel Alloy IN 718.

Courtesy: Materialise Solutions, U.K.

Significant Benefits & Applications

3. Gradient Materials

Courtesy: ZCorp, USA



Courtesy: Optomec, USA

Significant Benefits & Applications

4. Non-equilibrium Materials

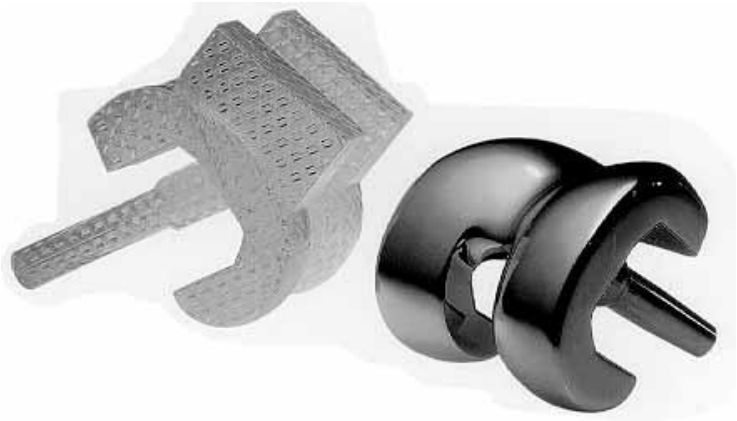
Make objects out of materials that do not form alloys.

Significant Benefits & Applications

5. Difficult or Impossible Shapes

Significant Benefits & Applications

6. Customized Solutions



Challenges in Additive Manufacturing

Total automation in AM is achieved by compromising on quality. Pre-build, inter-layer and post-build treatments help in overcoming them.

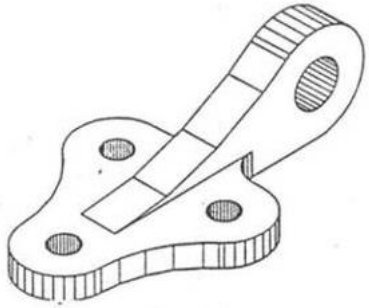
Challenges in Additive Manufacturing

Quality	i. Exterior or surface	- Surface finish
		- Accuracy
	ii. Interior or matrix	- Composition
		- Limited range of each process
		- Proprietary
		- Homogeneity (inherent anisotropy, porosity & residual stresses)
Time	Time to build	Not rapid enough! - Number of layers - Sacrificial support
	Life	Low life due to - Poor quality - Degeneration over time
Cost	Linear!	

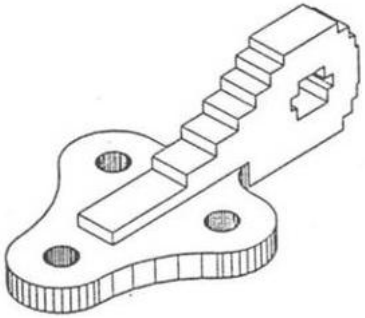
Challenges in Additive Manufacturing

Two sources of poor surface finish

(i) Poor surface finish due to stai-rstep error



CAD model



AM part

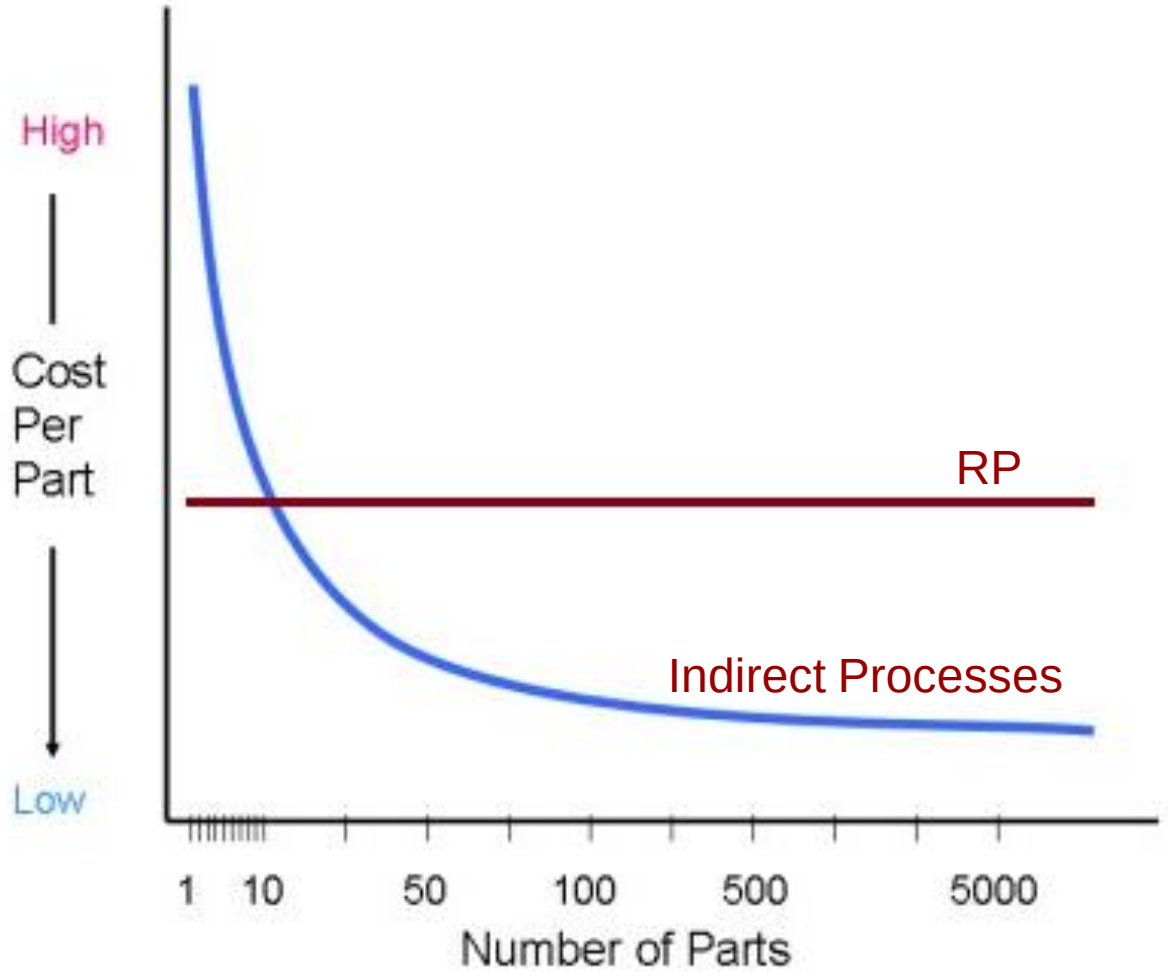
(ii) Irregularities created during support removal

When surface finish is very poor, tolerance cannot be better than that!

