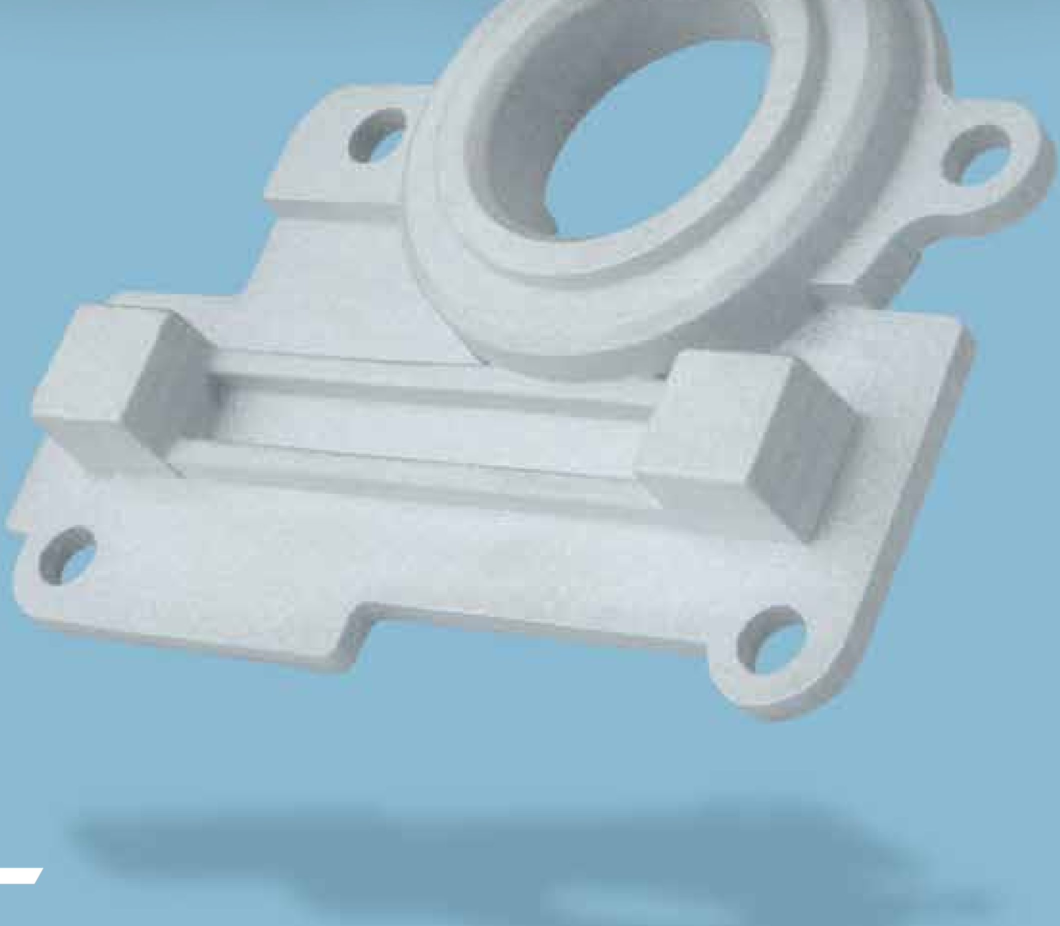
AMPOWER INSIGHTS

Design guideline
for sinter-based Additive Manufacturing



INSIGHTS GAINED:

- Functional principle of Binder Jetting and Metal FFF
- Best practices for design optimization
- Basic design guidelines to consider for print and sinter process

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About

This guideline is a collection of design rules developed by industry leaders in the field of Powder Metallurgy and sinter-based Additive Manufacturing. It is made possible by the gathered experience of more than 12 companies and institutions who contributed their knowledge into this continuously improving guideline.

Its purpose is to enable designers, engineers and students to leverage the full potential of sinter-based Additive Manufacturing technologies. We want to thank all contributors for their generous input and hope that many new users of sinter-based Additive Manufacturing technologies benefit from this guideline.

Contributors

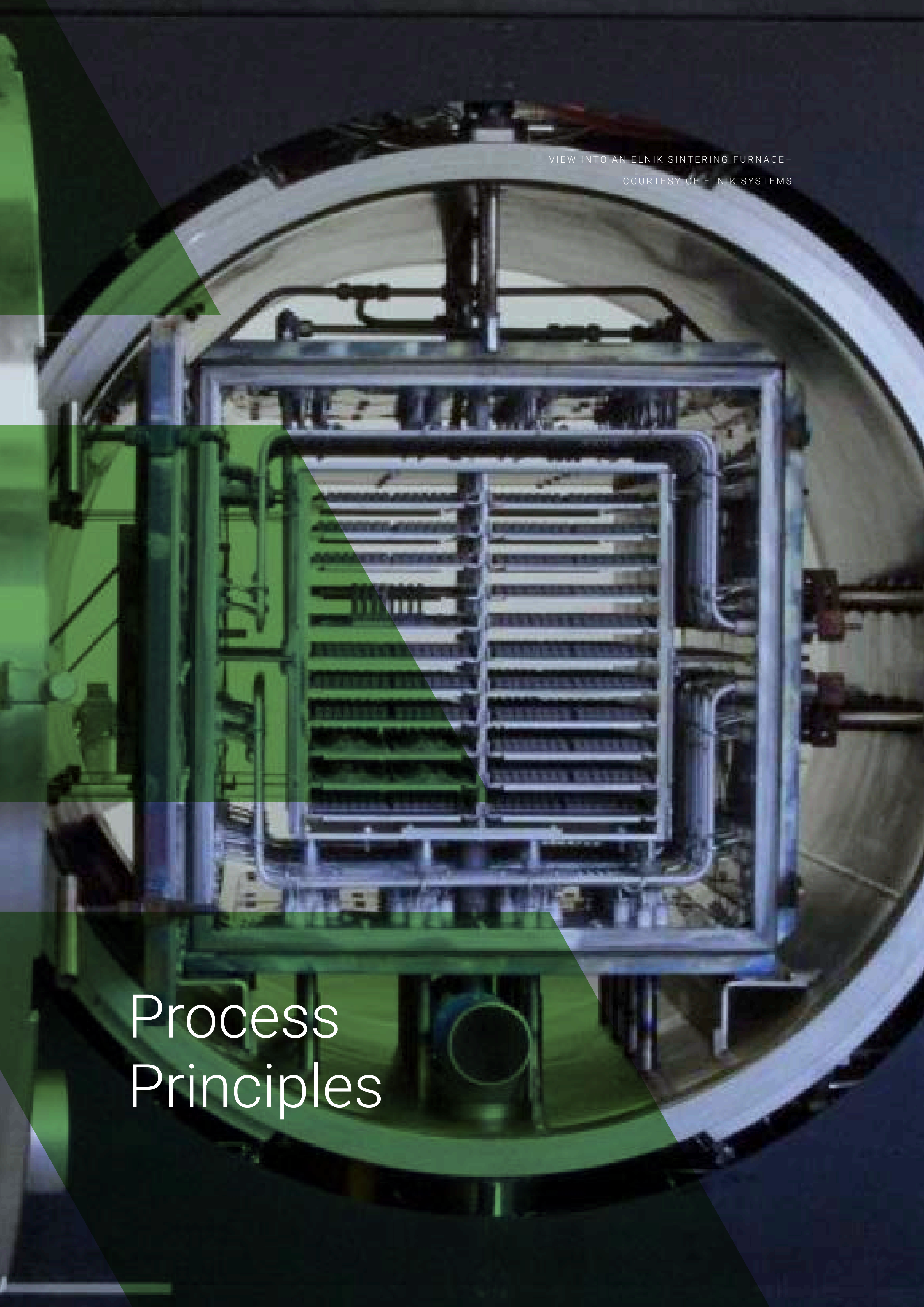
Alliance-mim · BASF We create chemistry · Forward AM · BOSCH · cetim · TIWARI Scientific Instruments · DSH Technologies · Digital Metal · ELNIK Systems · ExOne · Markforged · GKN · Fraunhofer IAPT · Fraunhofer IFAM · Desktop Metal

Content

About AMPOWER

AMPOWER is the leading consultancy in the field of industrial Additive Manufacturing. AMPOWER advises their clients on strategic decisions by developing and analyzing market scenarios as well as compiling technology studies. On operational level, AMPOWER supports the introduction of Additive Manufacturing through targeted training programs as well as identification and development of components suitable for production. Further services include the setup of quality management and support in qualification of internal and external machine capacity. The company was founded in 2017 is based in Hamburg, Germany.

