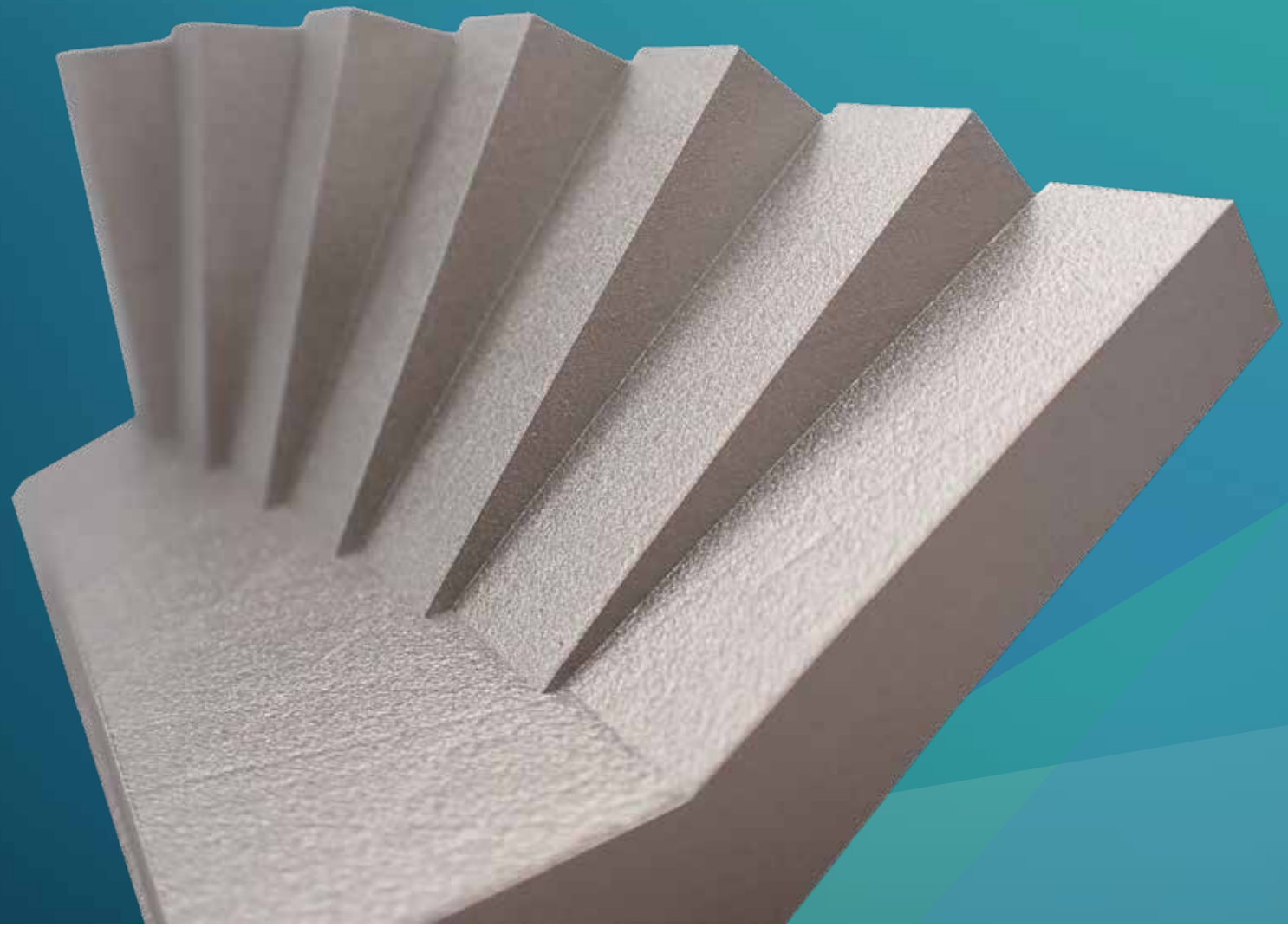
User Guide

Direct Metal Printing 101



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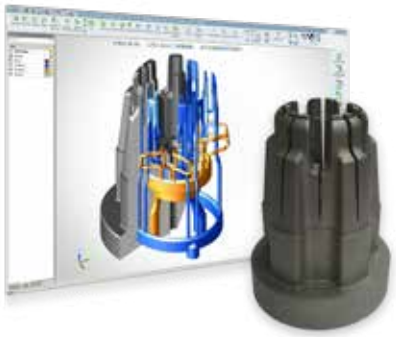
Contents

Why direct metal printing

Direct metal printing (DMP) is an additive manufacturing technique that produces parts in a broad variety of metal alloys.

Starting from metal powder, the product is manufactured layer by layer. Each layer is melted onto the previous one creating a strong and dense part (up to 99.9%) comparable with conventional manufacturing techniques (milling, casting). In this process almost no waste material is created and complex geometries can be built that could not be manufactured otherwise.



DMP is ideally suited for manufacturing complex, organically-shaped internal features (e.g. conformal cooling channels).

Combining multiple parts into one single product eliminates the weakness of assembly processes (e.g. welding), thereby adding functionality.

BENEFITS OF DIRECT METAL PRINTING

Increased functionality of parts
Including thermal, flow, and structural functionality, or integration of various functions into one part

Greater design freedom
Ability to make optimized organic shapes

Enhanced system-level performance
Improved fuel efficiency, reduced maintenance

Customized products
Internal structures like complex cooling channels that could not be produced otherwise, patient-specific applications in healthcare, etc.

