

ENSURING PROCESS CAPABILITY AND QUALITY ASSURANCE IN ADDITIVE MANUFACTURING OF HIGH-END PRECISION PARTS: CHALLENGES AND SUCCESS STRATEGIES

+ Christoph Hauck

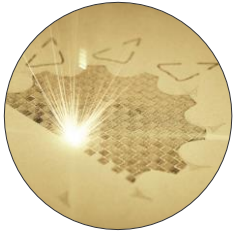
16 April, 2024

Pace Maker for
High-End
Precision Parts

CHRISTOPH HAUCK

- + **Managing director since 2012**
Member of the Executive Board since 2020
with focus on new technologies and new markets
- + **Cooperation in committees and associations:**
 - Member of the core competence team AM at BDLI
 - Member of various DIN standard committees on the subject of AM also of the DIN presidium on the subject of aviation
 - Main board VDMA
 - VDMA divisions: Robotics / Automation, Medical Technology
 - Deputy Chairman of the VDMA trade association "Additive Manufacturing"
 - Spokesman for the Additive Manufacturing Expert Committee in Bavaria





Brief introduction of toolcraft AG

Successful implementation of semiconductor-relevant, AM-specific guidelines and certifications at toolcraft AG

- European Pressure Equipment Directive (**PED**) 2014/68/EU for high-pressure components in the L-PBF process
- ASML Generic Standard (**GSA**) for Additive Manufacturing, based on international ISO & ASTM standards

PED and ASML AM GSA: Successful certification due to outstanding process quality and capability

- Illustration of the highly complex and challenging **process chain** of high-end precision parts for ASML
- **Key factors** for the high-end process capability and the resulting successful audits
 - The **laboratory**: toolcraft internal material laboratory and material certificates
 - The **AM system**: TRUMPF TruPrint 3000 ML and its monitoring tools
 - The **human factor**: Eliminating the human factor through semi automated support removal using an in-house developed dry ice blasting system
 - The **rework**: Self-developed clamping concept for final machining

Outlook: DED and hybrid manufacturing for additively manufactured structural components

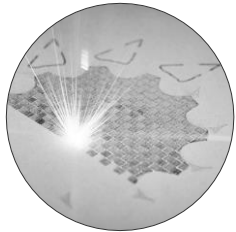
Final summary: With **TRUMPF** as system manufacturer and **toolcraft** as a full-service provider to high-end precision components for the semiconductor industry

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ASML

TRUMPF

toolcraft



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TOOLCRAFT – IN FACTS AND FIGURES

463 Employees including 59 Trainees

3 Board members

2 Facilities

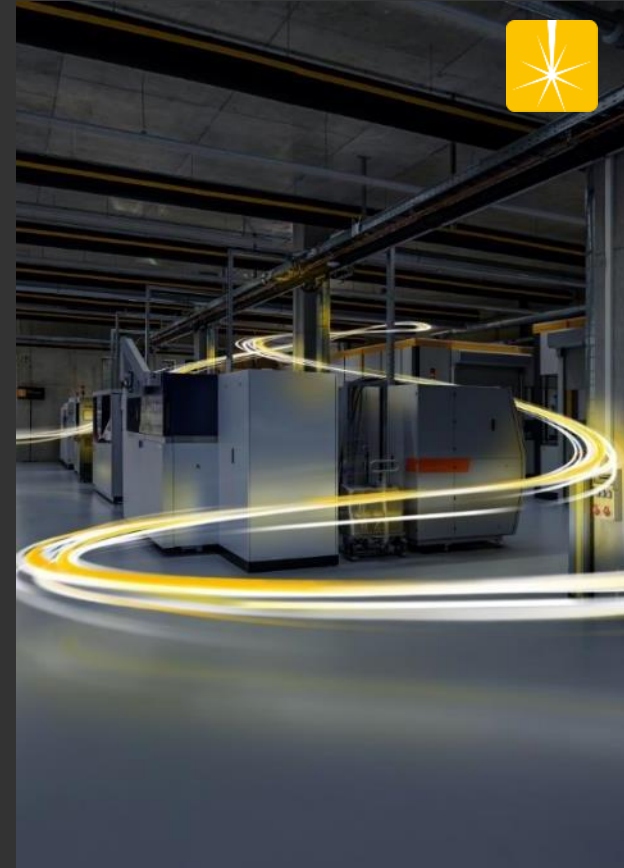
8 Certificates

Year of foundation

1989

Sales growth

Ø14% p.a.