Process Principles



VIEW INTO AN ELNIK SINTERING FURNACE–
COURTESY OF ELNIK SYSTEMS

Process chain

The process chain of sinter-based technologies differs from other AM Technologies. Especially the post-printing processes (debinding and sintering) are crucial to achieve the intended mechanical properties.

Printing

The green part is produced in the additive printing process. The part geometry is held together by a polymer or wax binder, which makes the part fragile for handling and post processes. Green part strongly depends on the amount and strength of the used binder system.

Debinding

The brown part is produced by debinding the green part. This step prepares the part for the sintering process by removing most of the binder from the part. The Brown part is even more fragile, because the metal powder particles are not yet bonded together to a solid structure.

Sintering

To reach the structural integrity and density of a metal part, a sinter process is required. The powder particles are bonded into a coherent, solid structure via a mass transport that occurs at the atomic scale. During the sintering process, a volume shrinkage occurs, which creates the final geometry of the part.

Green part printing technologies

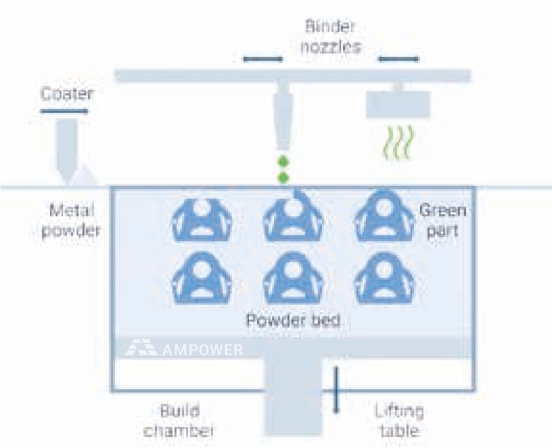
Binder Jetting

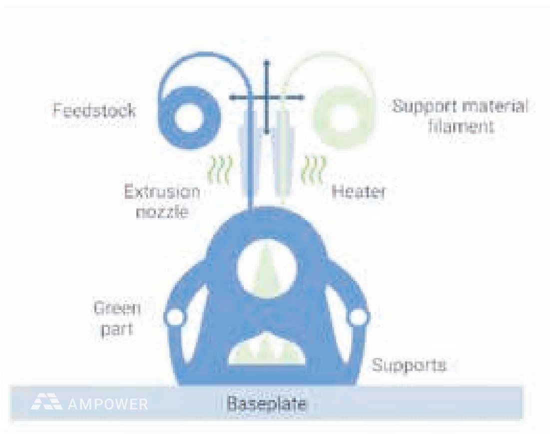
Binder jetting technology goes back to a development at the MIT which originally focused on sand casting forms. Since then, EXONE developed the first metal process based on binder jetting technology followed by DIGITAL METAL. DESKTOP METAL and HEWLETT PACKARD are among the latest suppliers that introduced Binder Jetting systems to the market.

The technology principle is still based on the original MIT patents which refer to a powder bed of sand or metal powder on which a fluid binder is locally applied by a nozzle array similar to 2D inkjet printing technology. This fluid binder solidifies by applying heat. After printing, the powder cake is being removed from the system and placed in a curing furnace. Depending on the binder, the curing temperature is between 100-200°C and takes around 24 h.

Metal Material Extrusion

Metal Material Extrusion (ME) uses filament, MIM feedstock or rods as base material. The raw material stock is a premixed compound of metal powder and polymer or wax binder. While the machine principle is very similar to polymer ME systems, the key difference lies in the material feeding system. The material extrusion has specific characteristics for applying the metal feedstock. Besides the compound feedstock, Metal ME offers the option to print soluble support material or separator material (e.g. ceramics) between metal supports and the part for easy removal after sintering. Most prominent system suppliers are MARKFORGED, DESKTOP METAL and AIM 3D. BASF offers a compound metal filament, which can be used in most polymer ME printers. The systems might require filament-specific modification to the extrusion mechanism as well as the hot end for best manufacturing results.





Depowdering and sinter preparation

Parts printed by Binder Jetting are separated from the powder cake and go through a manual depowdering process. Due to the fine powder particle size, the powder cake can be difficult to remove, especially from small cavities. The combination of fragile green parts and a firm powder cake is the reason for a mostly manual process, especially for fine details and thin-walled structures. For bulkier parts, semi-automated solutions are possible.

COURTESY OF FRAUNHOFER IFAM

After depowdering, the components are placed on trays to be sintered. To control the shrinkage behavior, different support strategies are followed such as life sinter supports made of green parts or ceramic supports that are reusable. Supported surfaces have to be separated by ceramic layers from the actual metal support.

PART AND SINTER SUPPORTS, COURTESY OF CETIM

Green part printing technologies

Green parts consist of 1st and 2nd stage binder fractions. Debinding mostly describes the process of removing the 1st stage binder which results in a brown part. The brown part is held together only by a minimum amount of 2nd stage binder which will be removed simultaneously with the sintering process. Thus, brown parts are extremely fragile.

Green parts with high binder volume such as Metal ME parts, can pe processed by grinding or milling before the debinding to achieve desired surface properties. Also support structures which were only needed for the printing but not sintering are removed. There a three debinding types adapted from the MIM industry:

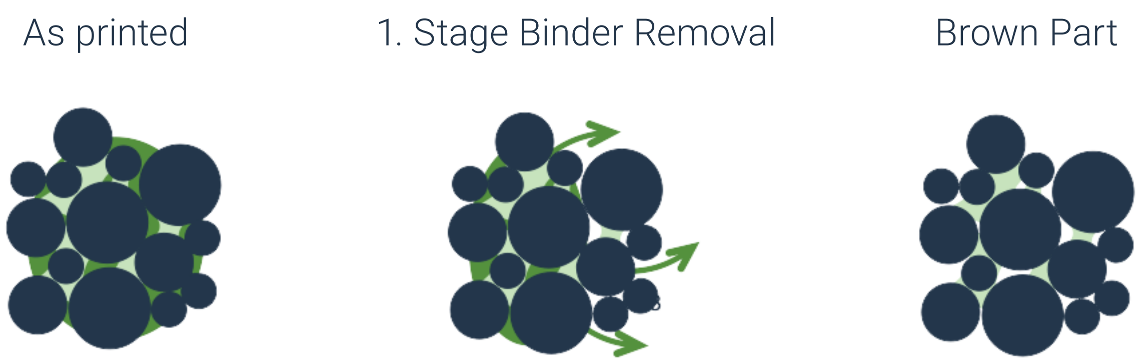
- solvent debinding
- thermal debinding
- thermal catalytic debinding

For solvent debinding, the part is placed in a tank with a solvent that dissolves the binder. This variant requires only simple equipment and is comparatively cheap. However, the handling of hazardous liquids can lead to safety concerns and the debinding process requires between 24-48 hours for effective removal of extractable solvents.

The thermal debinding process is based on thermal decomposition of the binder system. It can be performed in the same furnace that is used for the sintering process or a low-cost pre-process furnace. However, the process is time-consuming and only suitable for green parts with low binder saturation. Therefore, most Binder Jetting parts are debinded by thermal debinding. However, the equipment maintenance is increased due to the amount of organic material brought into the furnace.

For thermal catalytic debinding the part is placed in a gaseous acid environment and heated to about 120 °C. During this procedure, the binder system is removed even from thick-walled structures. The process works fast but is comparatively expensive and infrastructure for handling gaseous acids is required. The BASF Metal ME filament is debinded by catalytic debinding.

After the binder is removed, the part is in its brown state. The brown part consists of a minimum amount of secondary binder and therefore is extremely fragile when handling it.



