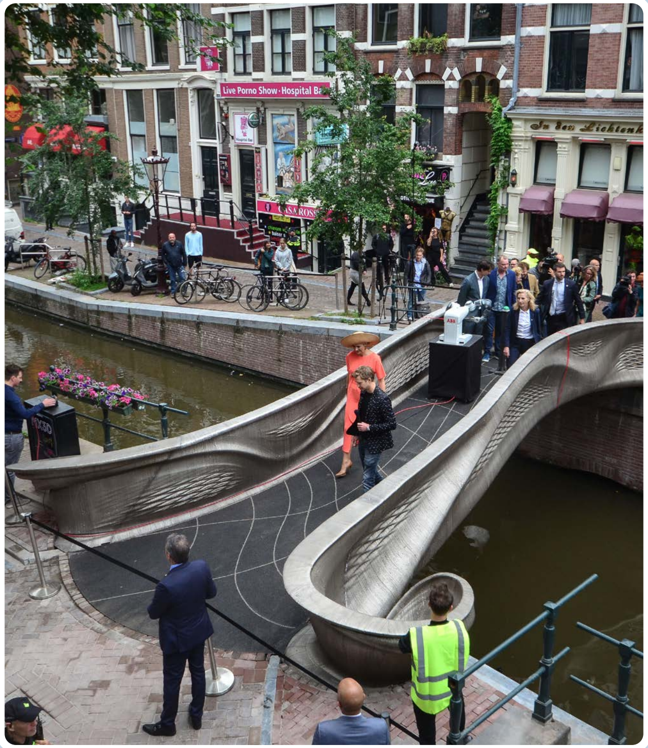
ISSF
INTERNATIONAL STAINLESS STEEL FORUM