Challenges in Additive Manufacturing

Linearity of cost & time/piece with total quantity

AM has linearity of cost (& time) with quantity.



Remedies

Challenge	Remedies
Poor surface finish	- Prevent poor finish (say, thro' orientation) or tolerate! - Sand blasting - Dissolving hills
Anisotropy	- Fine tuning of the process parameters - Post-build treatment with heat and pressure
Residual stresses	- Interlayer stress relieving through cold working (hammering, pressing, rolling) - Post-built stress relieving (vibration, magnetic, furnace treatment)
Slow process	- Preheating envelope and raw material - Multiple tools - New slicing concepts such as *adaptive slicing*
Linearity of cost	- Integration of process chain with indirect routes

Remedies

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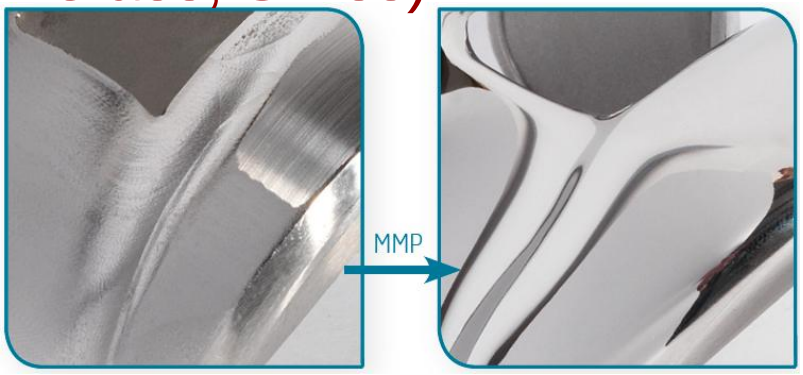
Remedies

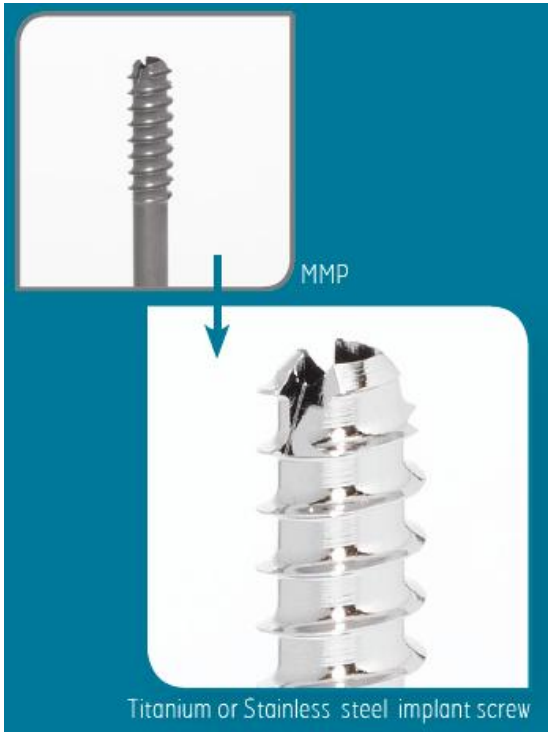
Improving surface finish

For non-metals: Solvents such as acetone for ABS plastics.

For metals: Shot blasting & Liquid polishing (Micro-Machining of BestinClass, Swiss)



Knee implant



Titanium or Stainless steel implant screw

Remedies

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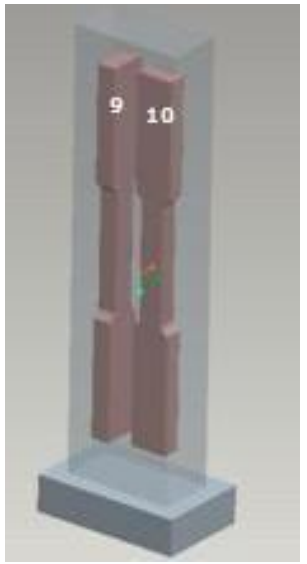
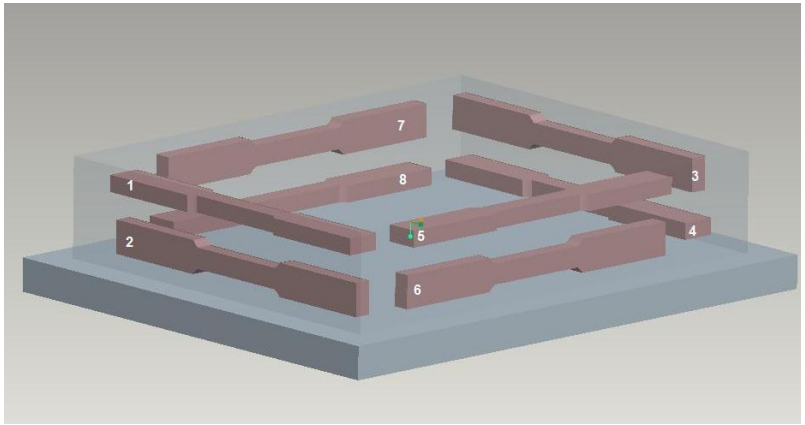
Remedies
Reducing anisotropy

Fine tuning the process parameters: Every AM process has a few parameters that can be fine-tuned to arrive at homogeneous properties.

In our HLM, initially strength was less along Z. By appropriately increasing the current, we could make it match X & Y directions.