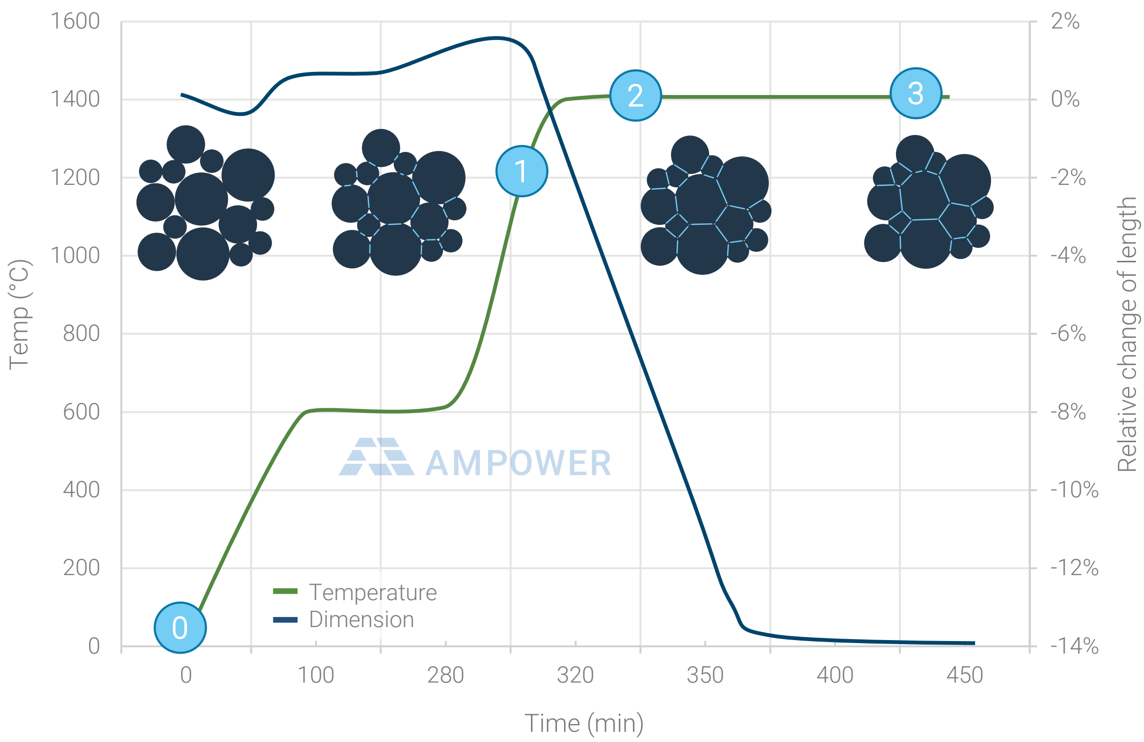
Sinter process

To reach the structural integrity of a metal part, a sinter process is required. The powder particles are bonded into a coherent, solid structure via a mass transport that occurs at the atomic scale driven via diffusional forces.

The part is heated in a furnace close to but under the melting temperature. The process is divided into three stages whereby a stage is defined as an interval of geometric change of powder particles and pores. In the **initial sinter stage (0)** powder particles are only bonded by Van-der-Waals forces. When the sinter temperature is reached, neck formation occurs between the particles **(1)**. In between a hold time for the thermal debinding process is set at the corresponding decomposition temperature of the secondary binder. In the **first stage (1)**, powder particles are bonded by round necks but channels between the particles are still present.

The **intermediate stage of sintering (2)** is characterized by an increase of packing density of the particles by merging of neighboring particles. In this stage, isolated pore structures are created. In the **final stage (3)**, the pore size decreases further until the porosity is eliminated almost completely.

During the sintering process a relatively large volume shrinkage occurs. The brown part shrinks 16 to 21 % in each direction. The shrinkage is anisotropic and larger in z-direction than in xy-direction due to gravitational forces, compression of the material and the fact that layers are bonded better horizontally than vertically in case of Metal ME.



Deep dive debinding & sinter parameter

Temperature & time

The sintering of metal particles is initiated by temperature. The bonding of the parts need a specific time to compact and reach the final density and mechanical properties. The control of temperature for a certain time is key to a working and economical process.

The combination of holding time and temperature is critical and must be adjusted to the material and geometry of the part. The sinter process parameters are therefore dependent on the material and cannot be described in general.

Atmosphere

Material specific atmospheres are used to protect material from oxidation, prevent decarburization of carbon-containing material or to reduce the carbon content for stainless steels. Therefore, the atmosphere must be adjusted to the material in use.

This causes the need of a high vacuum or Argon atmosphere when sintering e.g. titanium alloys while stainless steel such as 316L needs a near atmospheric high purity Hydrogen environment to prevent decarbonization.

The hydrogen atmosphere is used to reduce carbon from the binder system and prevent it from diffusing into the metal. Thus, H2 is crucial to control and minimize C content when sintering stainless steels.

Another relevant factor is the used gas flow within the debinding and sintering furnace. For optimal results, an even gas flow with partial pressure surrounding the part is recommended. This leads to an even temperature distribution and a consistent debinding.

Powder

Several powder characteristics influence the debinding and sinter processes. This includes the size of the particles, the composition and the powder density. Each having different effects on the debinding and sinter process.

Especially the debinding process is influenced by the particle size of the powder. The hold time for debinding can increase drastically with smaller metal particle sizes. This is caused by the smaller porosity of the powder to allow the decomposed gashouse binder fractions to evaporate.

Not only the characteristics of the powder is important, also the debinding properties should be investigated to design the process properly.

A Thermogravimetric analysis is sufficient to analyze and optimize the needed temperature and holding time. Particle size and distribution is also critical regarding the sinter process. Differences cause the powder to sinter at different times and temperature and therefore influence the parts properties. Smaller particle sizes support sintering at lower temperatures and / or dwell times due to the higher specific surface area, which increases sintering activity.

Insufficient sintering might also be caused by the powder chemistry. Containments, additives and oxidation can cause the metal part sintering to not be effective. Contaminations can also affect the behavior of the part during sintering and may cause unpredictable shrinkage.