Part count reduction and removal of secondary operations
Reduction or elimination of assembly

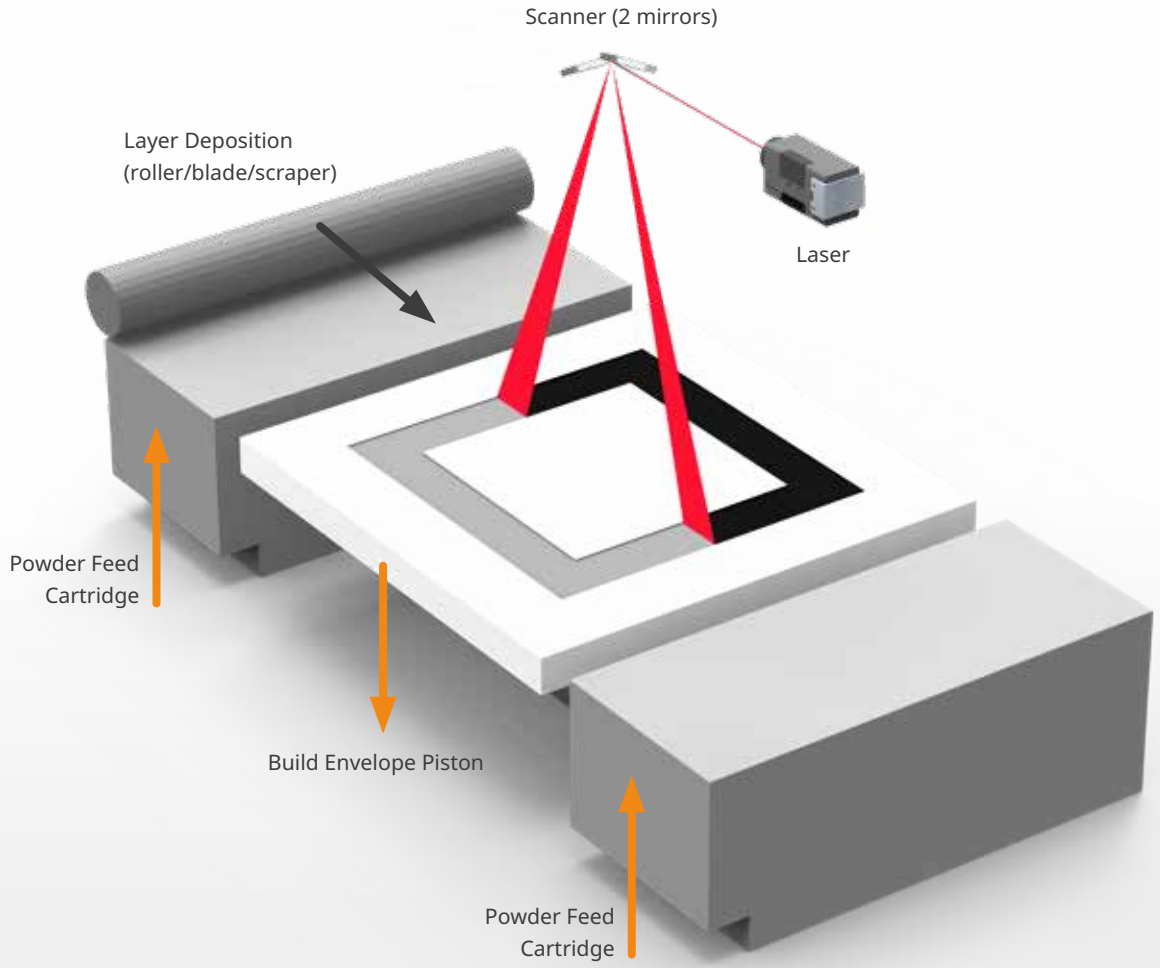
Fast production
No tools or extensive programming required

Waste reduction

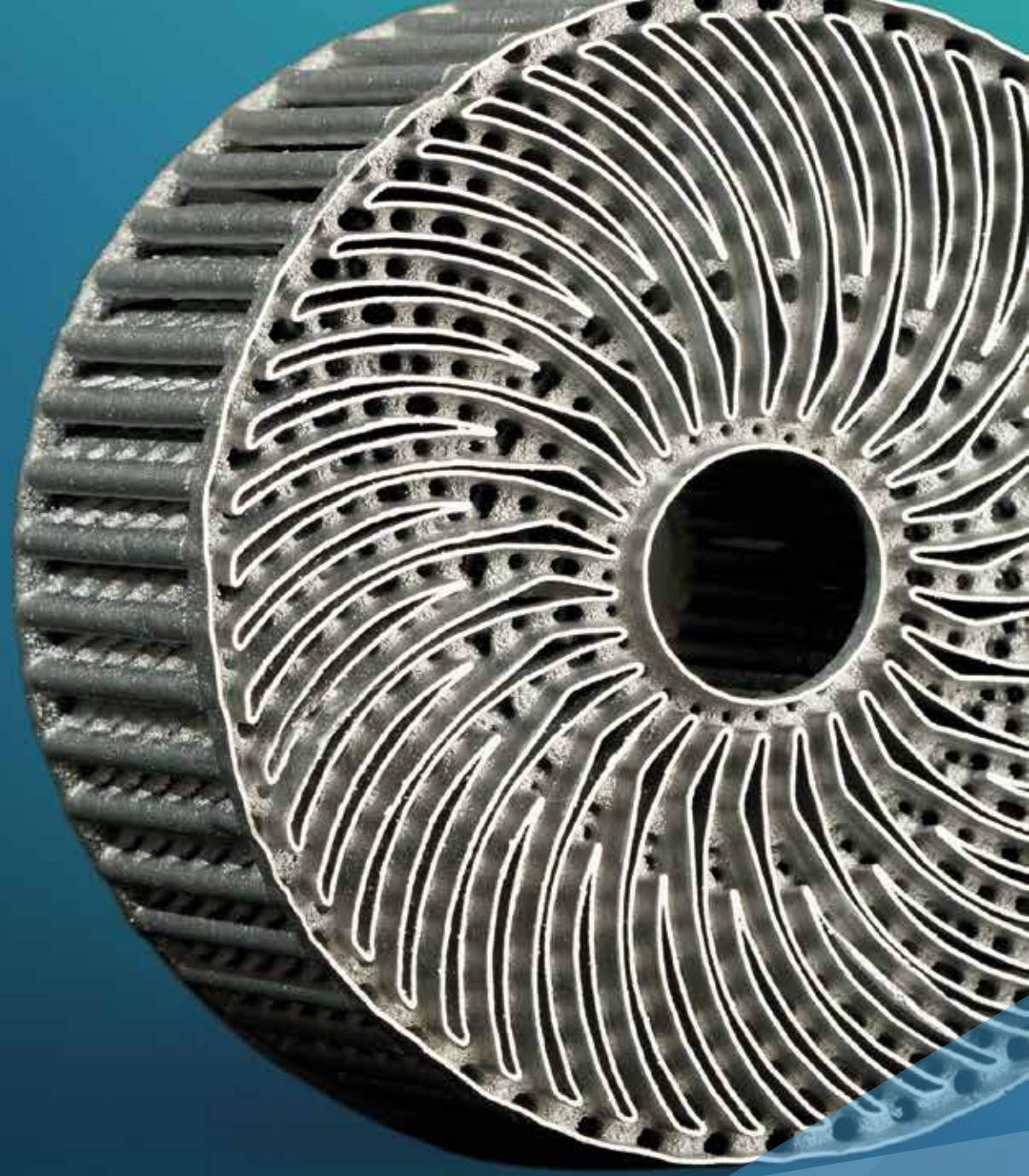
Weight reduction
Use of lattice structures, topology optimization, etc.