Direction	Yld (MPa)	Ult. (MPa)
Welding	396	528
Across	379	538
Vertical	406	544

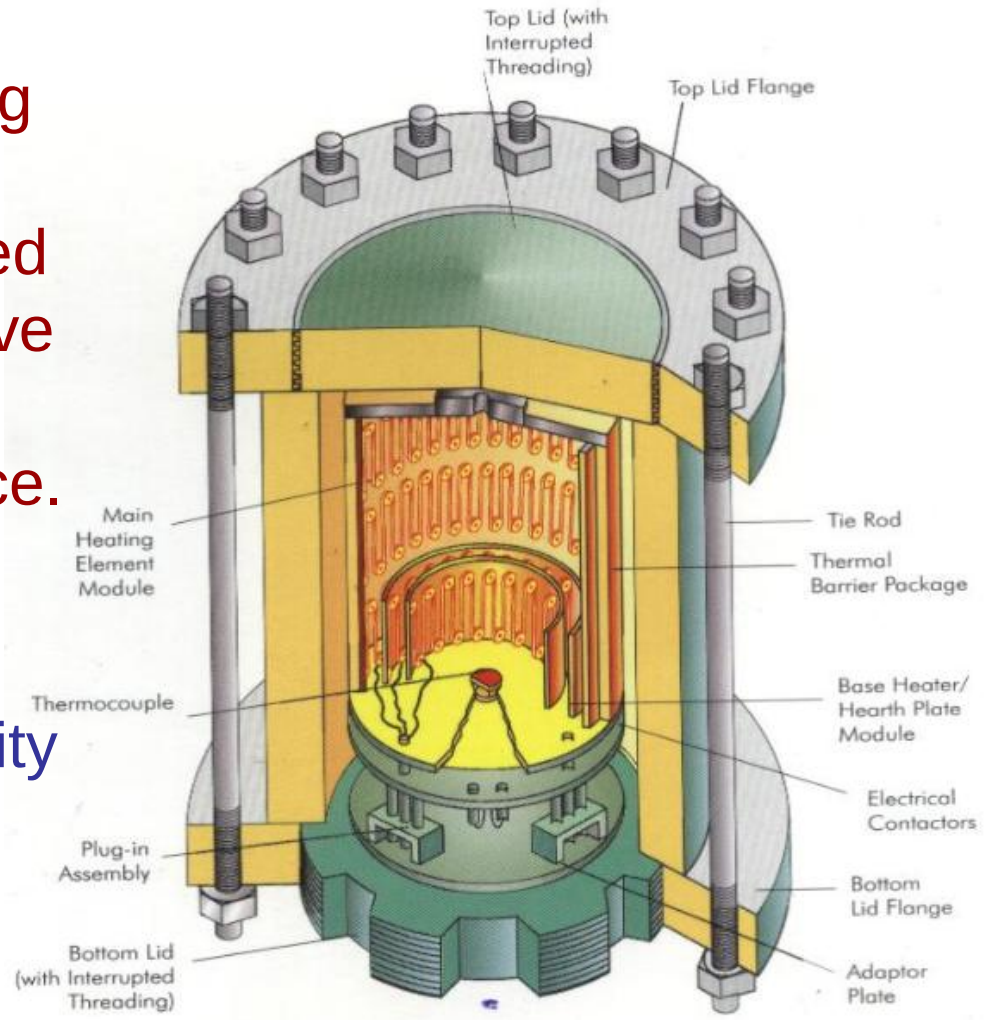
Mild Steel

Remedies

Interior improvements: Hot Iso-static Pressing (HIP)

Powder-based RP (laser/EB sintering or bonding) is not strictly PM as compacting is missing. Powder-based metallic AM processes invariably have some micro-porosities which reduce their fatigue life required in aerospace. HIP makes them as strong as machined or forged components by

- Eliminating surface cracks & porosity
- Improving homogeneity
- Releasing residual stresses.



Cutaway view of a Tie Rod PCS Hot Isostatic Press

Remedies

Interior improvements: Hot Iso-static Pressing (HIP)

- Leak proof joints and valves are critical in HIP. This was a restricted technology till now. Very recently, ASACO, Secundarabad, started offering these machines. Two of their machines are in India:

	Job size	Max pressure	Max temp.
DMRL	650mm dia x 1200mm long	2000 bar	1440°C/ 2000°C
VSSC	500mm dia x 1000mm long	2000 bar	1440°C

- It is expensive today (approx. Rs. 30 crore (Euro 3,750,000). When more people adopt it, price will come down.

Remedies

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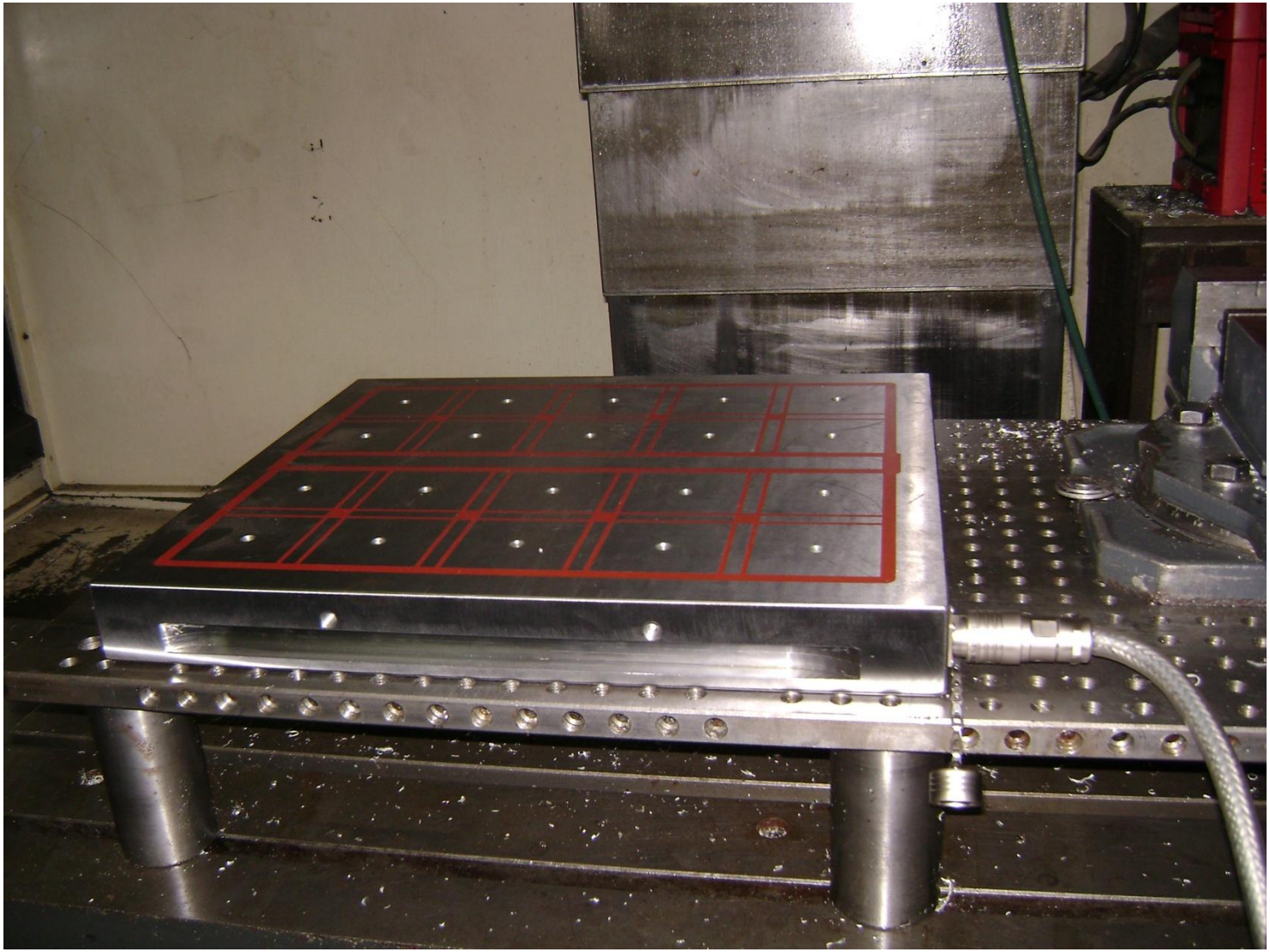
Linearity of cost	- Integration of process chain with indirect routes