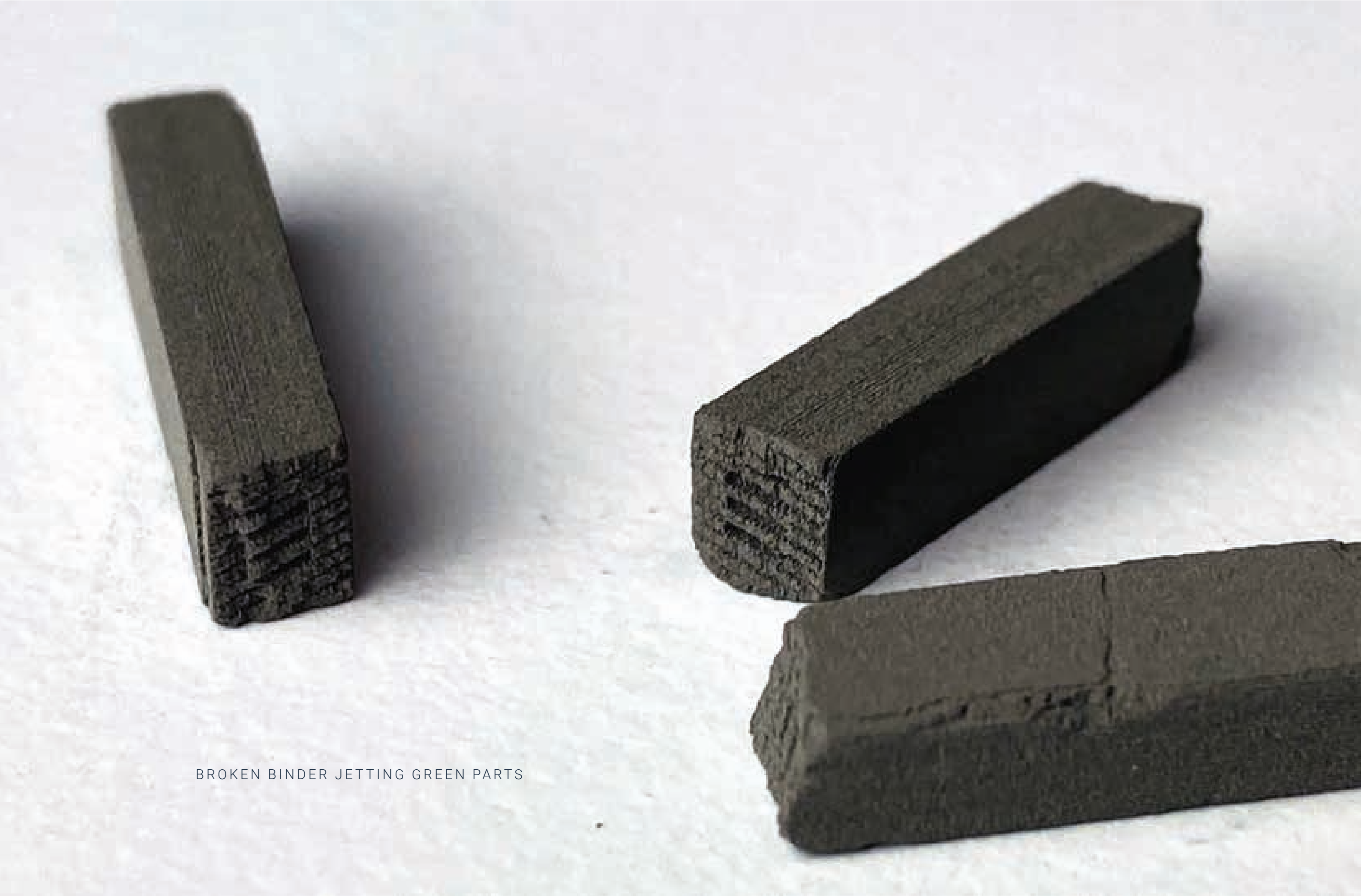
Effects of Design

Green part characteristics

A critical step within the post printing process is the handling of the green and brown part. During debinding the green part loses the stabilizing polymer resulting in a highly fragile behavior.

Green parts are made of metal powder and polymer or wax binder which means the stability is mostly given by the strength and density of the binder. Metal ME parts have a much higher binder content thus prove to be much less fragile than Binder Jetting parts which only have very little binder content. Metal ME green parts can be processed with conventional milling or grinding to achieve better surface quality due to their high stability. This is not possible for Binder Jetting green parts. On the contrary, BJT green parts are extremely fragile and can easily break even while unpacking or handling. After debinding both, Metal ME and Binder Jetting Parts are highly fragile due to the missing 1st level binder. The parts now cannot be mechanically handled anymore and have to be carried on trays.

The high fragility of Binder Jetting green parts limits the level of detail that can be achieved. Thin walls, pins or sharp edges are likely to break either during unpacking or handling. Still, resolution of BJT parts remains much higher than for Metal ME.



BROKEN BINDER JETTING GREEN PARTS

Shrinking and scaling

Shrinking and scaling is unavoidable due to the necessary sintering of the part to reach full density. The scaling factor might be different in each direction and has to be determined for every new geometry.

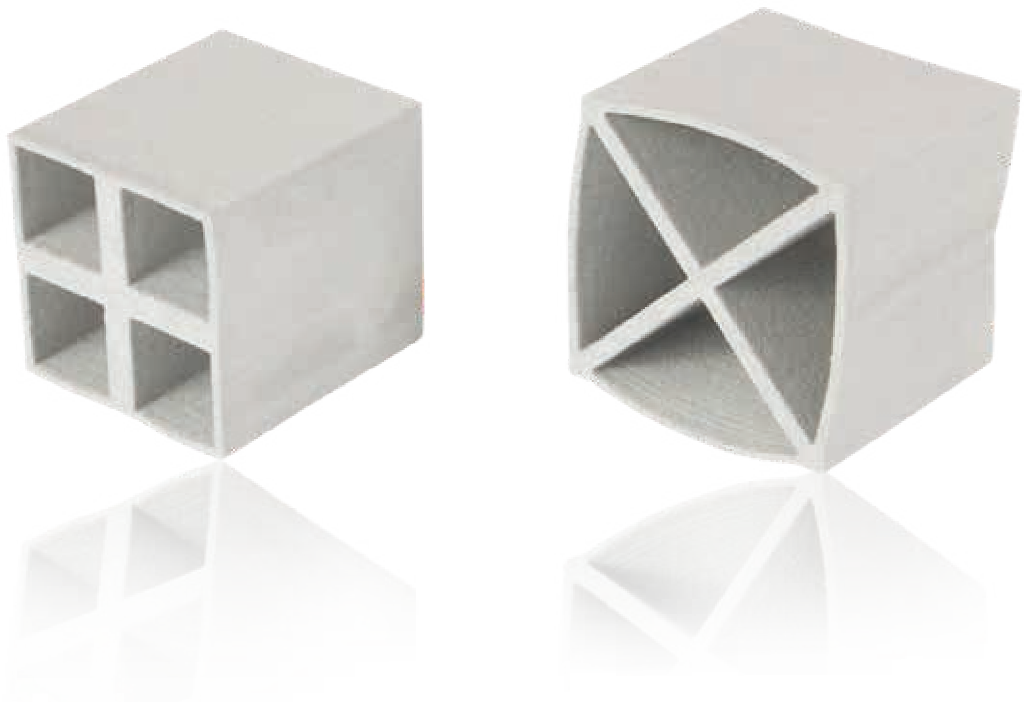
The shrinking of the part is caused by the sintering process. During this process, the bonding between particles is initiated and causes the particles to transport material to the contact area of the particles. The transport of material causes the densification of the part. The result is the shrinking of the part in every dimension.

The magnitude of shrinkage is also influenced by further parameters such as the parts geometry, the printing orientation, gravitational forces and green part density.

The x-y-z dimensions of the part show different dimensional changes due to shrinking. This aspect is important regarding the process knowledge but is irrelevant regarding the practical process chain.
The printing orientation should always define the debinding and sintering orientation. The orientation is not to be changed. Shrinkage can also be influenced by further parameters such as:

- Friction between baseplate and part
- Gravity
- Bending of unsupported features
- Powder contamination
- Particle Size
- Warpage during printing
- Wall thickness

These aspects must be considered for a proper design of the process chain.

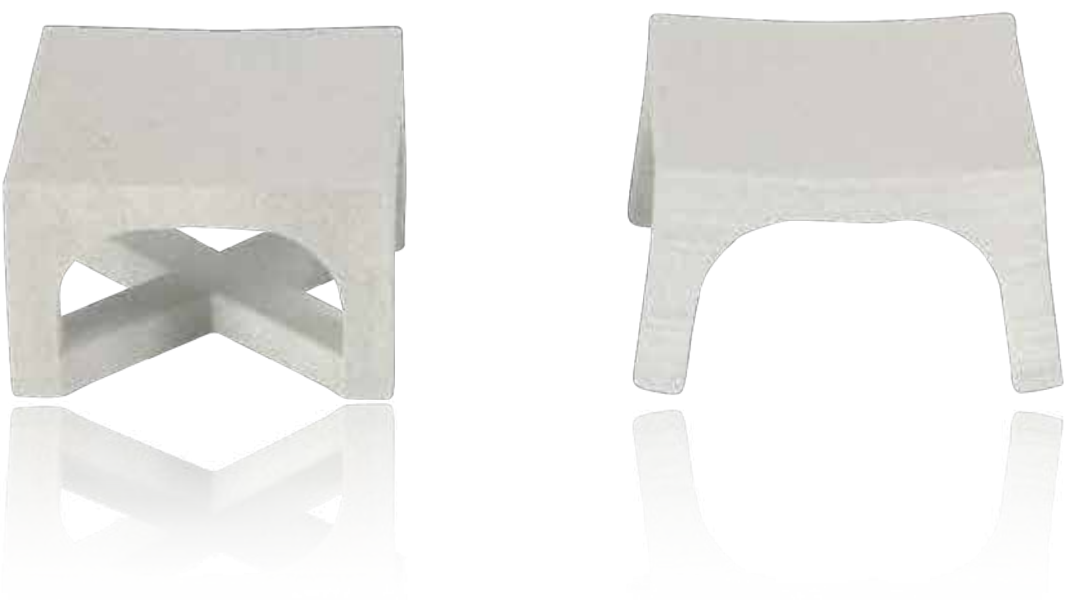


Friction of part and baseplate

Shrinkage of the parts in x-y direction induces friction between the part and the sintering plate. This effect might cause distortion of the part at the interface of plate and part.