The direct metal printing (DMP) process

- Layers of metal powder can be deposited in increments as low as 10 microns
- Laser scanners apply optimal energy density to fully melt the powder into fully dense parts (up to >99.9%)
- Bi-directional coating of the powder increases throughput
- Ultra-low oxygen environment allows for <25ppm oxygen
- Argon is recycled to minimize consumables for long builds
- Additional in-situ monitoring tools are available to inspect and qualify products

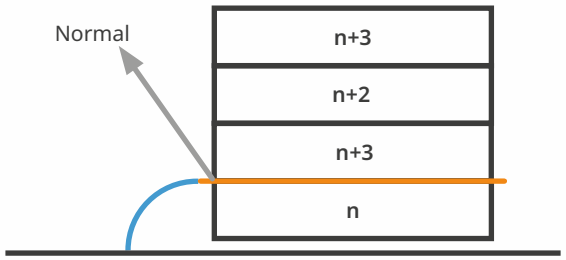


Basic principles of DMP



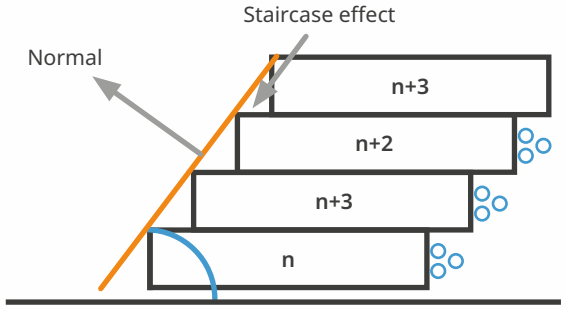
Basic terminology

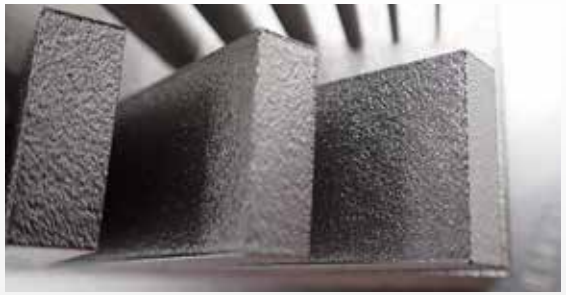
MIDDLE SURFACES



Middle surfaces are characterized by the normal of the object pointing parallel to the build platform.

UPFACING SURFACES

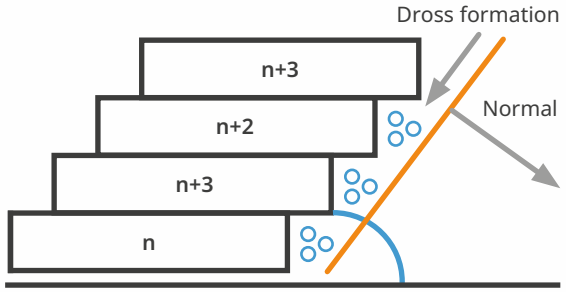




Upfacing surfaces are characterized by the normal of the object pointing away from the build platform.

DOWNFACING SURFACES

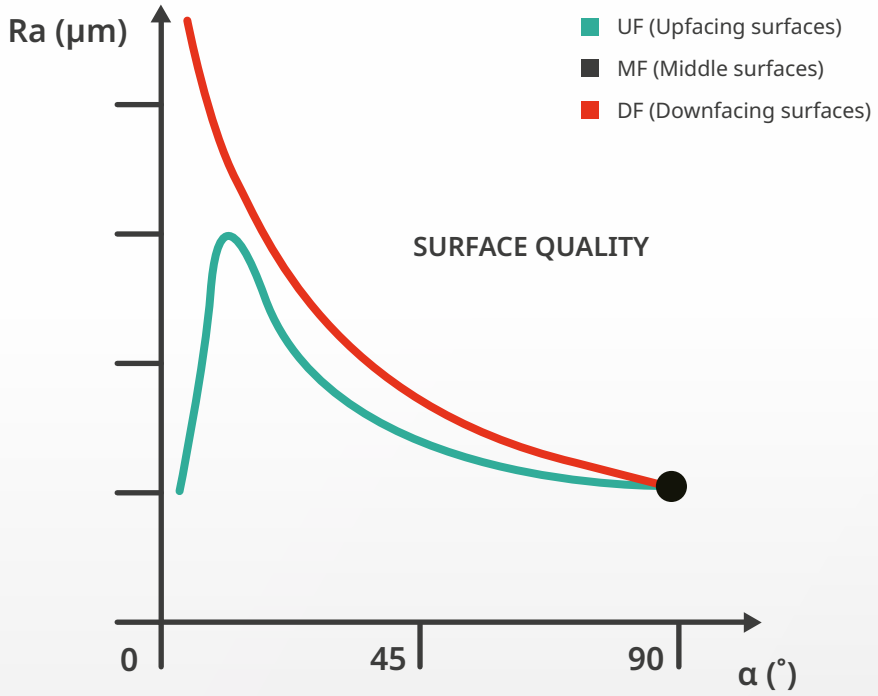
The edges of downfacing surfaces are built on unmelted metal

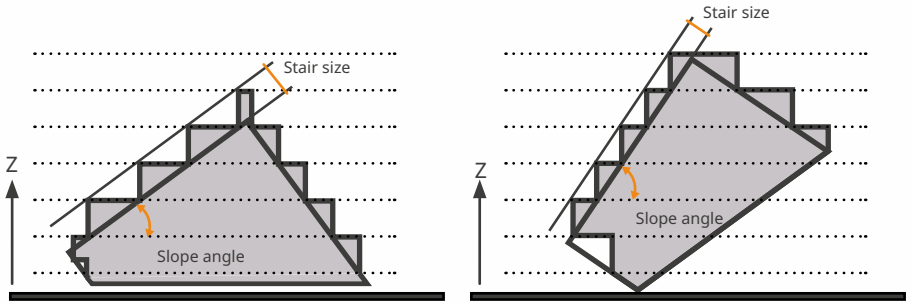


Downfacing surfaces are characterized by the normal of the object pointing towards the build platform.

