Design for Additive Metal Manufacturing

Additive Metal Manufacturing Inc.

Concord, ON, Canada

131 Citation Drive, Units 17 & 18,
Concord, ON, Canada, L4K-2R3, Ph: 905 738 0410
www.additivemet.com

Contents

1 Introduction

Additive technology especially in metals could lead us to produce real application parts which were impossible to produce using conventional processes. Light weighted components with intricate lattice structures, tools with conformal cooling channels for injection molding and die casting processes, and customized implants for the medical industry are some examples.

In order to take maximum advantage from the capabilities of additive metal technology in the most economical way, engineers should learn how to design for this technology by following its principles.

The design for additive metal manufacturing (DFAM) concept refers to the act of integrating product design and additive manufacturing principles into one activity.

This report introduces the designers to some of the DFAM rules of the additive metal technology by going thorough the details of its capabilities and constraints.

2 Design for Additive Manufacturing (DFAM)

In designing for additive manufacturing the following rules are usually followed:

- Design for minimum impact of DMLS geometrical constraints
- Design for minimum support material
- Design for minimum post-processing

The role of the current document is to introduce the principles in design for minimum impact of DMLS geometrical constraints.

2.1 Design for minimum impact of DMLS geometrical constraints

Some general rules to be considered in the design for additive metal manufacturing:

2.1.1 Accuracy

In additive metal manufacturing as parts are generated from metal powder, the surface roughness and the geometrical accuracy lies within the range of the powder grain size. Part accuracy depends on the powder material used. To achieve accuracy, the machine needs to be fine-tuned.

Tight tolerances are usually achieved by post machining. The following recommendations regarding post-machining have been made by EOS:

- 0.015"- 0.030" additional stock on milled and turned surfaces
- 0.005" additional stock per side for reamed surfaces
- 0.004" - 0.008" larger diameter for hole / passages to remain as built
- 0.002" – 0.004" for polishing

Electron Optical Systems (EOS) Inc. provides the data in Table 1 as the best achievable accuracy using their equipment:

Material	Accuracy	
MaragingSteel MS1	small parts (< 80×80 mm)	±20µm or $\pm 0.8\times10^{-3}$ inch
	large parts	±50µm or $\pm 2\times10^{-3}$ inch

Table 1

2.1.2 Surface Finish

In additive metal manufacturing due to the layer-wise building, the roughness of each surface strongly depends on its orientation in the building platform. Consider the cube in Figure 1. Depending on how this cube is orientated in the building platform, the surface normal is different for each face as will be the quality of the faces built by additive metal technology.