Additive Manufacturing with Stainless Steels

Applicable Additive Manufacturing Technologies

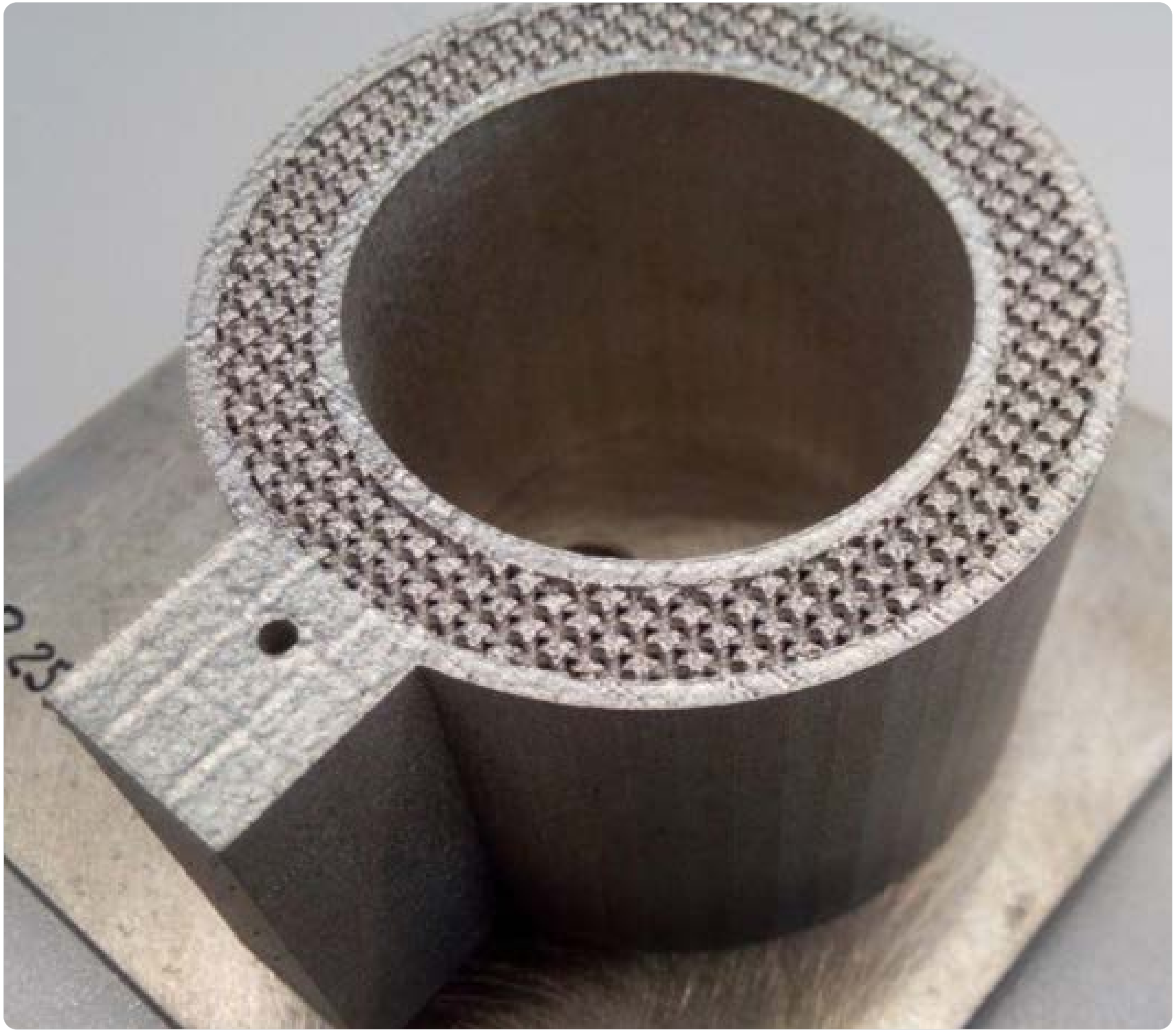


Introduction

Additive manufacturing (AM) technologies have emerged recently but have very quickly drawn a lot of attention thanks to their very attractive set of properties and attributes.

Their common feature is the build-up of objects by deposition of material layer upon layer, driven by a 3D computer model, thereby achieving near final shape (also known as near net shape [NNS]). The processes are the ‘polar opposite’ of most other manufacturing methods which progressively remove material, such as machining.

All AM technologies applicable to metals can be used with stainless steels. Their advantages and limitations are described in this new leaflet produced by the ISSF.

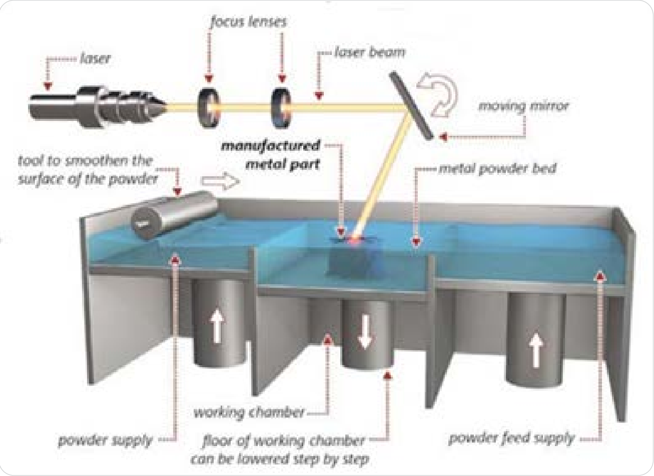


Right: Stirling generator

BACK ? ← →

1. Powder-Based Fusion (PBF)

Processing steps
1. A layer of powder, typically 0.04 mm thick, is applied over the build platform.
2. A laser beam fuses the layer according to the cross section of the part to be printed
3. The platform is lowered by the thickness of the fused layer
4. Step 1, then 2 and 3 are repeated as many times as required until the entire model is created. The unfused powder remains in position but is removed during post processing
5. The part is brushed and cut off the base. The unfused powder can be re-used.



PBF process.
Courtesy of EPMA

Properties of PBF parts in the as-printed condition
1. some porosity (between 1 and 5%),
2. anisotropic tensile properties, typically lower in the Z axis
3. lower impact values and fatigue life compared to wrought parts.

Restoring properties
1. Heat treatment may be necessary, depending upon the alloy
2. HIP (Hot Isostatic Pressing) processing can be used to reduce porosity (to less than 0,2%) , restores isotropy, improves ductility, fatigue life and impact resistance.