During the shrinking process, the bottom surface of the part is gliding on the sinter base plate. While the rest of the part can shrink freely, the friction hinders an even shrinking. This causes the part to distort.

The friction effect can be reduced by sintering base plates or live setters, that shrink the same way as the part as they are made of the same material. During printing, green plates can be generated which go through the same shrinking process and can be placed between the part and the sintering base plate.
Even with those life sinter supports parts still distort if the design is not suitable. Especially the bottom surface should be one, connected surface that can shrink evenly. If the bottom surface is split into several single surfaces, the part tends to deform while the bottom sticks to the sinter base plate.



Distortion and cracking

Distortion of the part may be a result of the dimensional changes, that are caused by the sinter process. Distortion comes in different forms such as deformation, bending, warping and cracking.

The sinter process is dependent on heating up the part to reach a certain density and mechanical properties. The input of heat may cause distortion of the part, if design aspects are not in line with sinter requirements.

Structural parts, that have an uneven volume distribution, thus a great aspect ration, tend to warp at the thinner portions of the part, because the heat is absorbed faster. This effect is critical regarding geometries that have:

- A thin disc-shape
- Long bushings
- Uneven wall thickness
- Thin walls

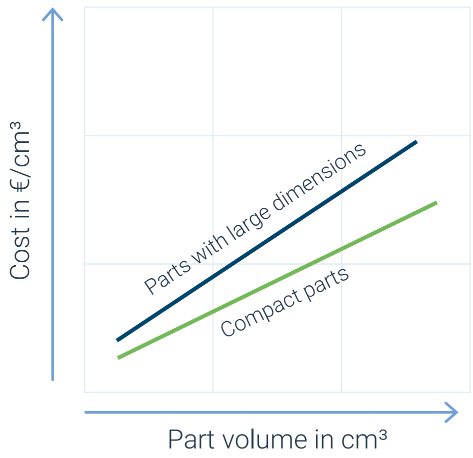
Besides thin geometries massive geometries are also likely to cause distortion. During sintering the surface is heated faster than the core, the temperature differences than cause tensions, that might lead to cracking.

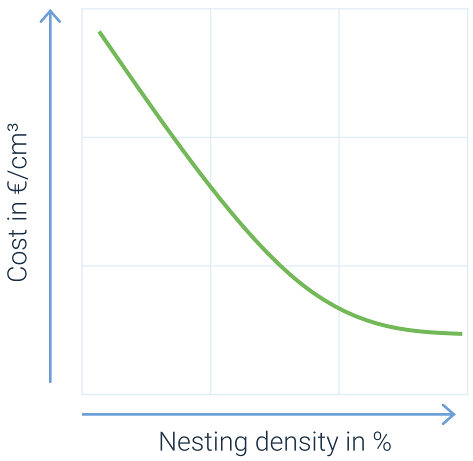
Gravitational forces can also influence deformation and even lead to cracks. While the part heats up, the material softens and large overhangs are forced downwards. Thus, overhangs should be avoided or supported during sintering.

Costdrivers

Besides volume and size, cost per part for Binder Jetting and Metal ME parts are influenced by several different parameters that can be influenced by the design.

Metal ME cost per part are mostly driven by the volume of each part. With increasing material volume, the part cost also increases linearly. High material cost and constant build rates influence a relatively constant cost per cm^3. While the sintering process cost are mostly driven by the overall dimensions of a part and the subsequent furnace utilization, debinding is dominantly influenced by the part thickness.





A full height Binder Jetting build job always takes the same amount of time. Thus, cost per part are driven down by increasing the number of parts in one build job.
Unpacking of green parts is mostly a manual job. If the design is optimized for unpacking, expensive labor time can be saved or even automatization solutions can be possible.
Debinding and sintering cost are only driven by the overall dimensions of the parts.

Design guideline

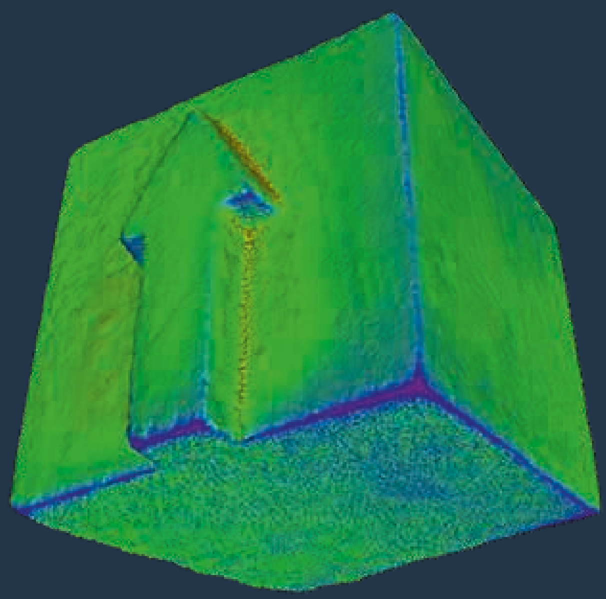
Why to follow the design guide

The design of sinter-based technologies such as Metal ME and BJT are not only limited by the printing process. The debinding and sintering are critical for the characteristics of the part and must be considered for an appropriate design.

This design guide will provide an overview of relevant features to ensure a proper part design regarding debinding, sintering and printing requirements. If the rules are not applied, parts may suffer from distortion, cracking, delamination and/or collapse, as illustrated by examples on the following pages.

Incorrect parameters within the debinding process such as, hold times, gas flow and pressure might lead to deformation, melting of parts and failures such as enclosed binder (bubbles) in the sintered part.

BUBBLES FORMING ON THE SURFACE DUE TO INSUFFICIENT 1ST STAGE DEBINDING WHICH CAN HAPPEN WITH THICK COMPONENTS.



Part dimension & scaling

Part dimension

Part dimension is limited by the systems needed for production. Regarding Metal ME and BJT the debinding and sintering systems have a major impact on the dimensions that can be realized. As a rule of thumb, part sizes of 100 mm in all dimensions can be processes with reasonable efforts. Larger dimensions are known to be challenging but possible. While Digital Metal describes a bounding box of 45 mm in x, y and z as sufficient for BJT process DESKTOP METAL suggests a limit to 150 x 150 x 100 mm for ME.
The minimal part dimensions are also relevant for production. In ME the minimum number of needed toolpaths to create a solid layer are relevant. The minimal part size in BJT is simply depended on the ability to handle the parts.

SOURCE	MAX. DIMENSION X-Y-Z [MM]	MIN. DIMENSION X-Y-Z [MM]
Desktop Metal ME	150x150x100	3x3x3
Markforged ME	230x120x140	2x2x2
Digital Metal BJT	45x45x45	1x1x0,5

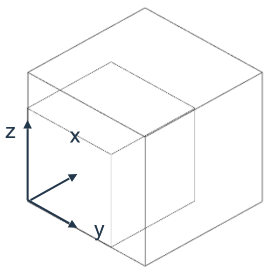
Shrinkage & Scaling

Shrinkage of the part due to sintering must be considered in the design of the part. Typical shrinkage can be quantified by about 20 %, therefore the dimension of the printed part needs to be adjusted with an oversize factor for printing. The scaling is usually automatically applied by the data preparation software, but due to the fact, that shrinking is dependent on the used material and the used geometry it can not be generalized. The shrinkage of the part during sintering is also affected by the orientation of the part. Typically, a higher shrinkage in z-direction is observed, while the x and y- direction show similar behavior.

This anisotropic shrinkage can be caused by several factors such as:

- Friction between Platform and Part
- Gravity
- Bending of unsupported Features
- Powder Contaminations
- Green part density

To minimize these influences the orientation between printing and sintering orientation should not be changed.