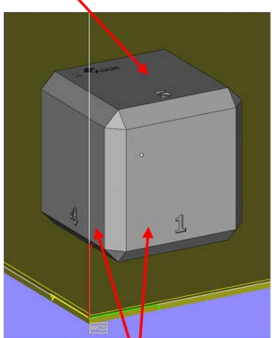
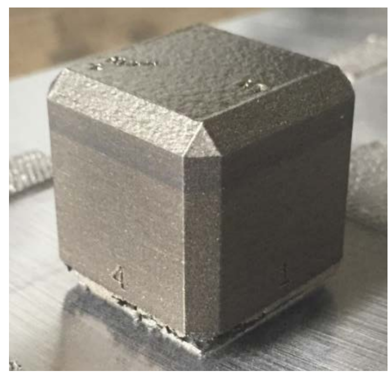
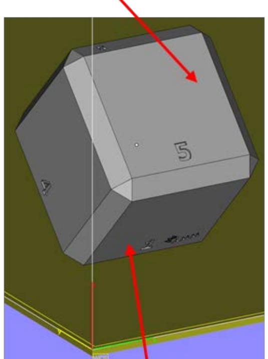
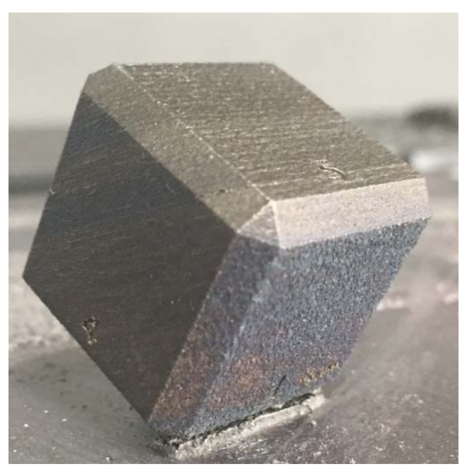
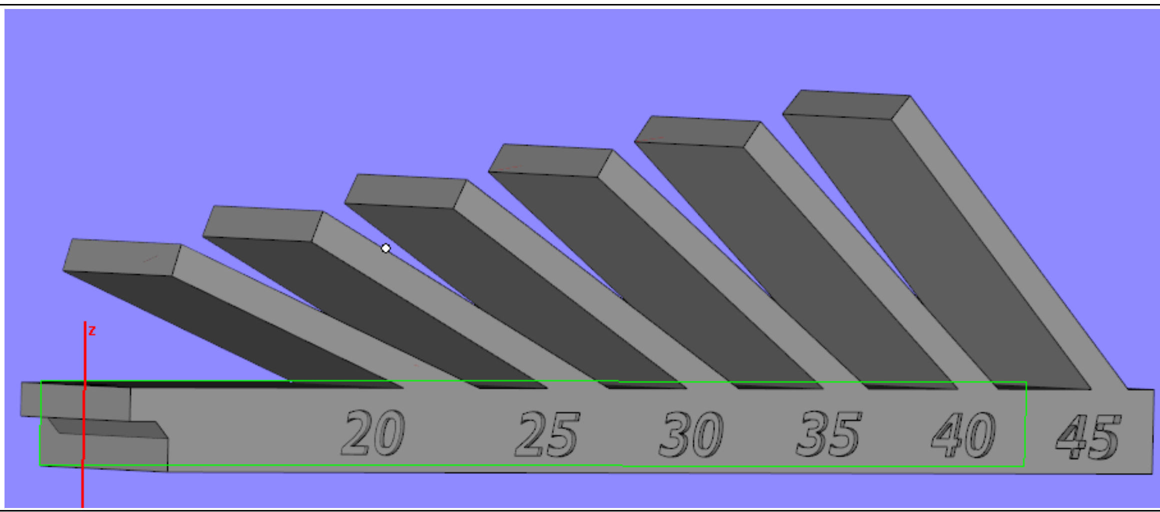
<table>
<tr><td>Horizontal Surface

Vertical Surfaces</td><td></td></tr>
<tr><td colspan="2">Cube surface roughness – orientation 1</td></tr>
<tr><td>Up-facing Surface

Down-facing Surface</td><td></td></tr>
<tr><td colspan="2">Cube surface roughness – orientation 2</td></tr>
</table>

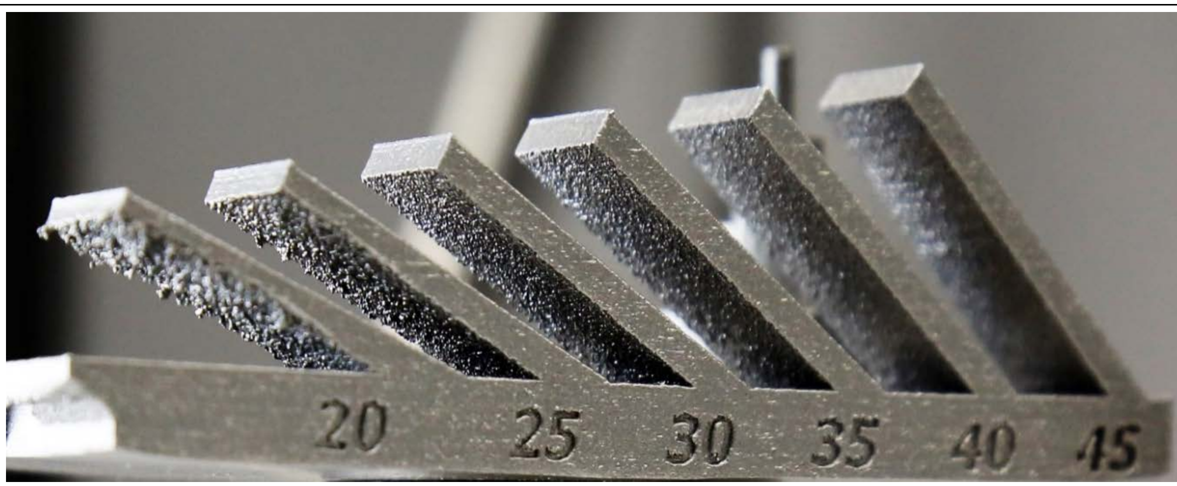
Figure 1; Surface roughness in different orientations