Influences on quality

Surface quality depending on type of surface and angle



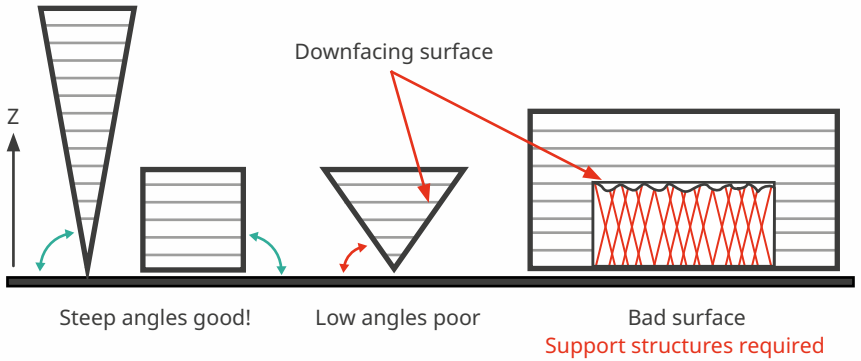


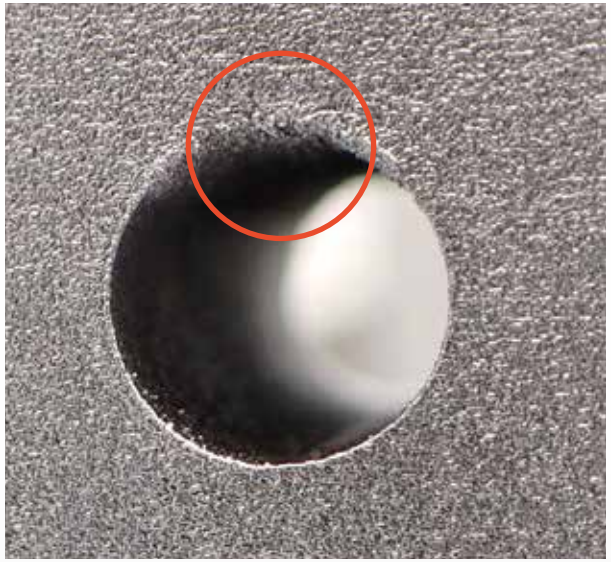
Surface quality in DMP is dependent on the orientation of the surface.

The stair stepping effect that is intrinsic to all additive manufacturing technologies can be reduced by building more vertically or completely horizontally oriented surfaces.

On upfacing surfaces this effect is clearly visible and important.

Influences on quality





On downfacing areas, the dross formation effect is in most cases bigger than the stair stepping effect. Dross is the undesired amount of molten material and particles as a consequence of melting on loose powder.

- The lower the angle, the more dross formation you have, resulting in
  worse surface quality
- Low angles need support structures, which are temporary features that provide additional stability during printing, and which are removed in post-processing operations
- Supported faces have worse quality

Basic principles

Why do we have thermal stress in the part?

- High melting temperatures (e.g. titanium: 1650°C; stainless steel: 1200°C)
- Fast cooling rate 1ms/100°C)
- Stresses accumulate throughout layers, because the top layers are heated and cooled down again for each layer. Expansion and shrinking, blocked by already solidified layers causes residual stresses
- Deformation behavior is material specific

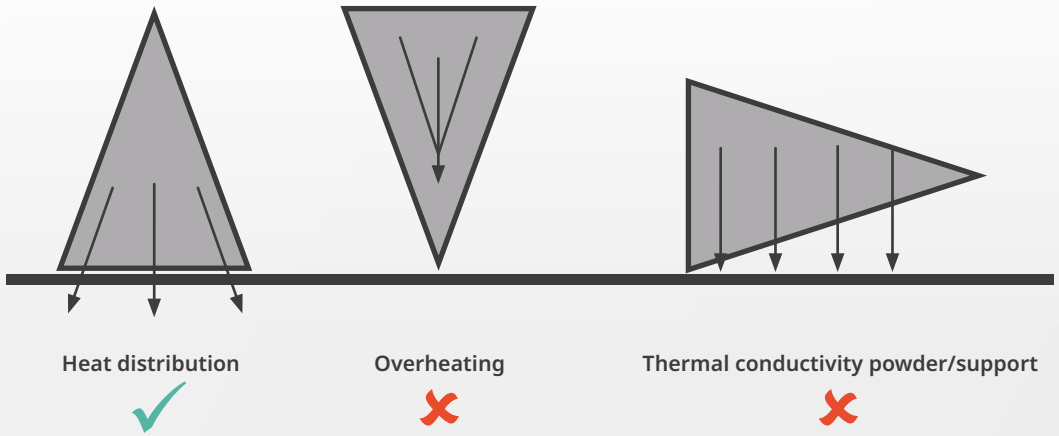
Important influences on those stresses

σT ~ A Thermal stress is proportionate to the melted surface area.
To mitigate this:

- Reduce area to be melted per layer
- Ensure longest direction of part along Z-axis
- High number of small sections is better than one big section

σT ~ ΔT Thermal stress is proportionate to the temperature drop during solidification

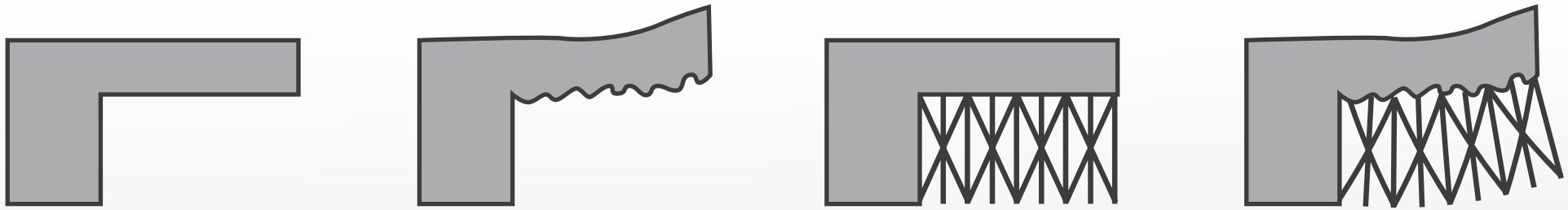
Make sure you have good heat transfer to the base plate and machine. The better the heat is transferred, the less a part will warp.