Remedies

Interlayer stress relieving: Clamping/unclamping



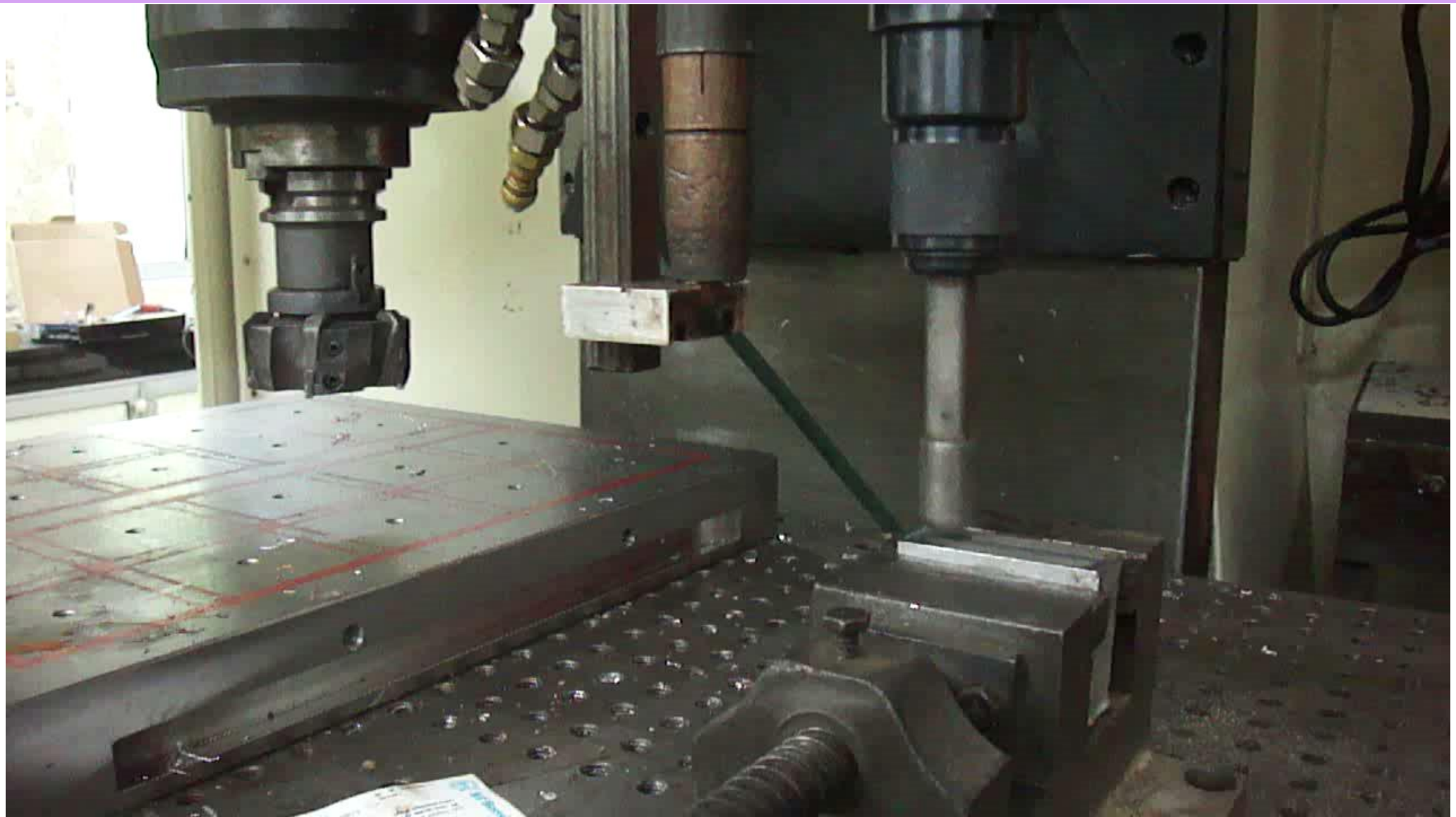
With some location pins, this works for steel. We have to build a steel structure on top to hold the non-metallic objects.

Remedies

Interlayer stress relieving: Pneumatic peening

Hybrid Layered Manufacturing (HLM)

Interlayer stress relieving: Pneumatic peening (Video)



Remedies
Interlayer stress relieving

- Due to the thermal cycles (heat and phase changes), warping takes place. If warping is prevented by clamping, they emanate as internal stresses. So preliminary experiments were done by unclamping during deposition. The surface also was pressed after every layer.

Case	Clamping	Pressing	Normal Res. stress (MPa)
1.	Clamped	Not Pressed	497.5
2.	Unclamped	Not Pressed	433.2
3.	Clamped	Pressed	479.5
4.	Unclamped	Pressed	355.4

- Unclamping is more effective than pressing.
- These experiments indicate that Hot Isostatic Pressing (HIP) will help. Proof for the same exists in literature also. We shall try peening first.
- Magnetic table has been bought to enable quick clamping/unclamping.

Remedies

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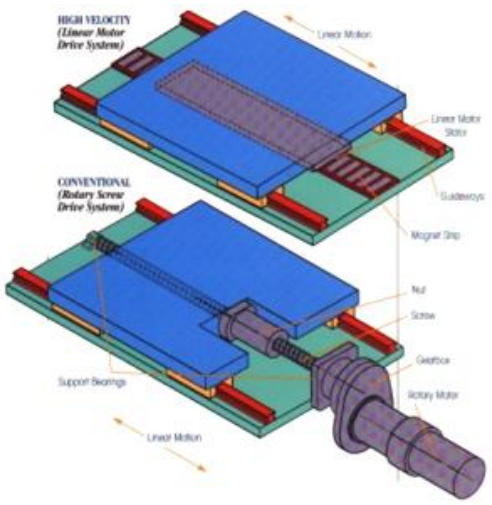
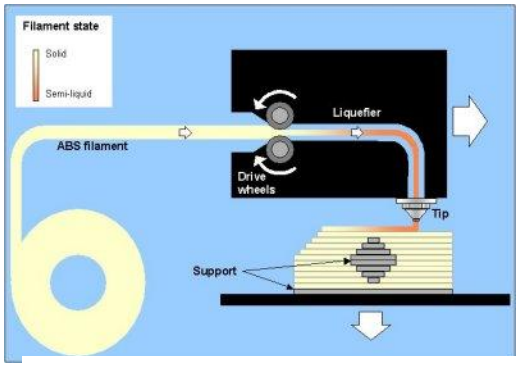
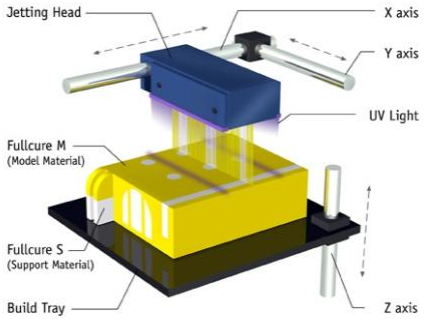
Remedies