ADDITIVE MANUFACTURING

10 L-PBF machines
2 LMD machines (powder)
1 LMD robotic cell
AM center, AM laboratory



ROBOTICS

Universally applicable
automation solutions and
machining cells



MACHINING

60 CNC machining centers
3-to 9-axis technology
Turning-milling systems



INJECTION MOULDING + MOULD MAKING

28 Injection moulding machines
0.01 to 350 g component weight
150 to 2,200 kN clamping force

CROSS-DIMENSIONAL MANUFACTURING

CERTIFICATES



+

+

+



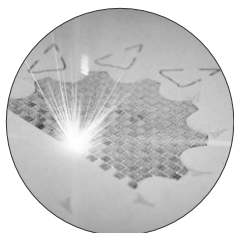
A JOURNEY THROUGH TIME IN ADDITIVE MANUFACTURING

AT TOOLCRAFT AG



Scan the QR code to watch the video





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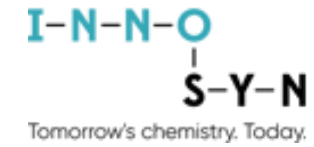
TRUMPF

toolcraft

EUROPEAN PRESSURE EQUIPMENT DIRECTIVE (PED) 2014/68/EU

FOR HIGH-PRESSURE COMPONENTS IN THE L-PBF PROCESS

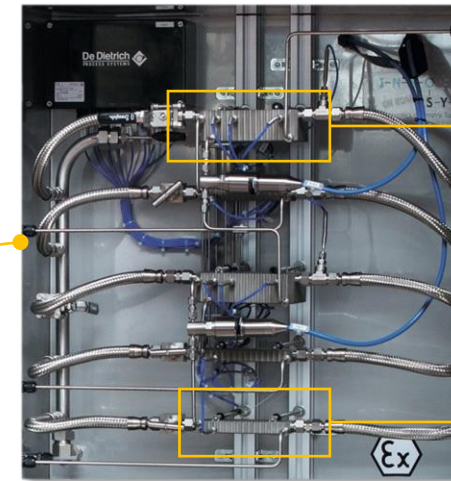
COLLABORATION *toolcraft* AND



Background and introduction

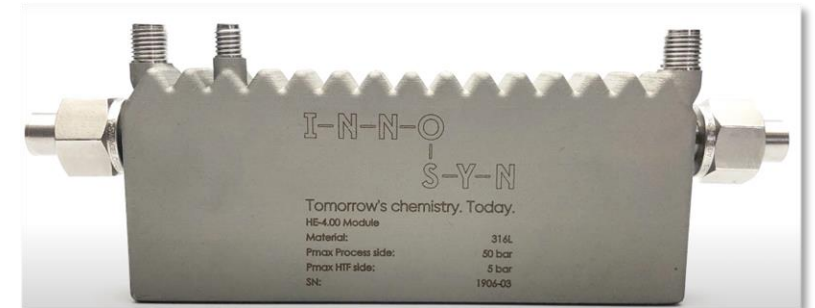
- AM has important applications in continuous chemical processes
- Chemical process streams are often pressurized (driving flows, above boiling temperatures)
- To avoid loss of containment (rupture), chemical process equipment must comply with regulations such as the **Pressure Equipment Directive (PED)** in the EU
- InnoSyn and toolcraft are working together to **serve chemistry applications with AM**

CryoFlowSkid: a chemical production unit



● 3 AM flow reactors

● 3 AM heat exchangers



WHAT IS PED?

The (PED) 2014/68/EU provides mandatory guidance for ...