How to handle thermal stresses

- Residual stresses result in parts that want to warp
- Support structures are needed to avoid warping and keep part in position
- Stresses remain in the part after building — if support is immediately removed, the part will still deform to the unwanted position

Heat treatment is required after powder removal, prior to platform and support removal, to release the stresses



DESIGNED MODEL

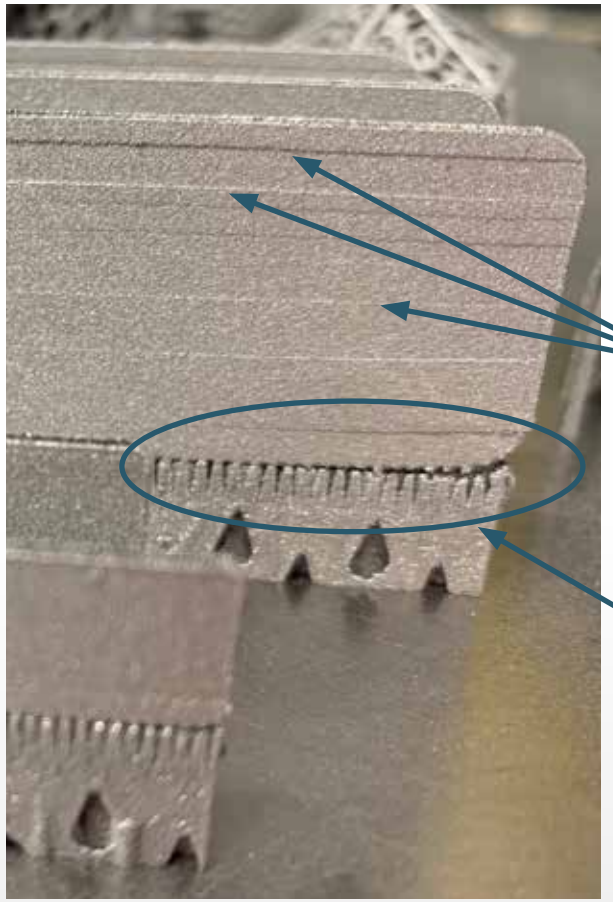
WARP AND DROSS FORMATION

SUPPORT STRUCTURE

WARPING IF REMOVED FROM PLATE PRIOR TO HEAT TREATMENT

Layer shifts

- Caused by improper supporting
- Connection between supports and parts crack releasing residual stress
- Part shifts as crack propagates
- Laser is unaware of this change and continues to scan according to design intent
- The result is a horizontal ‘shift’ across the entire scan area

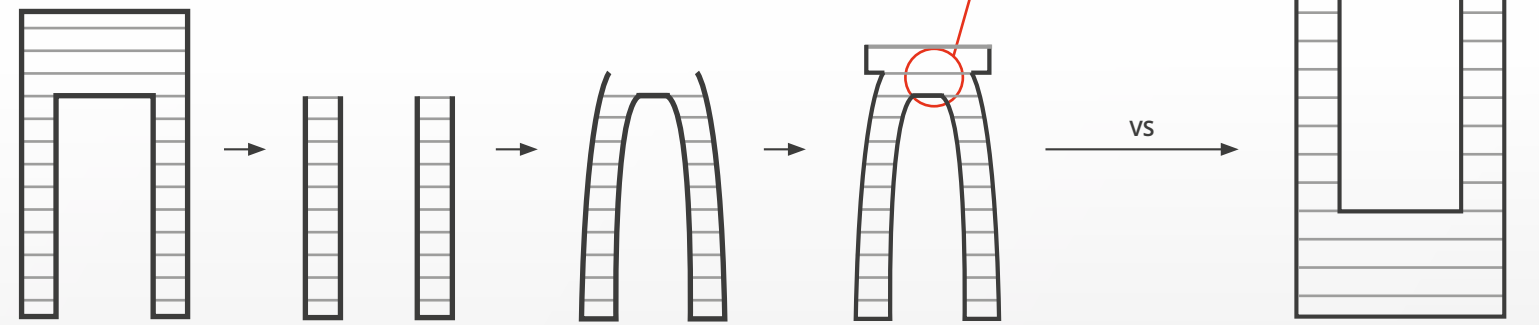


Causes of shrink lines

Shrink lines appear when two separate entities are connected in one layer

- The connection surface shrinks and pulls the two entities towards each other
- Next layer is printed on original dimensions again
- Line visible in the part
- Typical on bridges/internal channels

Layer shifts = supporting issue
Shrink lines = geometry issue



DESIGNED MODEL

VERTICAL BUILD

As these vertical columns build up, each has its own tensile residual stresses, but they are not interacting with each other.

HORIZONTAL BUILD

A large, sudden change in the cross-sectional area invites shrink line formation due to the interaction of residual stresses.

DEFORMATION

The laser continues to scan based on your designed model.

OPTIMIZED ORIENTATION

Avoid shrink lines by designing or orienting the part so that features diverge rather than converge as they build in the Z-direction.

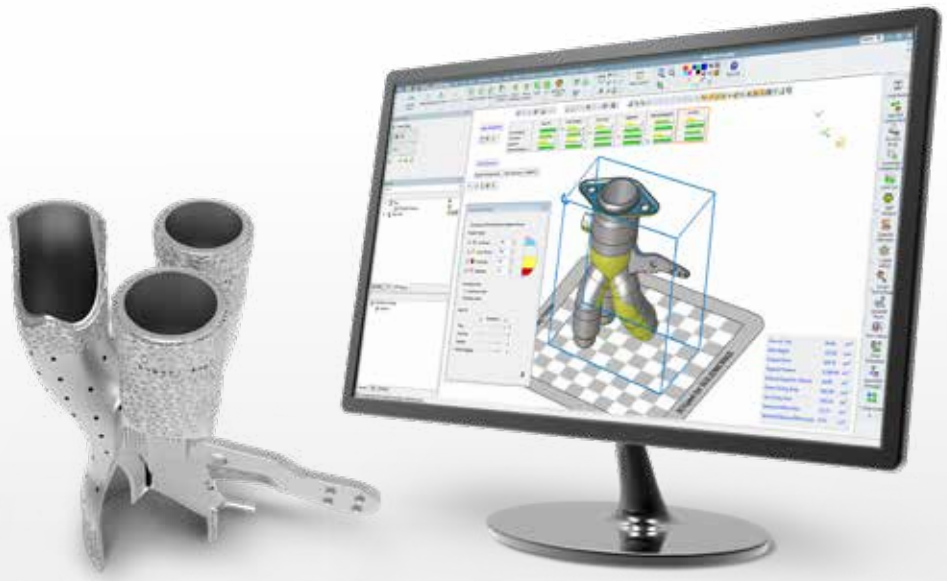
Predicting shrink lines using 3DXpert® software

3DXpert is an all-in-one integrated software for the entire AM workflow that provides the ultimate combination of automation and full user control.