PRINTING AXIS	SHRINKAGE [%]	OVERSIZING FACTOR
x	16,5	1,20
y	16,5	1,20
z	20,5	1,26

Orientation

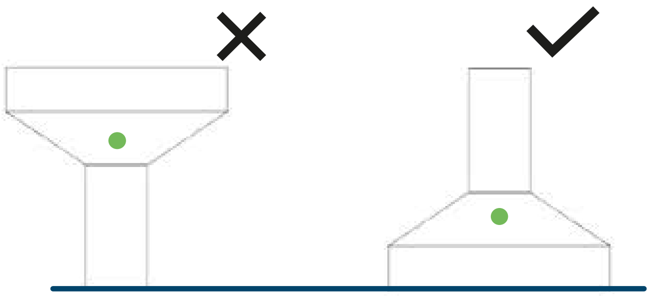
Part orientation

The orientation of the part is relevant for printing as well as the post processing steps. Therefor the orientation needs to be adjusted for a sufficient and effective process chain. Several external as well as process-related influences need to be taken into consideration.

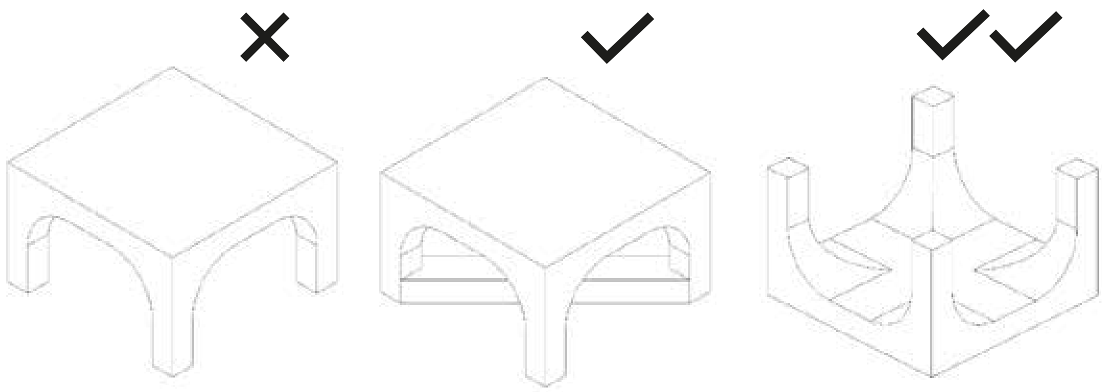
A described gravity influences the shrinkage during sintering and causes a greater deformation in Z. Gravity is also relevant regarding the **center of gravity**. Part should always be orientated to have a low center of gravity. This increases the stability of the part during the whole process chain.

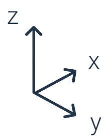
To further optimize the parts stability the orientation must be defined, so that the contact area of the part and the build plate is maximized. Elements of a component that are far apart can result in deformation due to friction. A **Flat bottom** of the part is therefore essential in order to withstand the deformation that may be caused by the friction between the part and the sintering tray. Warped bottom surfaces can cause parts to tilt or even collapse during sintering. The proper orientation of the part also considers the **minimization of support** structures. An efficient orientation therefore reduces the printing volume and safes time and money.

Center of Gravity



Flat Bottom Surface



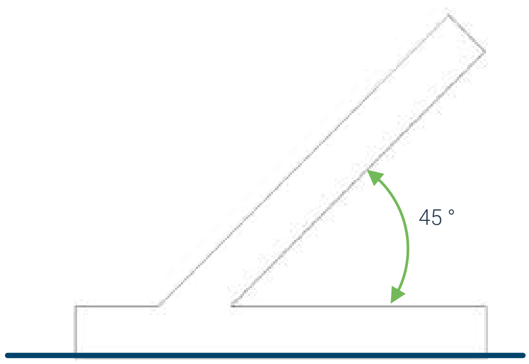


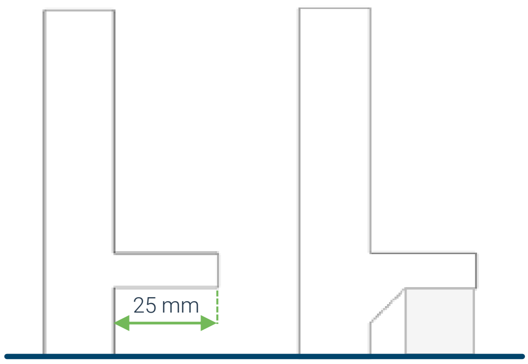
Overhang & support

Overhang

For ME printing overhangs with a higher angle then **45°** from the horizontal plane will need support to prevent collapse. For the sintering process, support structures might be needed for even steeper angles depending on aspect ratio and volume of the overhang. For an efficient process overhangs should be adapted so that support structures for printing as well as sintering are not needed.

Horizontal part features reaching out more then **25 mm** are also critical regarding sintering. To help support these elements fillets should be applied when designing the part.

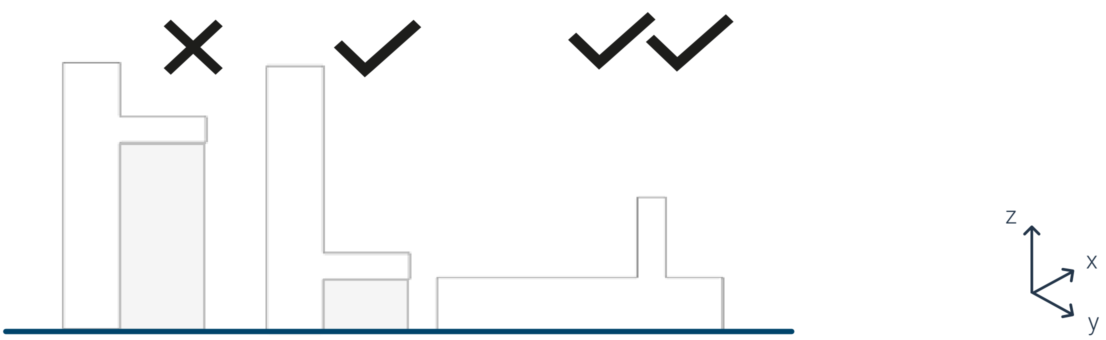




Overhang

If overhangs are unavoidable support structures are needed to prevent the part from collapse, distortion and failure in the sinter process. In general **support structures are to be minimized** by adapting the orientation and part geometry as well as maximizing part/platform contact. Nevertheless, some geometries require support for elements that may not be changed. For this purpose, several types of support structures are available. These include following:

- Printed Metal Supports (same shrinkage)
- Ceramic Supports



Wall thickness & aspect ratio

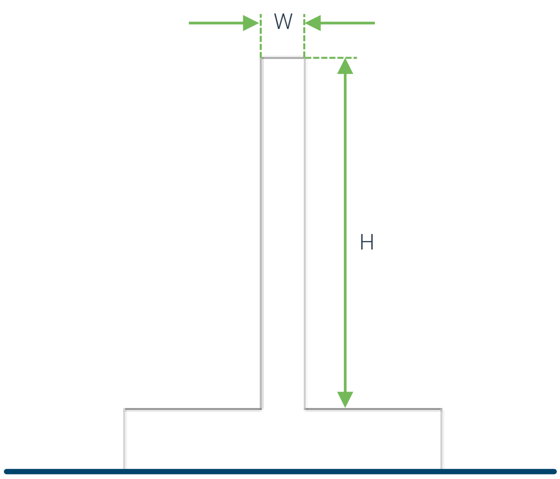
Wall thickness

The wall thickness dependents on the part size and geometry. Lager parts require thicker walls to maintain stability during the entire process chain, especially the handling and sintering of thin walls may be critical. A wall thickness of less than 1mm should not be chosen, without further investigation and analysis, but is possible withing the Binder Jetting process.

The minimum wall thickness for the Metal ME process is dependent on the extrusion width of the nozzle. At least two toolpaths are to be applied to generate a wall. 1 mm is a good rule of thumb for most Metal ME systems. Thick walls give stability but increase the hold times during debinding. A sufficient rule of thumb for BJT parts is 60 minutes hold time for 3-4 mm wall thickness in thermal debinding. For Metal ME parts, catalytic debinding needs the same time for 1-2 mm while solvent debinding only penetrates wall thicknesses of 0,1 – 0,2 mm in 60 minutes.