Based on the experimental studies it has been proved that the horizontal, vertical, and up-facing surfaces have the best surface finish quality and down-facing surfaces the worst.

In terms of the down-facing surfaces, these can be built without support approximately above 30°-35°. The quality of these surfaces increase as the orientation angle increases. This is illustrated in Figure 2.



CAD Model



DMLS part

Figure 2; Roughness on the down facing surface

Electron Optical Systems (EOS) Inc. provides the data in Table 2 as the best achievable surface finish using their equipment:

Material	Condition	Surface Roughness
Maraging Steel MS1	As manufactured (build)	Ra 12 -18 µm, Rz 60 – 80 µm Ra 0.47 – 0.71 x 10^{-3} inch, Rz 2.36 – 3.15 x 10^{-3} inch
	After shot peening	Ra 4 - 6.5 µm, Rz 20 - 50 µm Ra 0.16 – 0.26 x 10^{-3} inch, Rz 0.78 – 1.97 x 10^{-3} inch
	After polishing	Rz up to < 0.5 µm Rz up to < 0.02 x 10^{-3} inch (can be very finely polished)

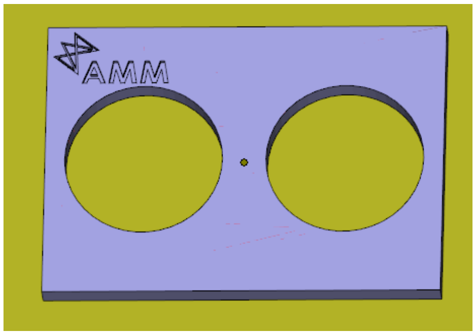
Table 2

Recommendations:

It is recommended that designers avoid down-facing and tilted surfaces as much as possible when designing for additive metal manufacturing.

2.1.3 Holes and Passages

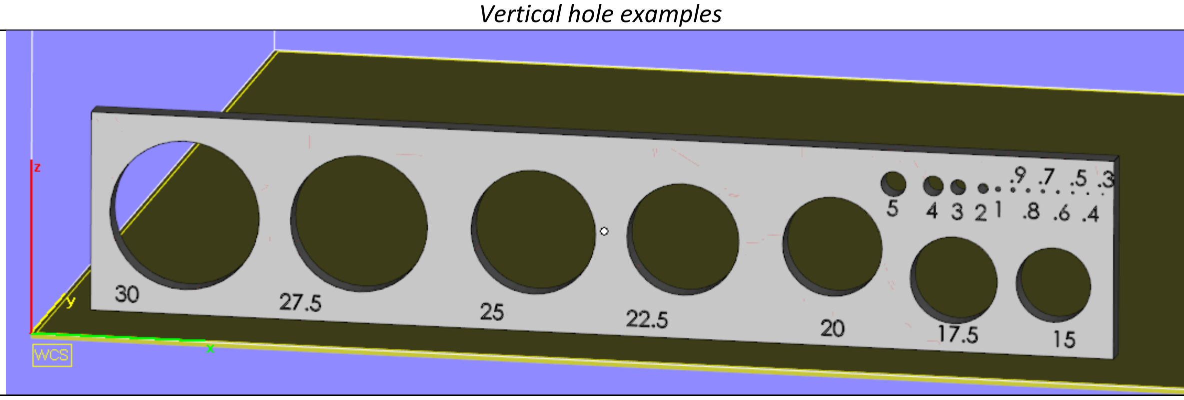
In additive metal manufacturing it has been generally proved that vertical holes and passages a better quality hole than horizontal ones. Figure 3 shows holes built vertically in comparison to those built horizontally.