Improving speed

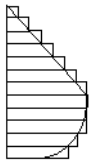
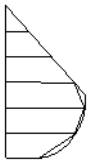
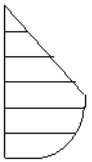
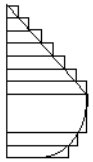
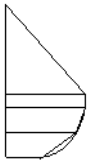
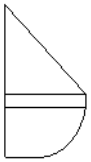


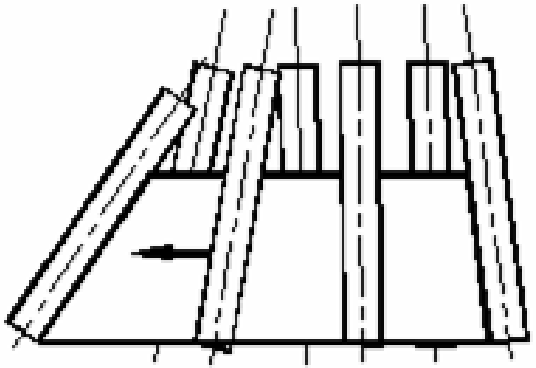
Speed	~~Faster motions~~ Faster processes Multi-tool systems
Speed+ Accy.	Hybrid systems New slicing concepts Multi-axis AM





The Objet PolyJet Process

	Order of Approximation		
	Zero Order	First Order	Higher Order
Uniform Layer Slicing			
Adaptive Layer Slicing			



Remedies

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Remedies
Indirect Processes

When RP is combined with an appropriate indirect processes,

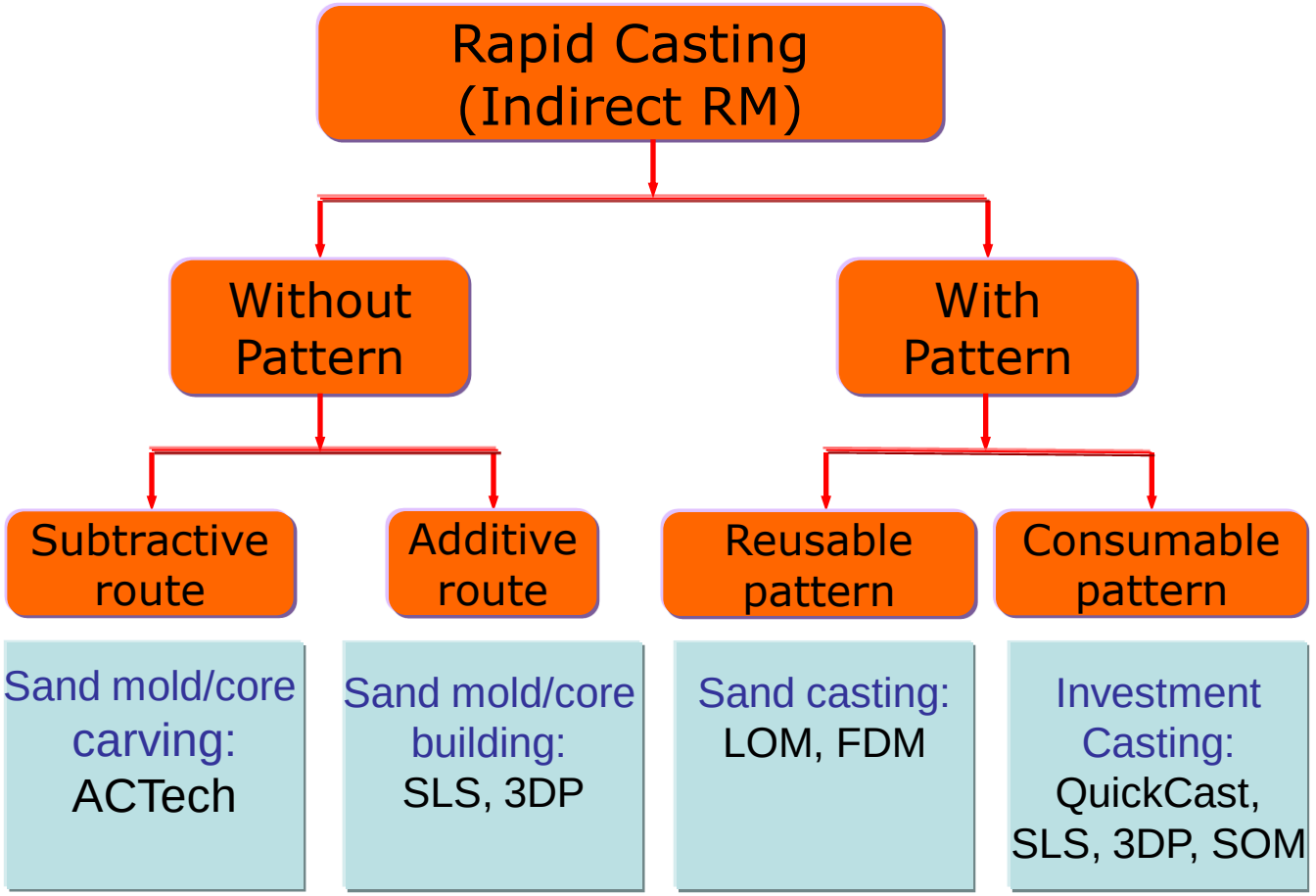
- cost/piece comes down

- the part can be made out of any desired material.

For Metals	For Non-metals
• Rapid Casting - Investment casting - Sand casting with patterns - Sand casting without patterns	• Vacuum casting (Silicon rubber molding) • Epoxy tooling • Cold metal spray • Kirksite tooling • …

Remedies

Rapid Casting: Various routes



The mold is created using AM. The rest, viz., melting, pouring etc. are the well known foundry science.

Molds can be made with or without the patterns.

The patterns may be reusable or consumable.