The simulation tools within 3DXpert enable users to effectively predict where and how displacement may occur on a part in order to optimally place supports for the intended outcome.

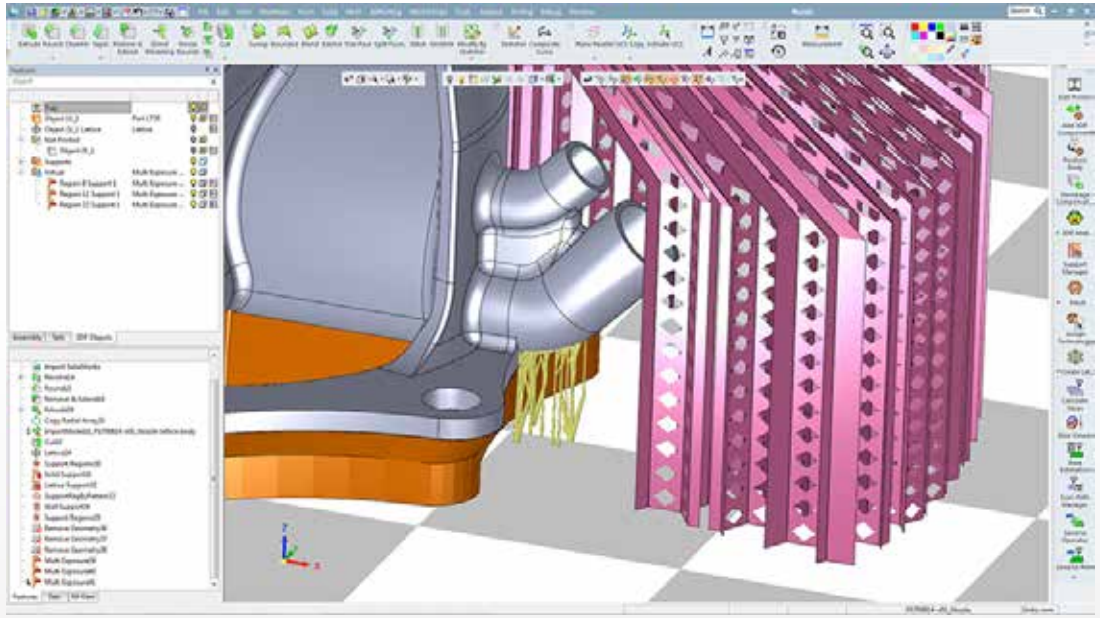
3DXpert also makes it possible to minimize manual operations through the use of compensated models, in which the software counteracts predicted displacements to achieve the ideal state.

Xp 3DXpert®



Support structures

Proper support is needed for heat transfer, to prevent warping, minimize dross formation and reduce shrink lines.

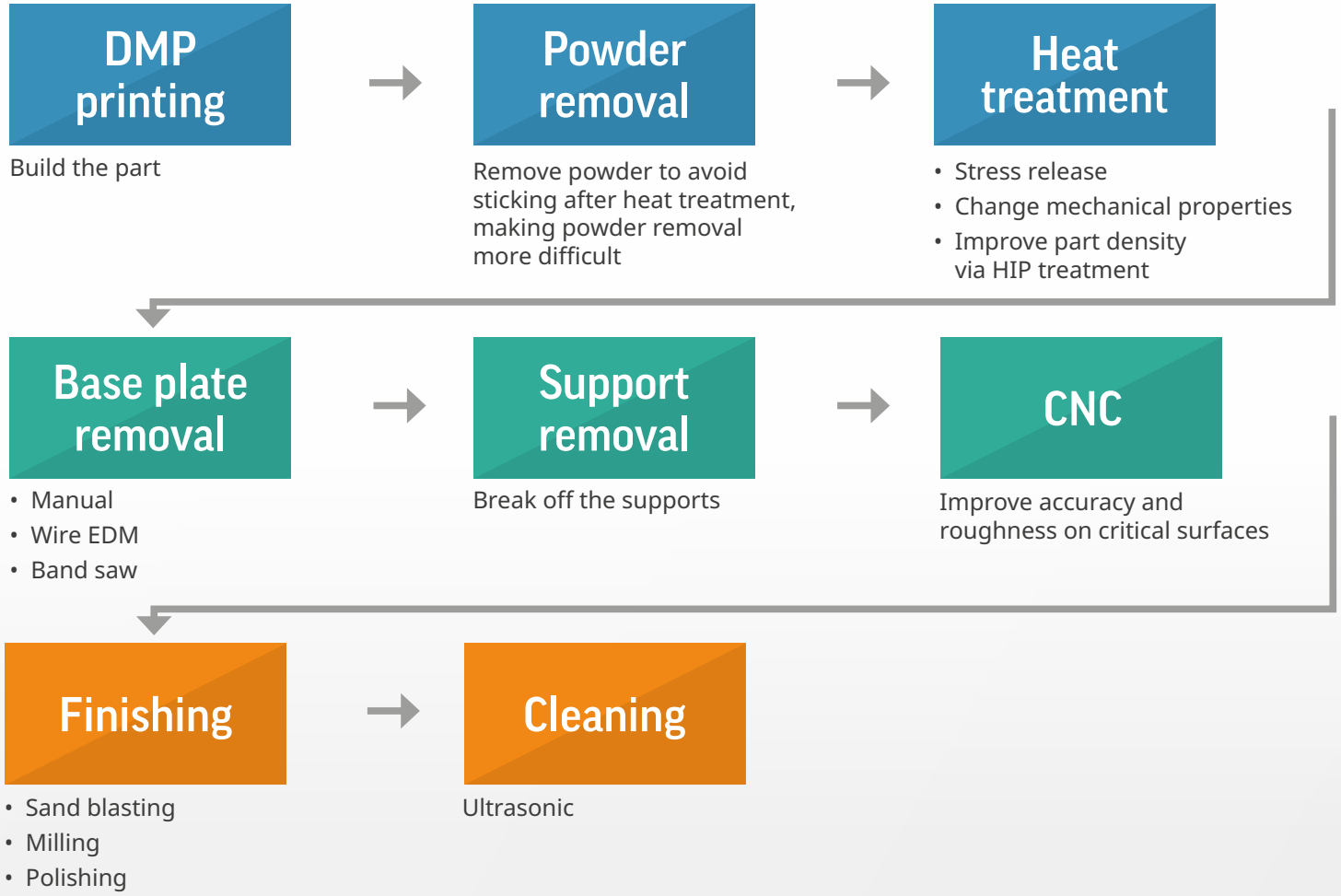


There are a multitude of possible support structures.

