Design for Additive Manufacturing (3D Printing)

Dr. Yogesh Kumar
Assistant Professor
Mechanical Engineering Department
National Instiute of Technology Patna
Bihar - 800 005, India
yogesh.me@nitp.ac.in

Design for Additive Manufacturing

Design for Additive Manufacturing

- Additive manufacturing (AM) has evolved from a prototyping to a Production Technology.
- It is used to produce end-use-parts for medical, aerospace, automotive and other industrial applications.
- Metal additive manufacturing processes are relatively slow, require complex preparation and post-processing treatment while using expensive machinery, resulting in high production costs per product.
- Design for Additive Manufacturing (DfAM) aims at optimizing the product design to deal with the complexity of the production processes.

Design for Additive Manufacturing

- **Design for Manufacturing (DFM):** Optimizing the part design for manufacturing feasibility and bringing down costs
- **Design for Assembly (DFA):** Design to reduce cost by making the assembly process easy
- **Design for Additive Manufacturing (DfAM):** Design for part consolidation. Process specific. Purpose specific.

Design for Additive Manufacturing Framework

1. **AM suitability**
2. **AM material, process and machine selection**
3. **Initial cost estimation**
4. **Build job considerations**
5. **AM process constraints**
6. **AM post-processing constraints**
7. **AM quality, inspection and certification**

Design for Additive Manufacturing (DfAM) Essentials with Metals

Design for AM (DfAM) considerations for laser melted metal parts include:

- feature size
- surface finish
- overhanging features
- minimizing supports
- avoiding component distortion

Feature Size

In machining, minimum feature size is governed by cutting tool size
In AM, the minimum size of solid feature is limited by the laser spot diameter:

- Spot heats powder and creates a weld pool
- Molten metal cools to form a dense solid
- Spot size and laser power determines minimum feature size

Minimum Producible Feature Size

Sintering of neighboring powder means minimum feature size is larger than laser spot size, dependent on:

- Thermal conductivity of powder
- Energy imparted

With a 70 μm spot:

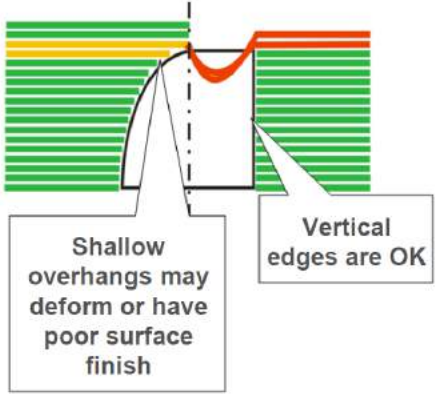
- Thermal Lattice struts down to 140 μm
- Wall thicknesses down to 150 – 200 μm

Overhangs

Avoid large overhangs;

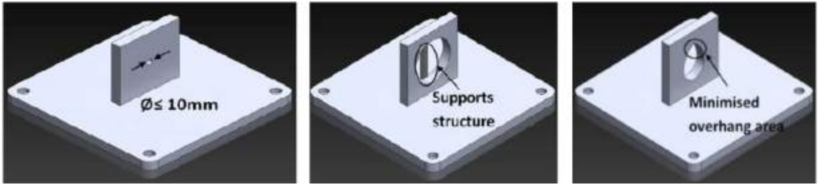
- Green builds OK
- Yellow poor surface finish
- Red distorts

Avoid overhang angles greater than 45 degrees to vertical;



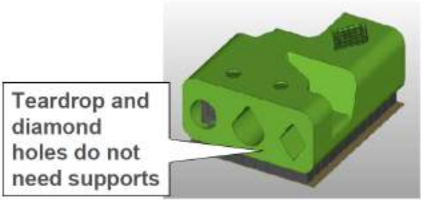
Lateral Holes

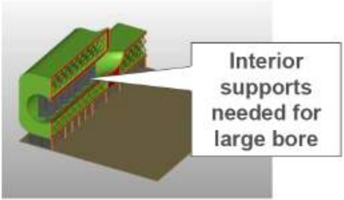
- Holes in the side of parts create overhangs
- Small holes ($<$ 10 mm) do not distort
- Large holes will need supports, or to be modified to reduce overhangs



Minimizing Supports – Feature Shape

- Overhangs can be built using supports
- Supports have to be removed after the build is complete
- Changing the shape of lateral holes can remove the need for supports





Minimizing Supports – Re-orientation

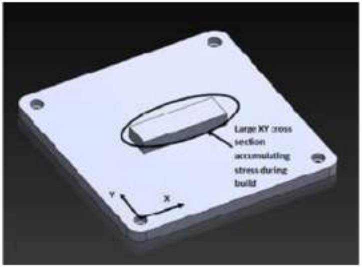
Re-orientation can be used to minimize supports,

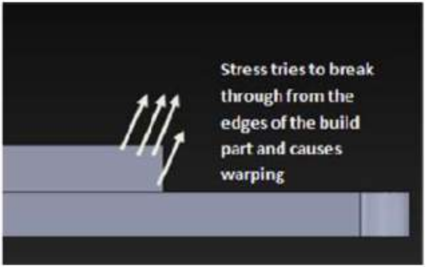
- May require addition layers and build time

Residual Stress

AM is a welding process, although spot size is small and energy density is high

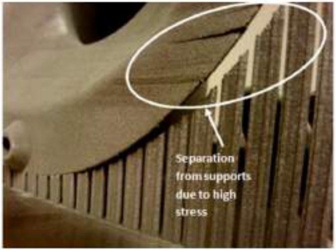
- Stress can build up in thick cross-sections, or where cross sections vary in thickness