Remedies

Rapid Casting: Direct mold through addition and subtraction (Video)

Additive route

Subtractive route

Courtesy: ACTech, Germany

Remedies

Rapid Casting: Investment Casting (QuickCast)

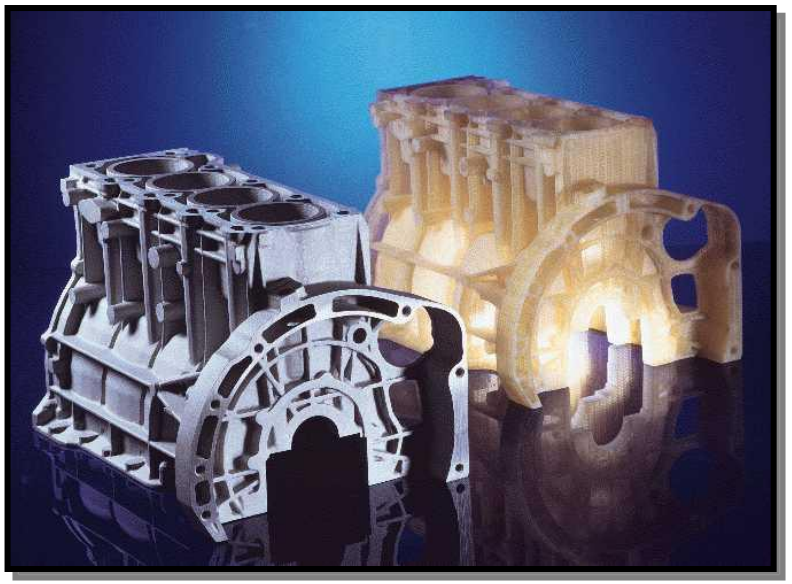
Courtesy: Bajaj Auto, India

3D Systems' SLA mchine produces quasi-hollow patterns. Note that:

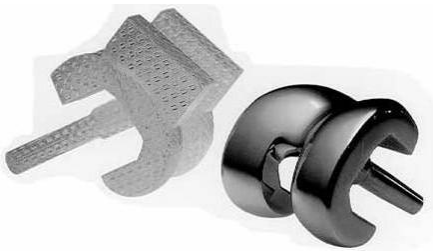
- the honeycomb structure is achieved using QuickCast build style and no special geometric pre-processing is required.
- Hollowness is not for saving material or speed but to avoid shell cracking.

QuickCast uses flask investment casting.

Of late, SLS's dense polystyrene patterns are replacing this.



Courtesy: Mercedes-Benz



Knee implant

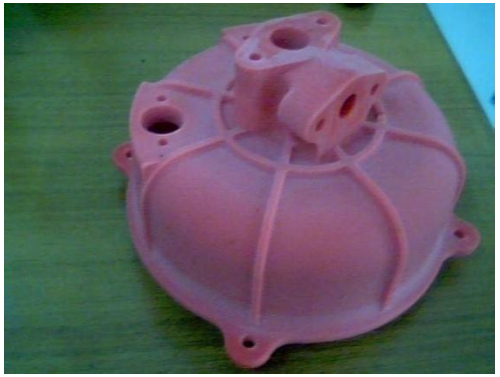
Remedies

Rapid Casting: Investment Casting (SLS for polystyrene)

Magnesium Seal housing of Kaveri engine (GTRE, Bangalore) made by Aerocast, France

Remedies

Rapid Casting: Investment Casting (SLS for polystyrene) …

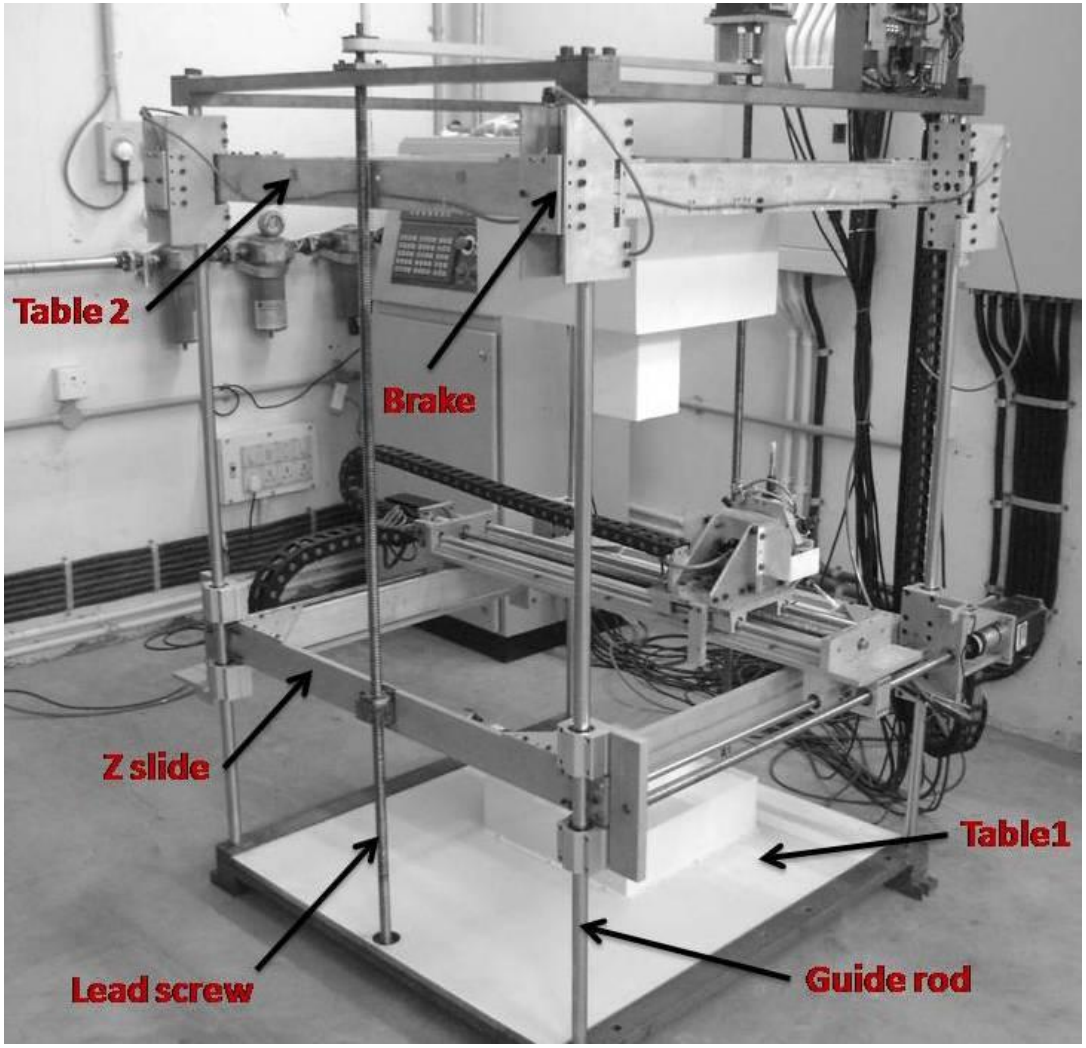


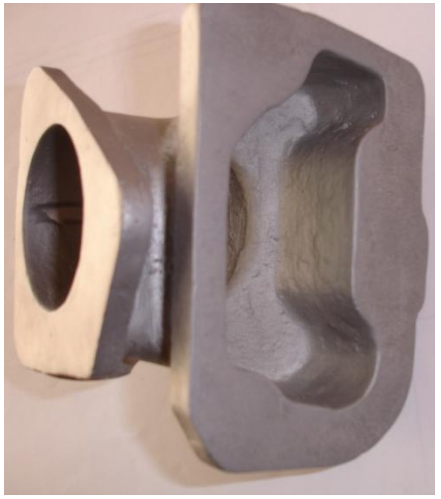
Indigenous Efforts in Rapid Casting (Aluminium)