Here are some examples:

Post-processing

Typical process flow*

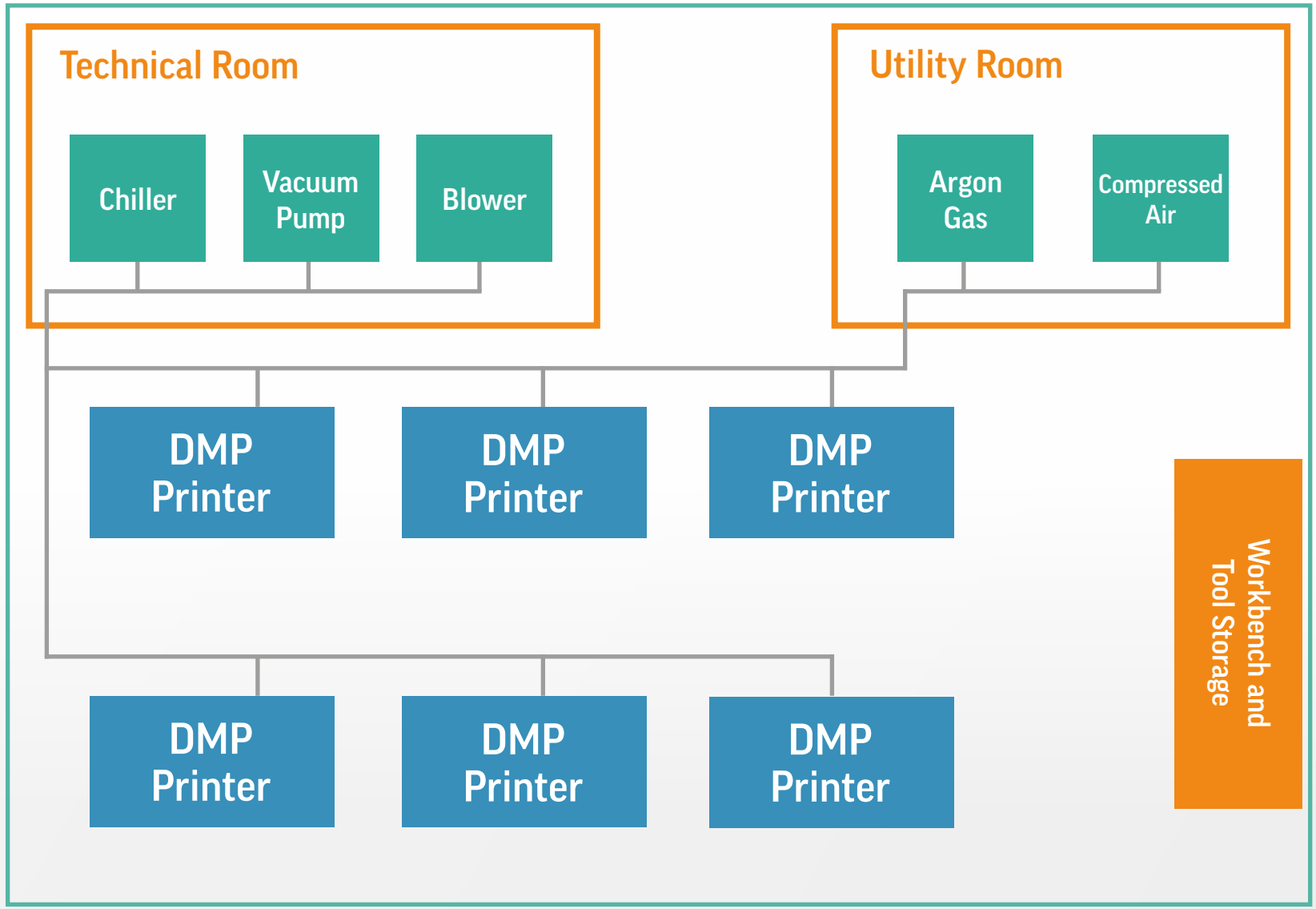


*This workflow is for illustrative purposes and is not exhaustive. Additional post-processing operations similar to other production techniques for like materials are possible, though they may require some fine-tuning from an AM expert.

Additional post-processing options

- Apply coating on parts
- Common quality checks:
  - X-ray to check internal channels
  - Optical scan to check dimensional accuracy
  - Geomagic software can show post-build deformation based on scan data
  - 3DXpert can predict post-build deformation and compensate for it

DMP LABORATORY SET-UP



DMP safety

Like any manufacturing process, direct metal printing requires safety equipment.

Personal Protection Equipment (PPE) that are required when working with metal powders:

- Masks and respirators
- Eye protection
- Nitrile gloves
- Head cover
- Shoes: anti-static, conductive soles, safety toe
- Anti-static or conductive outer garments (coveralls)
- Hearing protection depending on the dB level

Good housekeeping

Keeping a clean work environment is also a critical way to stay safe when printing with metals. Regular housekeeping can make sure that dangerous concentrations of dust are avoided. Some examples of good housekeeping include:

- Using a wet separator, explosion-proof vacuum cleaner after each use to avoid potential dust clouds
- Using a floor cleaning machine at the end of each shift, to avoid dust layers
- Using a dust extraction system to remove airborne dust
- Using pure ethanol to wipe down the modules after each use

Additional safety

Fire extinguishers
The facility must have a Class D fire extinguisher or dry sand, or salt and a fire blanket present in the work area. Also consider having a class ABC portable on hand as well for non-metal fires.

Room ventilation
During the preparation, loading and unloading, argon gas is released to the workplace. During cleaning of the machine, powder particles/dust may become airborne. It is recommended to use room and personnel oxygen monitors.