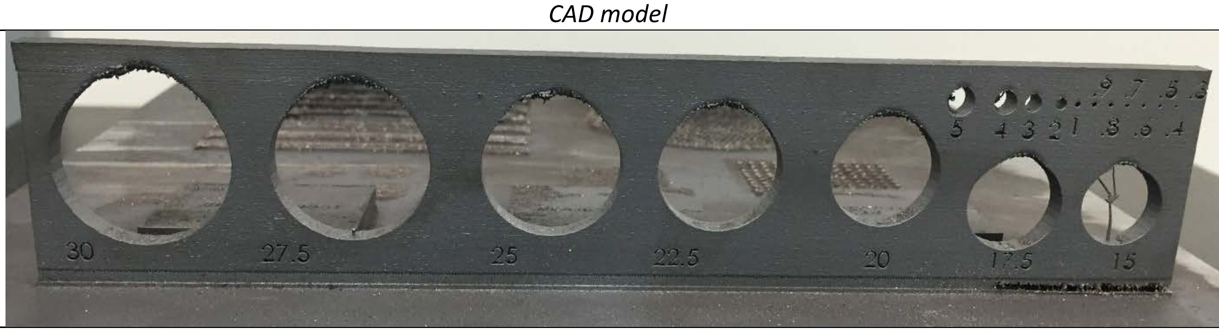
CAD model

DMLS part

Vertical hole examples



CAD model



DMLS part

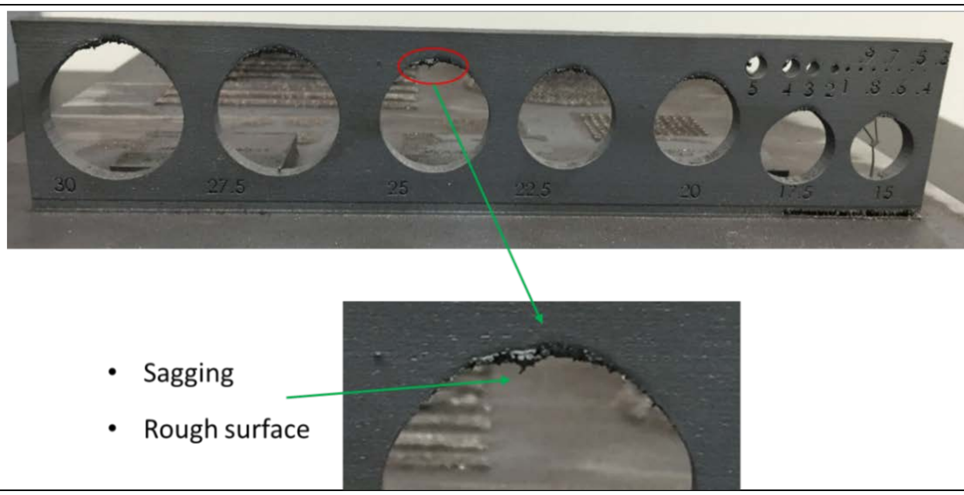
Horizontal hole example (Hole diameters = 20-30 mm)

Figure 3; Quality of the holes built vertically and horizontally

Two problems are experienced in building horizontal holes and passages:

- **Sagging**: Sagging refers to the fact that the metal powders are generally self-supporting when being built upward and over 40 to 45 degree angles. When the building process reaches the top of the circular cross section, the angle of the building direction is below the mentioned critical angle. Powders are not self-supporting and signs of sagging is observed.
- **Burning**: As the building process reaches the top of the circular cross-section, the surface area on top of which melting is occurring is decreased and that results in a reduction of the rate of heat transfer. This results in burning being observed in this area.