GTRE, Bangalore, IIT Bombay, CTR, Ludhiana and PTC, Lucknow

Remedies

Rapid Casting: Investment Casting (SLS for exp. polystyrene)



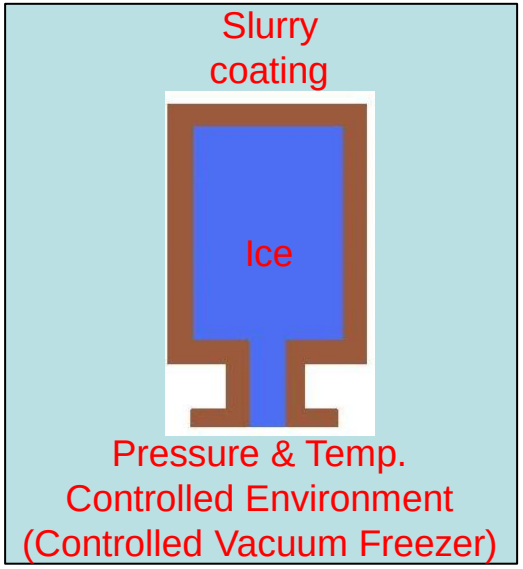


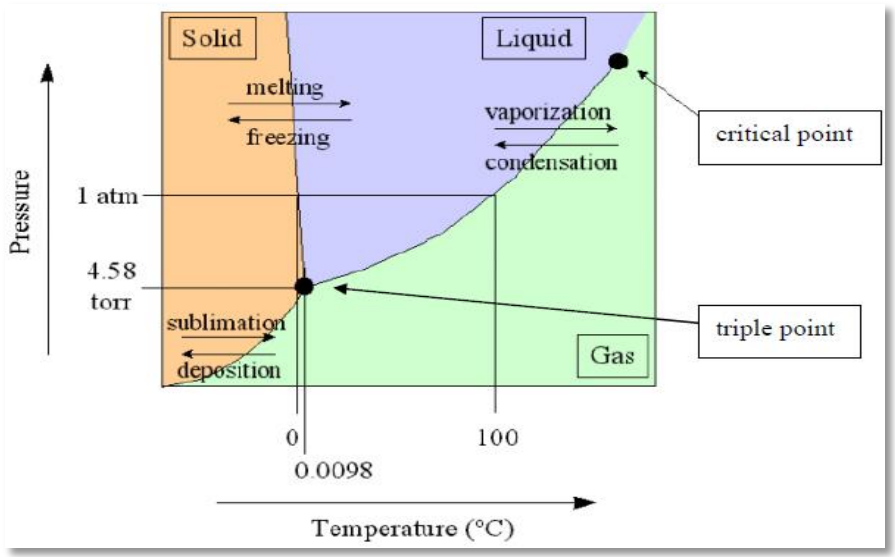
Remedies

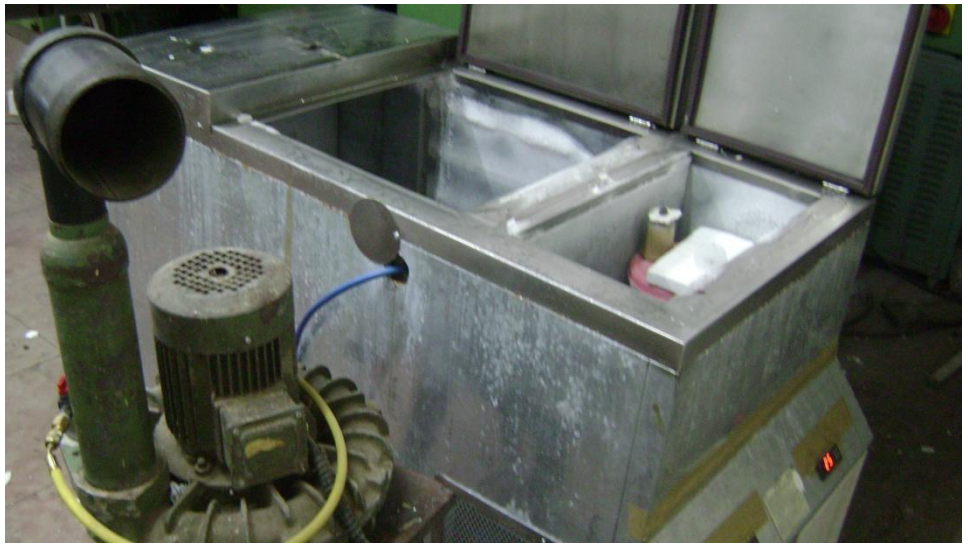
Rapid Casting: Investment Casting (SLS for exp. polystyrene) (Video)