Waste disposal areas
Closed metal containers need to be available for waste disposal. Containers should be stored in a closed environment outside the production facility.

DMP printers

DMP FACTORY 500

Scalable metal additive manufacturing for seamless large parts

- Build volume 500mm x 500mm x 500mm
- Integrated powder management
- Consistent, low O2 environment
- Intelligent, seamless part production
- Scalable production manufacturing
- Multiple materials

Accessories

- Depowdering module (DPM)
- Powder recycling module (PRM)
- Parking module (PAM)
- Transporter module (TRM)
- Removable print module (RPM)

DMP FLEX 350 AND DMP FLEX 350 DUAL

Robust, flexible metal 3D printer for 24/7 part production

- Build volume 275mm x 275mm x 420mm
- Fast, easy material change
- Consistent, low O2 environment
- High throughput, high repeatability
- Multiple materials

Accessories

- Removable print module (RPM)
- RPM Transport Cart

DMP FACTORY 350 AND DMP FACTORY 350 DUAL

Scalable, high quality metal additive manufacturing with integrated powder management

- Build volume 275mm x 275mm x 420mm
- Integrated powder management
- Consistent, low O2 environment
- High throughput, high repeatability
- Dedicated material

Accessories

- Volume reduction kit

DMP printers

DMP FLEX 100

Affordable, precise metal 3D printer for finest features and thinnest walls

- Build volume 100mm x 100mm x 90mm
- Fine features, thin walls
- Best-in-class surface finish
- Unique roller/recoater system
- Perfectly layers almost any powder
- Dedicated material

DMP FLEX 200

Professional and precise metal 3D printer with 500W laser source

- Build volume 140mm x 140mm x 115mm
- Easy loading and cleaning
- High performance at lower cost
- Fine features, thin walls
- Best-in-class surface finish
- Unique roller/recoater system
- Perfectly layers almost any powder
- Dedicated material

Accessories

- Volume reduction kit

Titanium

LaserForm Ti Gr5 (A)
High strength, low weight, excellent biocompatibility

LaserForm Ti Gr23 (A)
High strength, low weight, excellent biocompatibility, lower oxygen than Gr5

LaserForm Ti Gr1 (A)
High strength, biocompatible, extreme temperature and corrosion resistance

Stainless steel

LaserForm 316L (A)
Able to be sterilized and highly corrosion resistant

LaserForm 316L (B)
Able to be sterilized and highly corrosion resistant

LaserForm 17-4PH (A)
Excellent corrosion resistance, high strength with good toughness

LaserForm 17-4PH (B)
Excellent corrosion resistance, high strength with good toughness

Maraging steel

Certified M789 (A)
Cobalt free, high strength tool steel with excellent corrosion resistance

LaserForm Maraging Steel (A)
Excellent hardness and strength, good wear resistance

LaserForm Maraging Steel (B)
Genuine tool steel (1.2709), high strength and hardness

Cobalt-chrome

LaserForm CoCrF75 (A)
Highly corrosion, wear and heat resistant; biocompatible

LaserForm CoCr (B) or (C)
Highly corrosion resistant, suitable for biomedical applications

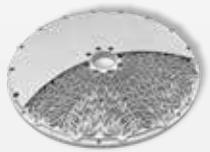
Aluminum alloy

Certified ScalmAlloy (A)
High strength aluminum with excellent corrosion resistance

LaserForm AlSi7Mg0.6 (A)
Lightweight, good mechanical properties, and improved thermal conductivity

LaserForm AlSi10Mg (A)
Good mechanical properties and good thermal conductivity

LaserForm AlSi12 (B)
Metal powder for lightweight parts with good thermal properties



A6061-RAM2 (A)
Improved strength, ductility, and surface finish versus AlSi10Mg

Nickel super alloy

LaserForm Ni625 (A)
Excellent corrosion resistance, high strength and heat resistance

LaserForm Ni625 (B)
Excellent corrosion resistance, high strength and heat resistance

LaserForm Ni718 (A)
Oxidation-, corrosion- and extremely high-temperature resistance

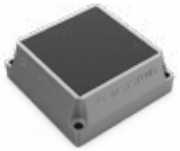
Certified HX
High-performance nickel alloy for enhanced strength, resistance to corrosion

Copper alloy

Certified Copper Nickel CuNi30
Excellent stable material properties and corrosion resistance in salt water

Certified Copper CuCr2.4
High-performance copper alloy with conductivity in structural parts

Refractory metals

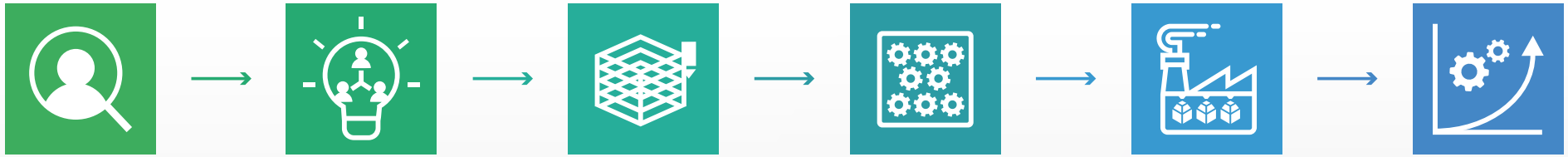


Tungsten (A)
High-density refractory pure metal with excellent radiation shielding capabilities and outstanding corrosion resistance

We're here to help

For more than three decades, 3D Systems has demonstrated our industry leadership and expertise to help manufacturers across a variety of industries redefine their workflows to realize the benefits of additive manufacturing.

We are committed to accelerating the development of advanced applications. From installation to hands-on training and consulting support, 3D Systems' experts enable you to quickly and effectively ramp from prototyping to volume production. 3D Systems' Application Innovation Group is a dedicated group of engineers, technicians and designers who can help you solve your most difficult design and production challenges. Whether that means identifying skill gaps, improving part performance, or scaling your manufacturing flow, we are available at every stage to apply our professional expertise to your unique goals.



Explore

Strategic consulting to identify customer needs

Innovate

Joint applications development and design for additive (DfAM) for specific needs

Develop

QA and process characterization from pre-prototype through prototype

Validate

Training, validation and certification

Develop

Production and manufacturing services

Scale

Scale up and technology transfer

What's next?

Our experts are here to support you.
Get in touch today – we will be right with you.

Talk to an Expert