Due to sagging and burning, the top of the circular cross sections being built in a horizontal direction generally have rough surfaces. This is illustrated in Figure 4.



DMLS part

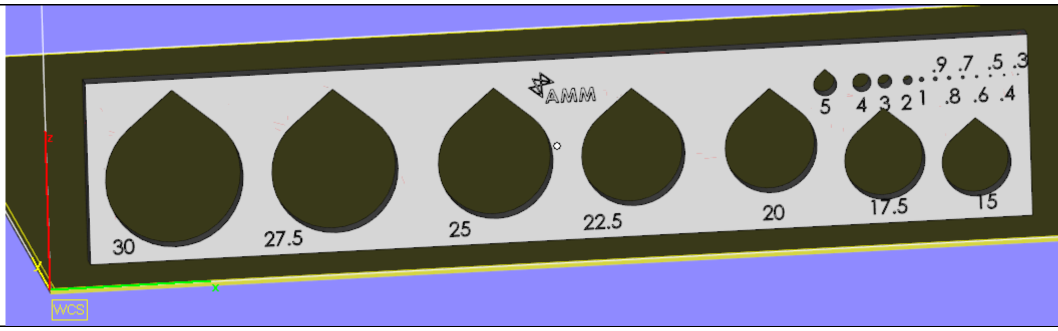
Figure 4; Holes built in a horizontal direction

Recommendations:

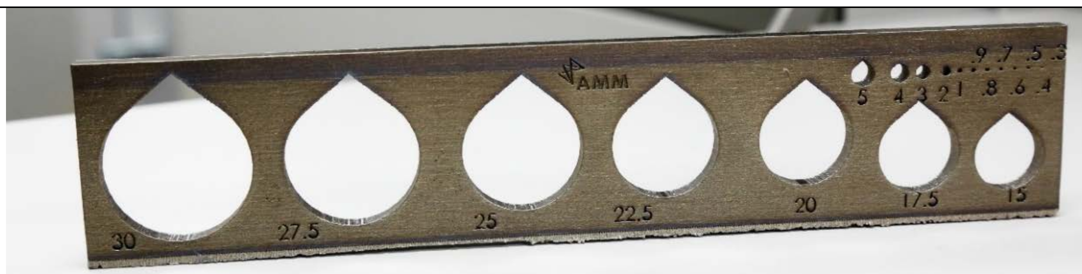
It is recommended that:

- Avoid horizontal holes and passages with circular cross-sections

- If not avoidable, the circular geometry of the cross-section should be modified to pear or cone shape:



CAD model



DMLS part

Figure 5; Modified holes built in horizontal direction

- If there is no freedom to change the design, the horizontal holes can be still be built, but their top down facing surfaces need to be supported if their size is larger than 10 mm. However, it should be noted that supporting the long horizontal holes and passages such as in conformal cooling channels in molds and tool inserts will be problematic as support removal will not be an easy task and in fact, is almost impossible:

2.1.4 Wall Thickness

The thickness of the wall that can be printed without support has been reported to be highly material dependent. The minimum wall thickness also depends on the offset of the laser beam (beam diameter plus the size of the curing zone). Very thin wall sections -or placing a thin section against a thick section - may result in significant distortion due to the very high temperatures involved in the process.