Finishing steps are carried out as dictated by the blueprint requirements
Electron Beam Melting (EBM) is a possible alternative to Laser, but is more expensive without additional benefits for stainless steel and therefore not used.

Artwork
Picture courtesy of EPMA

Impeller made of super Duplex 2507 stainless steel for offshore applications
Picture Courtesy of Sandvik Additive Manufacturing

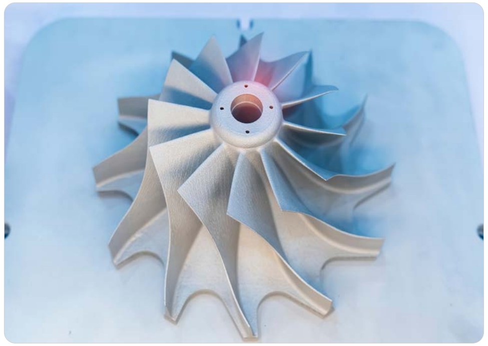
Advantages and limitations

Advantages of PBF	Limitations of PBF
Allows intricate shapes that are impossible to produce otherwise	Powder is expensive
Replaces in a single part an assembly of several parts	Low deposition rate, slow process
Design can use geometry rather than bulk to achieve structural strength with less material and less weight	Not competitive for series
Saves raw material as the parts are near-net shape	Size limited to that of the chamber
A digital library replaces a physical inventory	Anisotropy of properties, with lower strength in the Z direction
Parts can be produced anywhere, close to where they are needed	Residual porosity - but less than 0.5 vol%
Saves inventory and shipping costs, limits logistics, packing, with associated energy use	Lower impact properties and fatigue life than wrought products
Ideal for rapid prototyping	HIP is expensive and increases the lead time.
	Usually requires finishing steps (brushing off powder, cutting off from the base, polishing and/or final machining) , but no more than near-net-shape cast parts

PBF of Stainless steels

- PBF of Stainless steels
- Stainless Steels are very well suited for PBF
- A number of grades are available in powder form, all are possible
- New alloys, impossible to produce by the traditional routes, can be produced by the gas atomizing technology
- Post-PBF heat treatment and finishing are similar to castings
- HIP with rapid gas cooling results in an annealed and quenched metallurgical condition

Most of today's applications are found in very demanding industries: aerospace, medical, energy…



Picture Courtesy of BEAMIT Group / Sandvik

2. Metal Binder Jetting & Sintering (MBJ)

This process involves more steps than Powder-Based Fusion.

MBJ step

After applying a powder layer on the build platform, the metal powder is agglomerated thanks to a binder fed through the printer nozzle. The process is repeated until the part is completed, consisting of metal powder agglomerated by a binder.
The as-MBJ'd parts (nicknamed "green") are fragile, and must be handled with care.