Part Distortion

Stress (particularly thick sections),



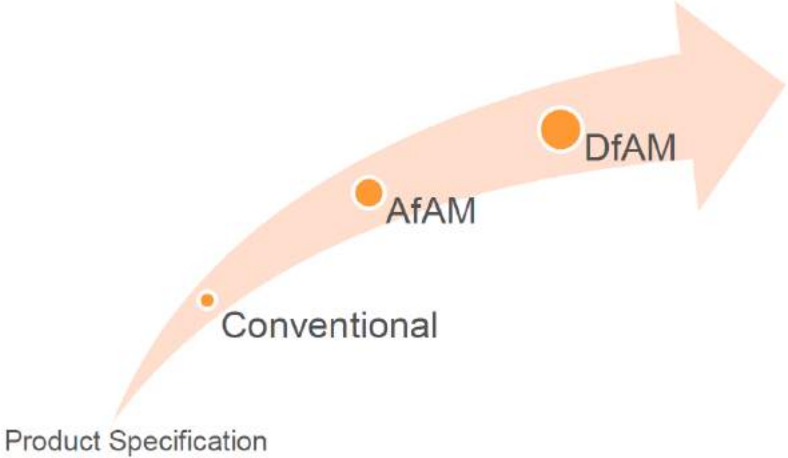
- Avoid thick part sections
- Thin and consistent sections are best
- Use thicker build plates where stress is likely to be high

Standard and thick build plates

Design evolution

- Adaptation for AM (AfAM):
  - The redevelopment or modification of existing product designs to better suit the design constraints imposed by additive manufacture; leveraging AM specific benefits
  - Existing product design specification (PDS) and system-level design reduce available 'design space'
- Design for AM (DfAM):
  - The wholesale 'blank sheet' design and development of a new product; fully exploiting the opportunities the technology provides
  - Considerably more open design space and ability to influence system-level design decisions

Design evolution



Case Study -1

Hydraulic Manifold

- Hydraulic manifold for a circuit operating at pressures in the order of 200-500 bar
- Weight limited application
- Simple circuit consisting of two check valves, a solenoid valve and their associated outlet ports (male insert type)

Hydraulic Manifold

Benefits

- A simple solution to the problem
- Easy to design
- Fast to manufacture

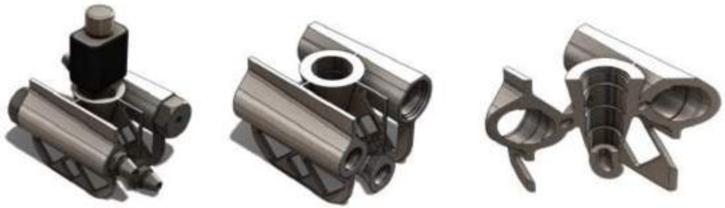
Limitations

- Sub-optimal performance due to cross-drillings
- Massively inefficient use of material
- 8 additional components in the form of pressure plugs

Mass: 4.6kg (10lbs)

AfAM Design Flow

Adapted for AM



Benefits

- A significant reduction in mass
- Improved hydraulic performance
- ‘Drop-in’ replacement for conventional part
- Pressure plugs no longer needed

Limitations

- Horizontal passageways need support and machining allowances can’t be too aggressive

DfAM Checklist

- True DfAM products are always clean sheet designs
- Customer has a specific product application in mind
- Adherence to a product development methodology as per any other conventional design process
- Engineering due diligence: cost/benefit, concept evaluation, design optimisation, compromises for manufacture etc.

Designed for AM

Benefits

- Extremely efficient use of material
- Alignment of valves allows for entirely self-supporting part
- Consolidation of outlet ports into design

Limitations

- High degree of CAD complexity/difficulty
- System-level engineering and design must be flexible in order to react to and incorporate the potential advantages of DfAM

Summary

Conventional

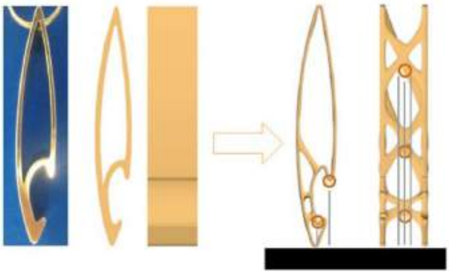
AfAM

DfAM

Version	Mass (kg)	Saving (%)
Conventional	4.6	-
AfAM	1	76.3
DfAM	0.4	91.2

Case Study - 2

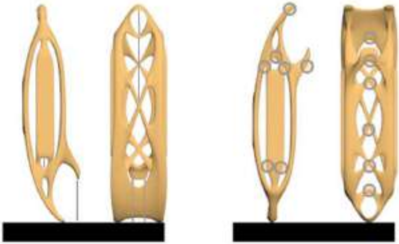
Minimizing Supports



AM beer bottle opener

- Original sleek design (left)
- First optimisation to reduce weight (right) resulted in several overhangs (orange circles), needing supports (grey)

Minimizing Supports



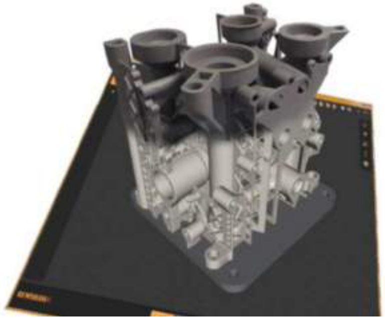
AM beer bottle opener

- Second iteration (left) included modifications to the shape to minimise support
- Third iteration (right) involved a re-orientation, leaving only self-supporting overhangs (grey circles), needing just one tiny support to connect the bottle opener to the build plate

Minimizing Supports

Summary

- Awareness of AM characteristics & limitations is critical to success
- DfAM rules encourage reduction in part weight, build time and cost
- Modern build preparation software simplifies and speeds up the DfAM process



Thank You