Hight to width ratio (aspect ratio)

Regarding the debinding and sintering process high and thin unsupported walls and pillars are challenging. These features are likely to collapse or distort during sintering when exceeding an Aspect Ratio of about 8:1.



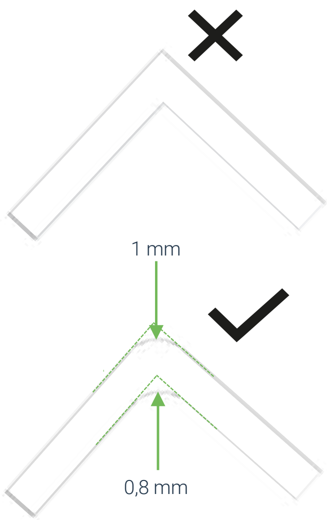
PROCESS	MIN. WALL THICKNESS	MAX. WALL THICKNESS	ASPECT RATIO
Metal ME	1 mm	10 – 20 mm	8:1
Binder Jetting	0,3 – 1 mm	10 – 20 mm	

Edges, corners & level of detail

Edges & corners

Edges are especially critical regarding the handling of the green and brown part. Due to the fragility in these stages fileted edges are to be preferred. A radius of at least 1 mm is recommended.

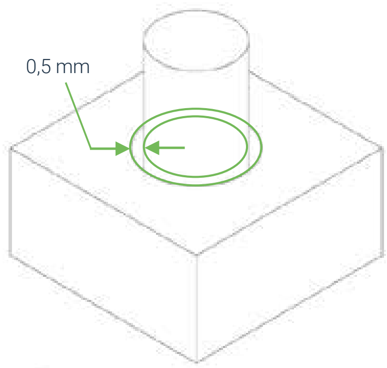
Inside corners should be designed without sharp intersections. Filleted edges and corners are always to be prefer. A radius of **0,8 mm** should always be applied. The filleted edged help to prevent distortion and cracking of the part during sintering.

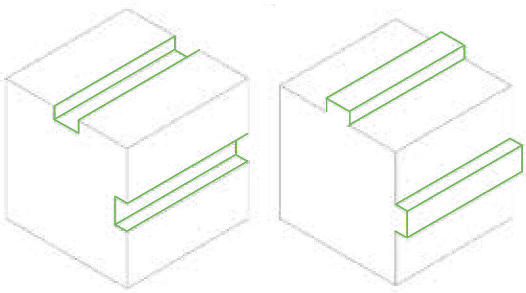


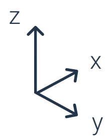
Level of detail

The level of detail must also be considered during design of the parts. Elements of the parts are limited in their detail by the accuracy and resolution of the printing process. For the design of embedded moving components, a **minimum gap of 0,5 mm between parts** is recommended. This should also be considered for the nesting for the part.

Embossed and debossed elements need be scaled to the limited dimension of the printing process. To be able to show embossed and debossed elements, the wall thickness should be at least 0,5 mm, better **1 mm** in all dimensions. Deeper debossed features are to be handled like cavities, where the powder removal process is the limiting characteristic. The maximum resolution for material extrusion systems is depending on the used nozzle diameter and selected layer height. A feature dimension needs to be minimum double the nozzle diameter.



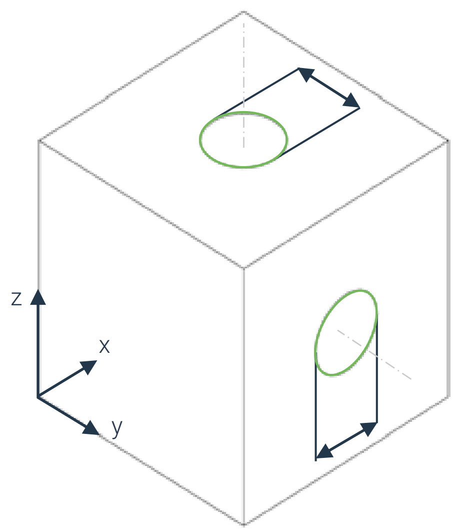




Holes, cavities & drain holes

Holes & cavities

Holes & cavities are critical regarding the printing process. Small holes & cavities might close off during printing due to inaccuracy of the printer. Hole diameters under 1,5 mm in the vertical plane and 1 mm in the horizontal plane should be avoided. For Metal ME hole diameters in the horizontal direction might cause critical overhangs which require support. A tear drop shape hole is suggested when having a diameter larger than 8mm.

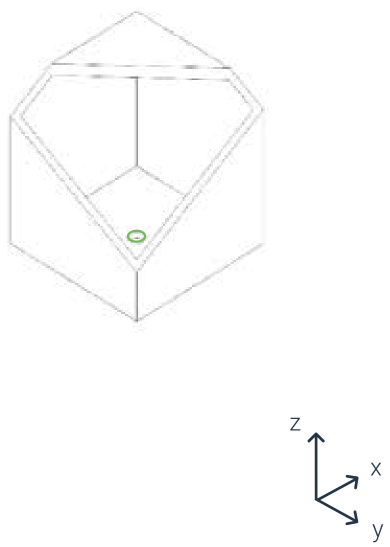


VERTICAL (X, Y)	HORIZINTAL (Z)
1,5 mm	1,0 mm

The minimum hole size in BJT depends mainly on the powder removal process. The design should therefore allow the manual removal of powder from holes and cavities. A minimal diameter of 1,5 mm is to be preferred. The hole diameter must also be adapted to the depth of the hole. The design of powder drain holes needs to be adapted to the geometry of the part. Complex parts might need larger or several drain holes. It is also recommended to place the holes in a centralize position, to be able to remove the majority of the powder.

MINIMUM DIAMETER [MM]	DEPTH [MM]
0,2	0,1
0,5	1
1	5
2	10
5	30

Drain holes are also needed when the debinding process is based on solvent or acid debinding fluid. The design of the part must allow the debinder to drain. Cup shaped parts might lead to the collection of debinder fluid in the part and prevent the debinder to drain.



Design to cost

Binder Jetting

To reduce the cost of printing Binder Jetting parts, the first measure is to increase the build volume utilization. This can be achieved by nestering or overall reduction of part dimensions.

Since depowdering is labor intensive, sharp edges, holes and thin structures should be avoided to ease removal of powder.

The sintering process cost have less impact on the total cost per part however a minimum of overall part dimensions and optimization for less sinter supports can further reduce the cost per part.