Debinding

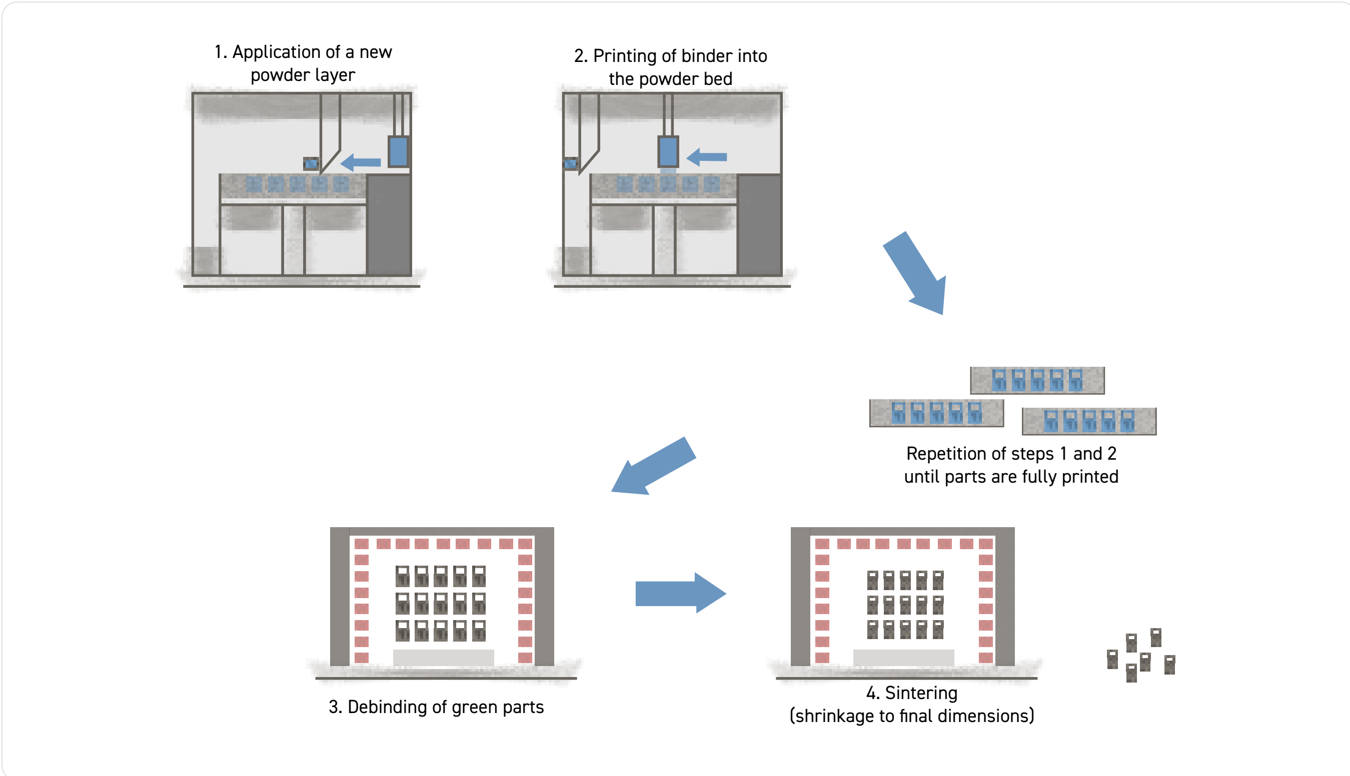
The next processing part is debinding in which most of the binder is removed from the part. This is done by either solvent, thermal or catalytic methods, each one having its merits and drawbacks. Care has to be exercised to avoid warping, blistering or cracking. Parts are still fragile and delicate to handle after this stage.

Sintering

Sintering is the process of densification, where diffusion of particle surfaces take place and metal parts begin to bind together, closing off the voids where the binder material previously was. The part shrinks between 15 to 20% (linearly).

The result

The result of sintering is a dense, polymer-free metal. The metal has no evidence of its manufacturing method - either printing or molding - and is isotropic, showing the same properties in all directions.