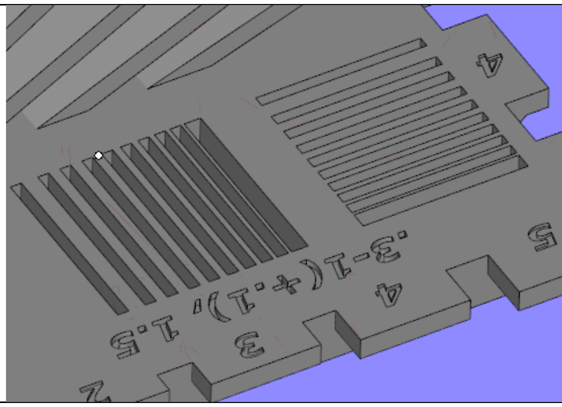
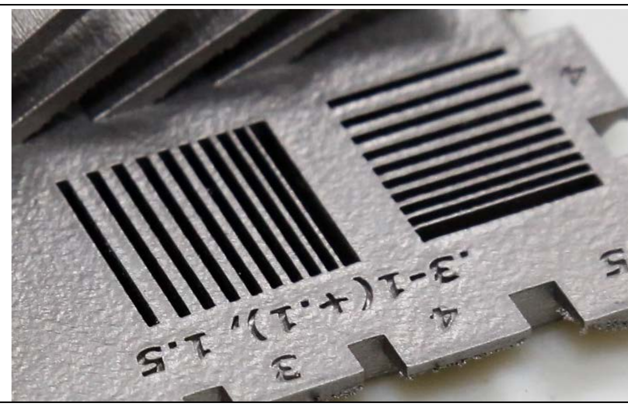
	
CAD Model	*DMLS Part*

Figure 6; Building thin walls in additive metal manufacturing

Electron Optical Systems (EOS) Inc. provides the data in Table 3 as the minimum wall thickness that can be built without any support. Walls with smaller thickness can be printed but they will need support.

Material	Minimum Wall Thickness
Maraging Steel MS1	approx. 0.4 - 0.6 mm approx. 0.016 - 0.024 inch

Table 3

Recommendations:

It is recommended to:

- Keep the minimum wall thickness as 0.4 mm.

2.1.5 Over-hangs

Any feature on a part that has a down-facing surface is defined as the over-hang. Over-hangs can be built without any support material if their orientation angle is above 35°. If they are below 35° they need to be supported.