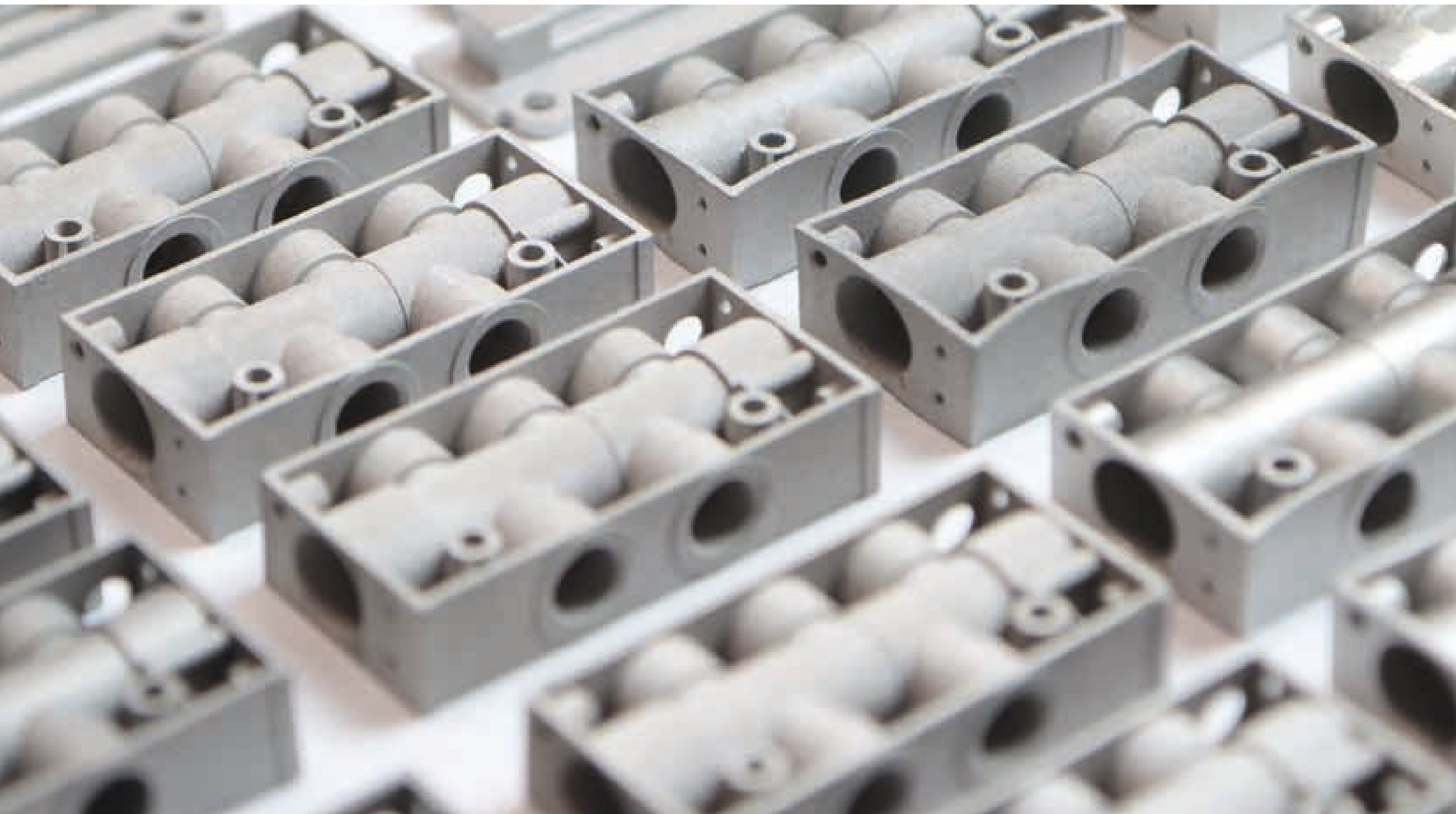
1. **Maximize parts per build and increase nesting**
2. **Optimize powder removal**
3. **Reduce sintering space and support efforts**

Metal ME

To reduce the cost per part of Metal ME parts, the first target is to minimize the part volume. Besides reducing the material by design optimization and reducing wall thicknesses, working with an infill of solid parts can also be an approach to reduce the necessary material and print time.

For debinding and sintering, the design should avoid supports which reducing additional handling and the cost per part.

1. **Minimize part volume**
2. **Adjust wall thickness to 1-5 mm**
3. **Reduce sintering space and support efforts**



Checklist: Metal ME

1. Are overhangs reduced to a minimum?

2. Are sinter supports available for unavoidable overhangs?

3. Can the bottom surface glide and shrink evenly?

4. Can debinding fluid reach all surfaces and flow through the tank?

5. Is the wall thickness even and between 1-5 mm?

6. Is the volume of the part minimized?

Checklist: Binder Jetting

1. Are overhangs reduced to a minimum?

2. Are sinter supports possible for overhangs?

3. Can debinding fluid reach all surfaces and flow through the tank?

4. Can powder be removed easily?

5. Are there no small cavities or holes below 1 mm?

6. Can the part be stacked to achieve high nesting density?

7. Is the wall thickness even and between 1-5 mm?

About the authors

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Matthias successfully led multiple projects in Additive Manufacturing with focus on business case and strategic development for AM users as well as system and material supplier. With a history in management consulting he has a wide experience in business development, strategy development and communication. At AMPOWER he led multiple projects concerning DED, BJT and Metal FDM as well as a wide range of polymer AM technologies.

Timo Führer

Timo joined the AMPOWER team in 2020. With a Master of science in the field of production technology and management he combines profound engineering know-how with an eye for economic correlations. In former affiliations he has been intensively involved in Additive Manufacturing and worked on numerous projects in research and consulting. At AMPOWER Timo is leading the market and technology analysis as well as consulting projects involving polymer based Additive Manufacturing.

Global Contributors

This guideline is a collection of design rules developed by industry leaders in the field of Powder Metallurgy and sinter-based Additive Manufacturing. It is made possible by the gathered experience of more than 12 companies and institutions who contributed their knowledge into this continuously improving guideline.

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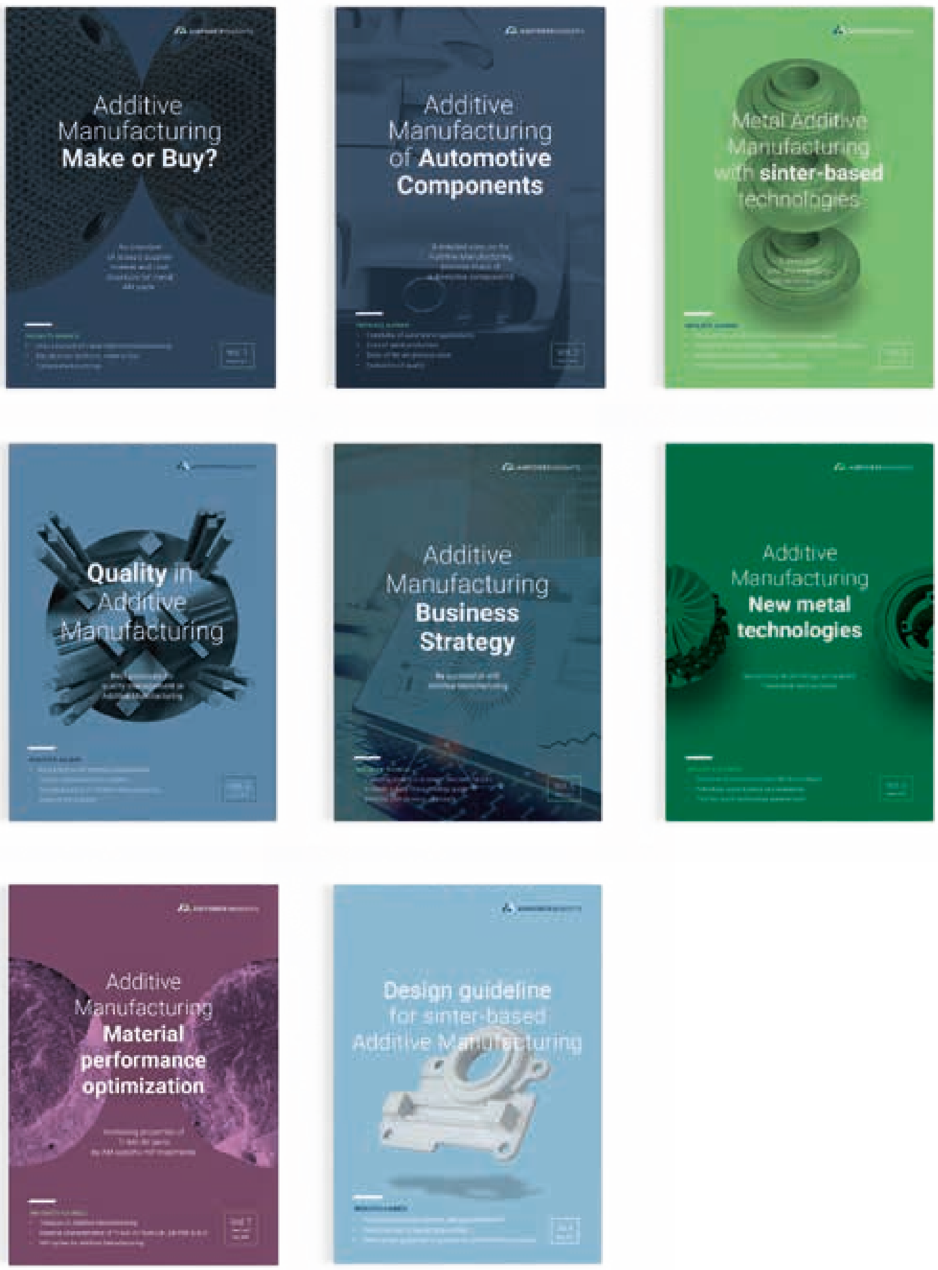

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