Remedies

Rapid Casting: Investment Casting using ice patterns



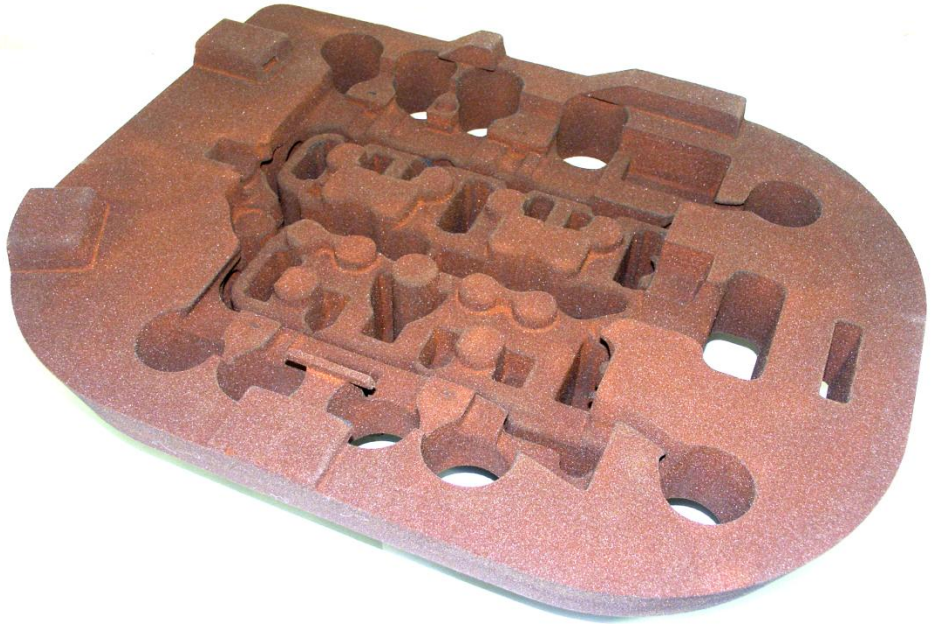


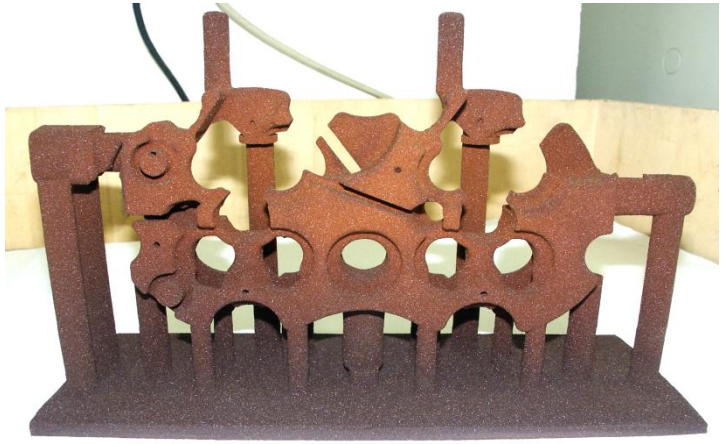


Prof. M.C. Leu of USA has developed a RP machine for ice. This work was inspired to dovetail his research.

Remedies

Rapid Casting: Sand casting without pattern



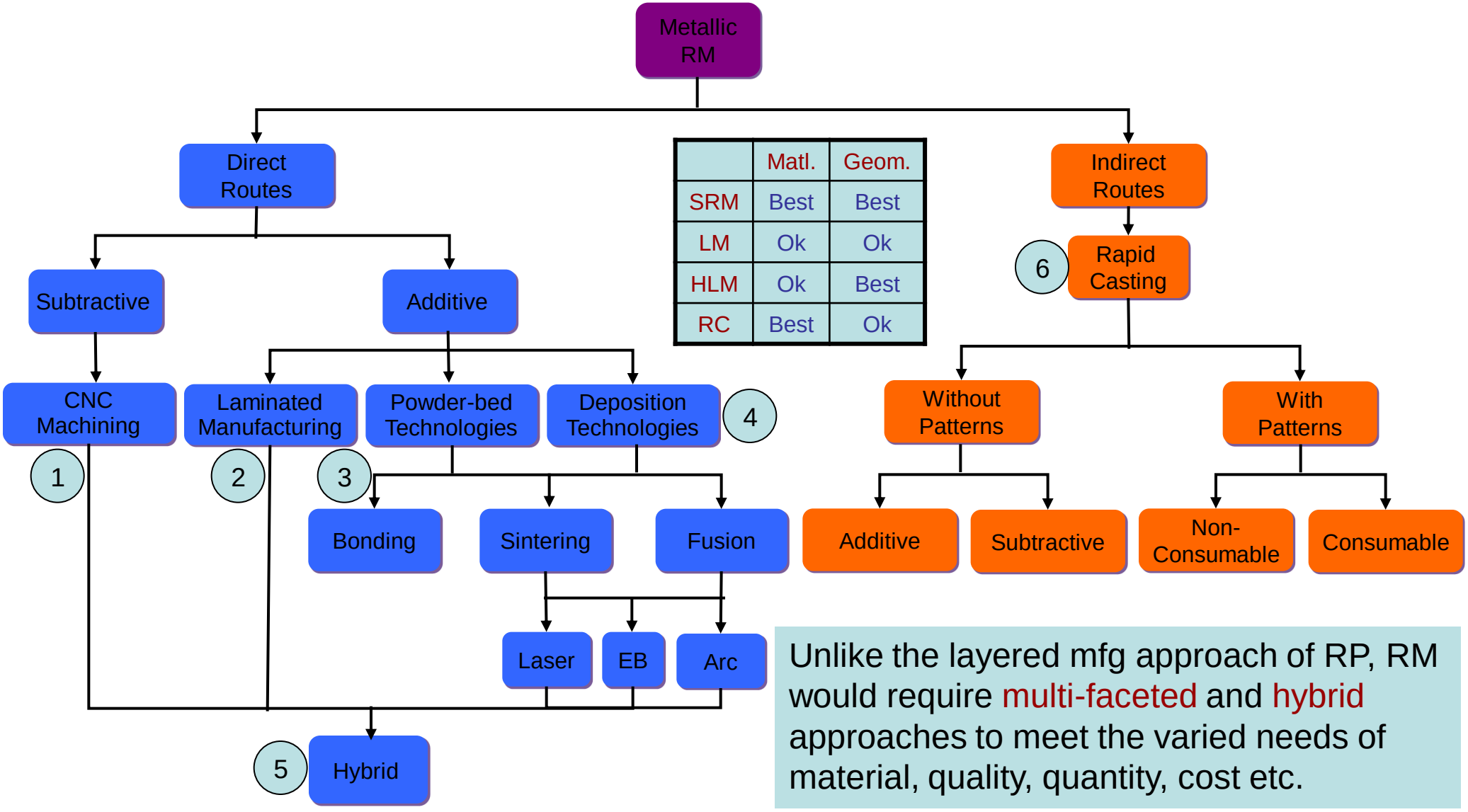


Conclusions

- "Divide & Conquer" approach of Additive Manufacturing made it totally automatic. This revolutionized the way products are designed and manufactured today.
- But the same "Divide & Conquer" approach is responsible for its pathetic quality, short life, long production time and high cost. So, Additive Manufacturing alone can go only upto a point. When it is combined with appropriate post-processes, its QCD performance dramatically improves. Additive Manufacturing along with these allied processes can be called Rapid Manufacturing.
- RM requires multi-faceted and hybrid approaches: Powder-bed technologies, deposition technologies, CNC machining, Laminated Manufacturing and indirect routes such as casting.
- Optimal automation rather than total automation is the focus in RM.

Conclusions

Rapid Manufacturing



	Matl.	Geom.
SRM	Best	Best
LM	Ok	Ok
HLM	Ok	Best
RC	Best	Ok

Unlike the layered mfg approach of RP, RM would require multi-faceted and hybrid approaches to meet the varied needs of material, quality, quantity, cost etc.

Thank You!

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Till July 15:

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