Steps in Metal Binder Jetting and Sintering

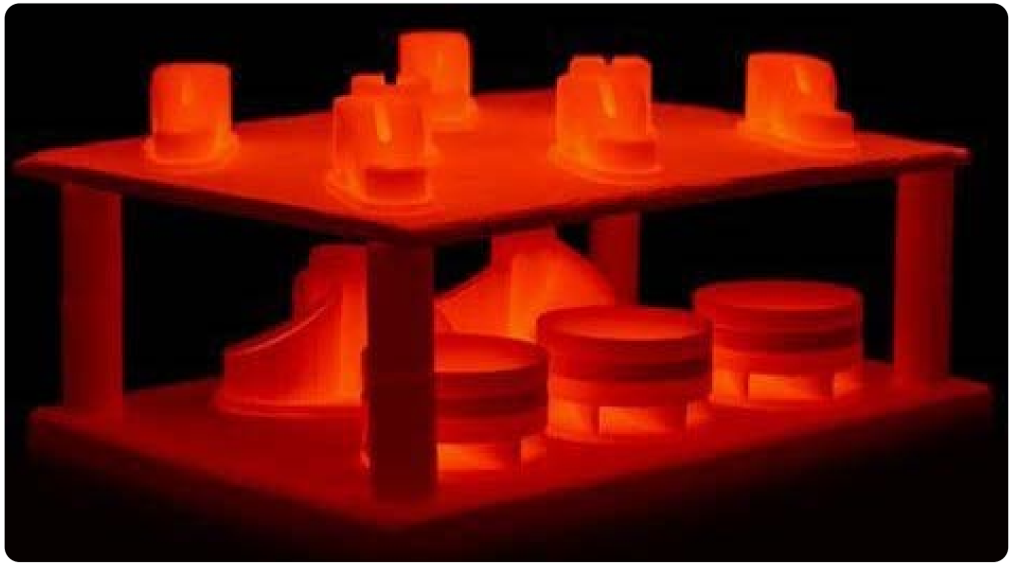
Advantages and limitations

Advantages of MBJ	Limitations of MBJ
50-100 times faster than PBF	Expensive powder
cost 20 times lower than PBF	Limited size
No anisotropy	Residual porosity (~3%)
No supports are required	Several processing steps are required (print → debind → sinter)
Good resolution	Delicate manipulation of green parts
Suitable for great complexity parts	Shrinkage control during sintering is essential
Suitable for intermediate series (MIM is better suited for very large series)	Risk of deformation during sintering
Near-net shape	Limited wall thickness (5-10 mm)
	Usually requires final machining

MBJ is applicable to stainless steels but not frequently used

Note: Metal jetting & sintering offers similarities with MIM (metal injection molding)

Example of shrinkage during sintering



Parts in a sintering furnace

MX3D Bridge Opening in Amsterdam by Her Majesty The Queen Maxima
Picture courtesy of Adriaan de Groot

MX3D Bridge in Amsterdam. Her Majesty the Queen.
Picture courtesy of Jan de Groen

3. Direct Energy Deposition

A. Wire Arc Additive Manufacturing (WAAM)

WAAM, a Direct Energy Deposition (DED) process, is similar to robotised multipass MIG, TIG or PAW welding. The part is built by successive passes.

There are, however, some important differences:

- More process parameters are computer-controlled with the help of sensors, in order to minimize porosity and inclusions.
- DED head displacements can be programmed to follow a preset sequence which minimizes warping and optimizes mechanical properties
- Several wires can be used simultaneously

Advantages and limitations

Advantages of WAAM	Limitations of WAAM
Inexpensive feedstock (wire)	A prior test is necessary to optimize process parameters
High deposition rate	Fine details not possible
No part size limitation	Requires finishing steps
Multi-metal deposition possible	Not for large series
Some cold work to increase strength is possible	
Final machining possible on same machine tool	
Warping can be reduced by proper sequencing	

WAAM of stainless steels

- Stainless Steel is easy to deposit
- Welding wire grades are readily available
- Post-WAAM heat treatment and finishing are similar to those of multipass welds
- Ideal for repairs

Picture courtesy of waam3D Ltd.

Picture courtesy of waam3D Ltd.

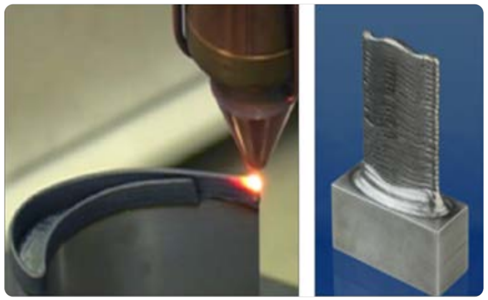
B. Laser Metal Deposition (LMD)

LMD is a different DED process. It used a robotised arm to move the deposition head as in WAAM, but the feedstock is powder and it is melted by a focused laser beam. A protective gas, usually Argon, is used.

This technology offers a higher productivity than PBF and also the ability to produce larger parts, but the freedom in design is much more limited: for instance, lattice structures and internal channels are not possible.

Variations of this process are possible, by replacing powder by wire for instance.