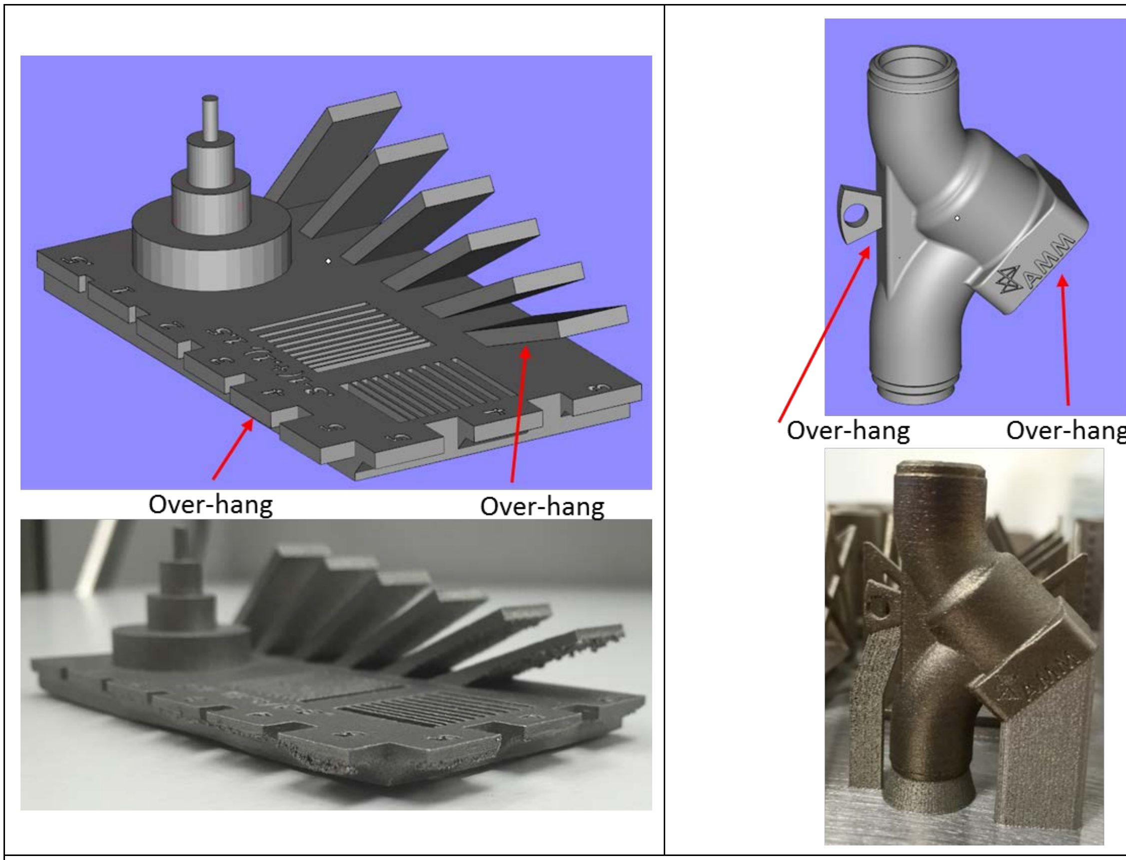


Illustration of over-hangs in CAD model and correponsing DMLS part

Figure 7; Over-hangs in additive metal technology

Recommendations:

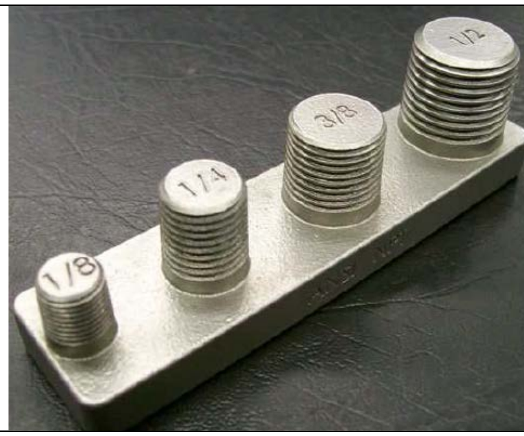
- Avoid over-hangs in the design as much as possible
- Modify the design to optimize the geometry of the over-hang

2.1.6 Threads

Threads are not a good candidate for additive manufacturing. They generally consists of down-facing surfaces with an orientation angle below 35°. However, if they are to be manufactured based on DMLS, the following points are recommended:

Recommendations:

- Place them in a vertical direction
- Standard threads are usually chased with a tap
- Small threads are usually recommended to be removed from the CAD file and post-machined



Threads (courtesy of EOS)

Figure 8; Threads in additive metal technology

3 Appendix I – Maraging Steel (MS1) for DMLS

The name Maraging comes from "mar"tensite + "aging" [treatment].

- Parts built in EOS Maraging Steel MS1 have a chemical composition corresponding to US classification18% Ni Maraging 300, European 1.2709 and German X3NiCoMoTi 18-9-5
- It is a low-carbon steel with martensitic structure
- Yield strength; as built is 1000±100 MPa and after age hardening is 1990±100 MPa
- Tensile strength; as built is 1100±100 MPa and after age hardening is 2050±100 MPa
- It is hard and tough; hardness as built is 33-37 HRS and after age hardening 50-56 HRC
- It has a very low shrinkage factor
- There is no difference between MS1 and the conventional 1.2709

- This material is best suited to this process (best possible results) and fulfils all tooling requirements
- The maximum operating temperature for MS1 is 400°C (750°F). The majority of plastic materials are injected at approximately 280°C and for this reason the factor temperature is not critical at all for MS1.
- In both as-built and age-hardened states the parts can be machined, spark-eroded (EDM), welded, micro shot-peened, polished and coated if required. Due to the layer-wise building method, the parts have a certain anisotropy, this can be reduced or removed by appropriate heat treatment
- Porosity is not an issue for the MS1 material. The process allows complete control of the porosity values and a mold relative density of nearly 100 %
- After polishing it is possible to achieve roughness values of "Ra (ISO) up to < 0.5 µm" and "Rz (DIN) up to < 0.02 mm"