Advantages of LMD vs. WAAM	Limitations of LMD vs. WAAM
Finer resolution	Powder is more expensive than wire
More alloying possibilities given by powder feedstock	Deposition rate lower .... but higher than PBF
	More expensive

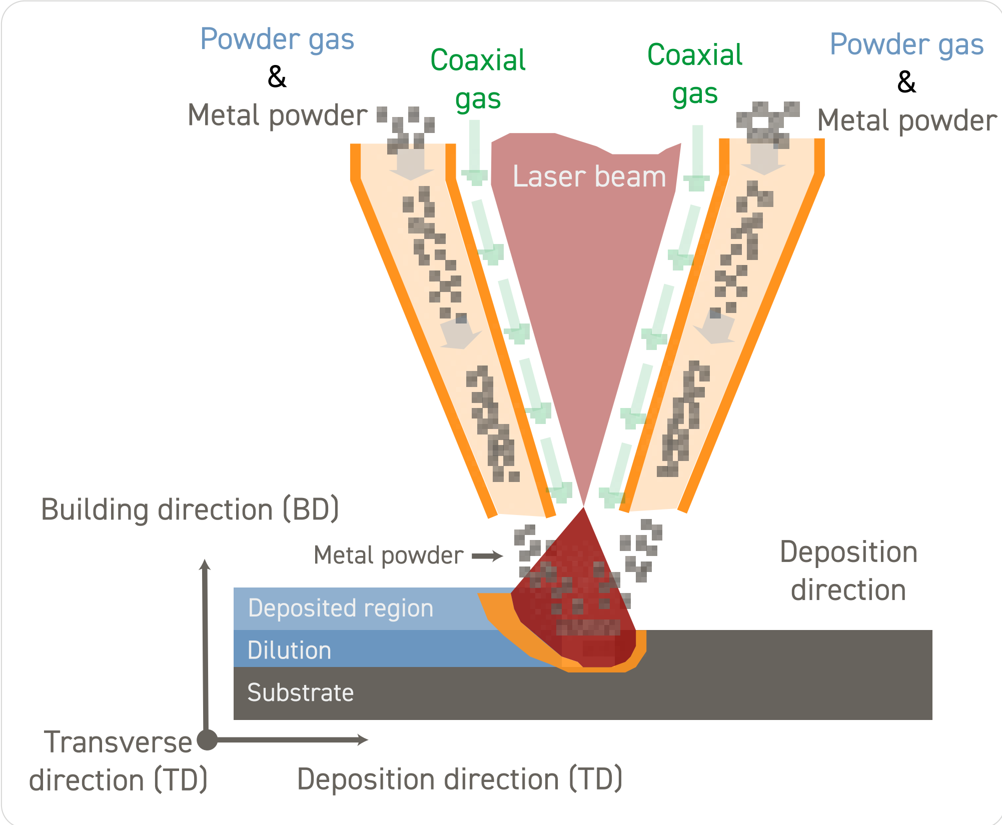


Picture courtesy of EPMA

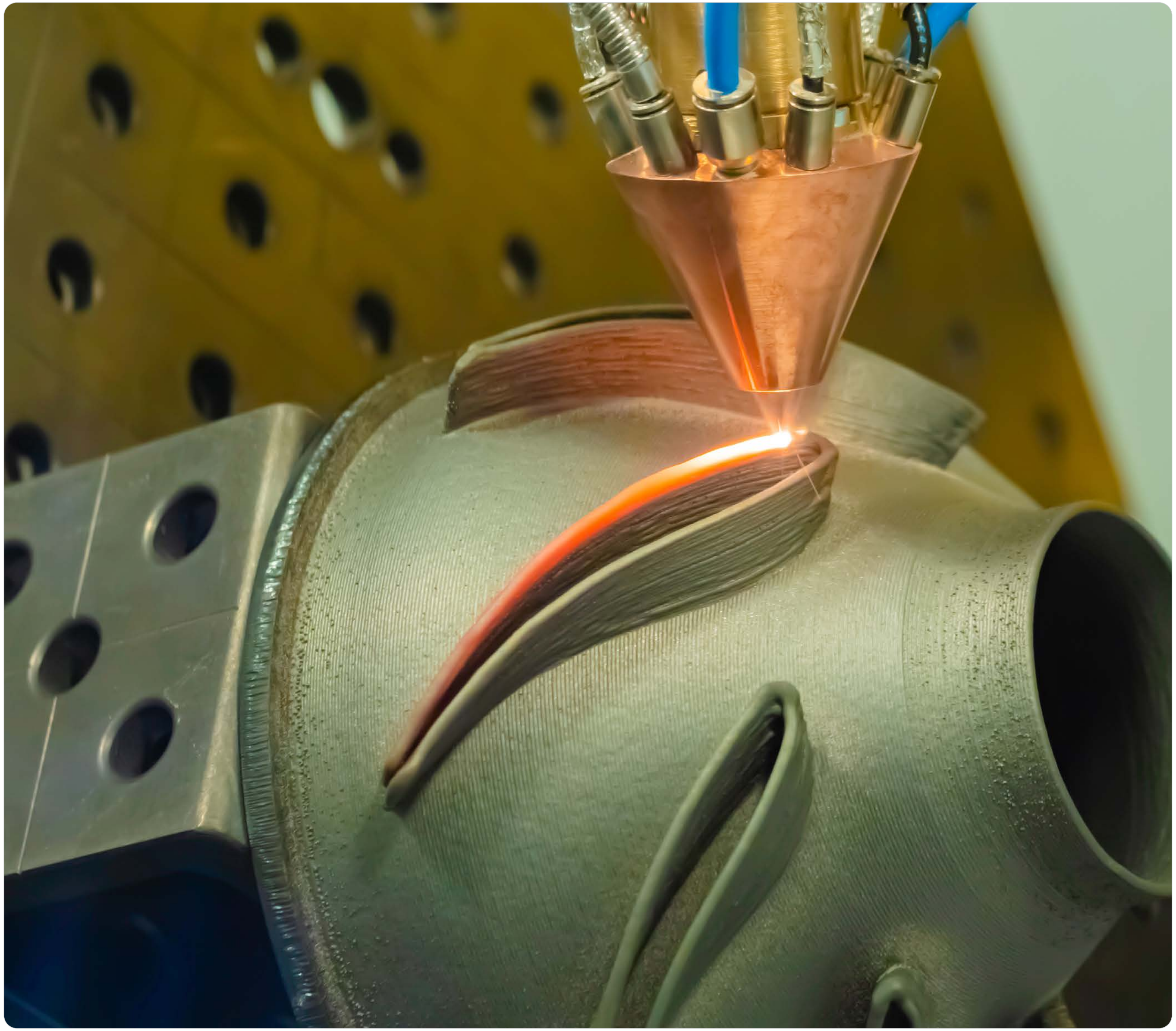
LMD of Stainless steels

Can be readily used.

Applications: repair, overlay, joining



Laser Metal Deposition process



4. Conclusions

Additive manufacturing technologies will generate a paradigm shift in both operational efficiency and component costs thanks to:

- new, optimized designs
- drastic reduction of lead times for prototyping and for spare parts
- smaller and simpler supply chain inventories
- size not limited to producing small items

Further developments will increase capabilities, such as new grades in powder form, successive deposition by DED of different metals and improved productivity by more powerful heat sources.

The development of standards, carried out by ASTM F42 and by the ISO TC261 committee is still in its early stages, requiring therefore a good connexion between the client and the AM processing company.

Stainless steels, with their good corrosion resistance and their wide range of properties have been used already as one of the preferred additive manufacturing metallic materials.

Help

? Help page

☰ Contents page.

← Previous page.

→ Next page.

BACK Previous view.

About ISSF

The International Stainless Steel Forum (ISSF) is a not-for-profit research and development organisation which was founded in 1996 and serves as the focal point for the global stainless steel industry.

Vision

Sustain our future with stainless steels

Membership of the ISSF

ISSF has two categories of membership namely:

a. company members who are producers of stainless steels (integrated mills and re-rollers)
b. affiliated members who are national or regional stainless steels industry associations.

The ISSF now has 57 members in 26 countries. Collectively they represent approximately 90% of the total production of stainless steels.

More information

For more information about ISSF, please consult our website worldstainless.org.

Contact us

issf@issf.org
+32 2 702 89 00

worldstainless.org