- The design
- The manufacturing
- The conformity assessment

... of pressure equipment with a maximum allowable pressure above 0.5 bar or 7.25 psig

Regulated area "Pressure equipment"

- To be considered regular and therefore marketed, pressure equipment must pass **rigorous tests**
- Only if the products are considered compliant, they can obtain the approval according the PED certification
- Every certified component receives a CE mark



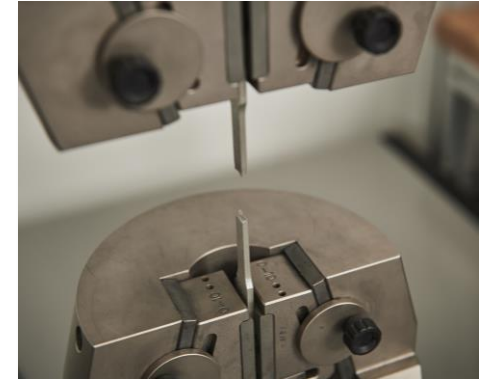
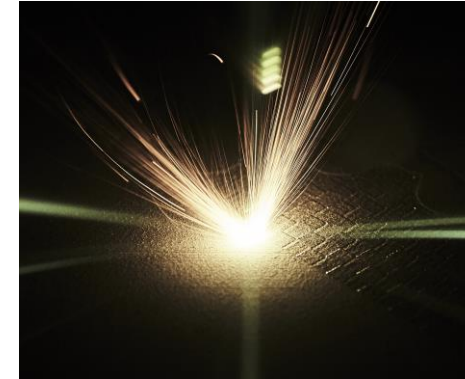
PED **AUDIT** 2022

Comprehensive requirements for

- QMS, design, AM process capability, laboratory tests, material properties, personnel, quality assurance and more






Challenges:

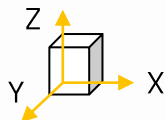
- Relatively **new** area of application overall (additively manufactured components as pressure equipment)
- Basic clarification of an adequate **scope of testing** (in cooperation with TÜV Rheinland) with **Certificate of Conformity** in acc. with 3.1
- Development of statistics, build space qualification & process testing
- Need for a separate, legally binding **material specification** for Hastelloy® C22
- CoC **confirms** that all accompanying samples meet the values of the material spec
- CoC must be issued for **each** component in accordance with PED



toolcraft AS A QUALIFIED & CERTIFIED SERVICE PROVIDER

+ Certified based on Hastelloy® C22 according to Directive 2014/68/EU for high-pressure components in the L-PBF process

Possible component size in mm (X-Y-Z)	Processed material
∅ 300 x 400 	1.4404, Inconel® 718+625
∅ 300 x 400 	TiAl6V4
420 x 420 x 530 	AlSi10Mg
250 x 250 x 280 	Haynes® 282®
250 x 250 x 325 	Hastelloy® C22



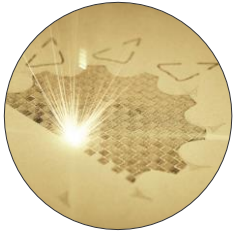
ASML GENERIC STANDARD (GSA) FOR ADDITIVE MANUFACTURING

BASED ON INTERNATIONAL ISO & ASTM STANDARDS

ASML GSA AUDIT 2023

- ASML Standard distinguishes between 3 different groups of components:
 - **Complexity Level 1, 2 & 3**
- On this basis, ASML has decided to build up its AM qualification with foresight
- An audit in Aug. 2023 confirmed that we meet all requirements of **Classes 1 and 2**
- After identifying and successively closing the last gaps, we were certified as "Readiness for **Class 3**" in Dec. 2023
- Used Standards:
 - **ASML AM GSA Draft 2023 – technical readiness**
 - **ISO/ASTM 52920:2023, 52901, 52930, 52928, 52907, 52904**





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HIGH-END COMPONENTS ADDITIVELY MANUFACTURED

BY **toolcraft** FOR **ASML** WITH A **TRUMPF** SYSTEM

D-ECKWEILER
connecting flow to purity

LR
PURE SYSTEMS

ASML COMPONENTS AT *toolcraft*

Exemplary: Manifold

2024 expected:

Total number of components to be supplied:

- 1407 components - 67 assemblies

Number of **different** components to be supplied:

- 21 components for 2 systems

Assembled by **D-ECKWEILER** and **LR**

connecting flow to purity

PURE SYSTEMS



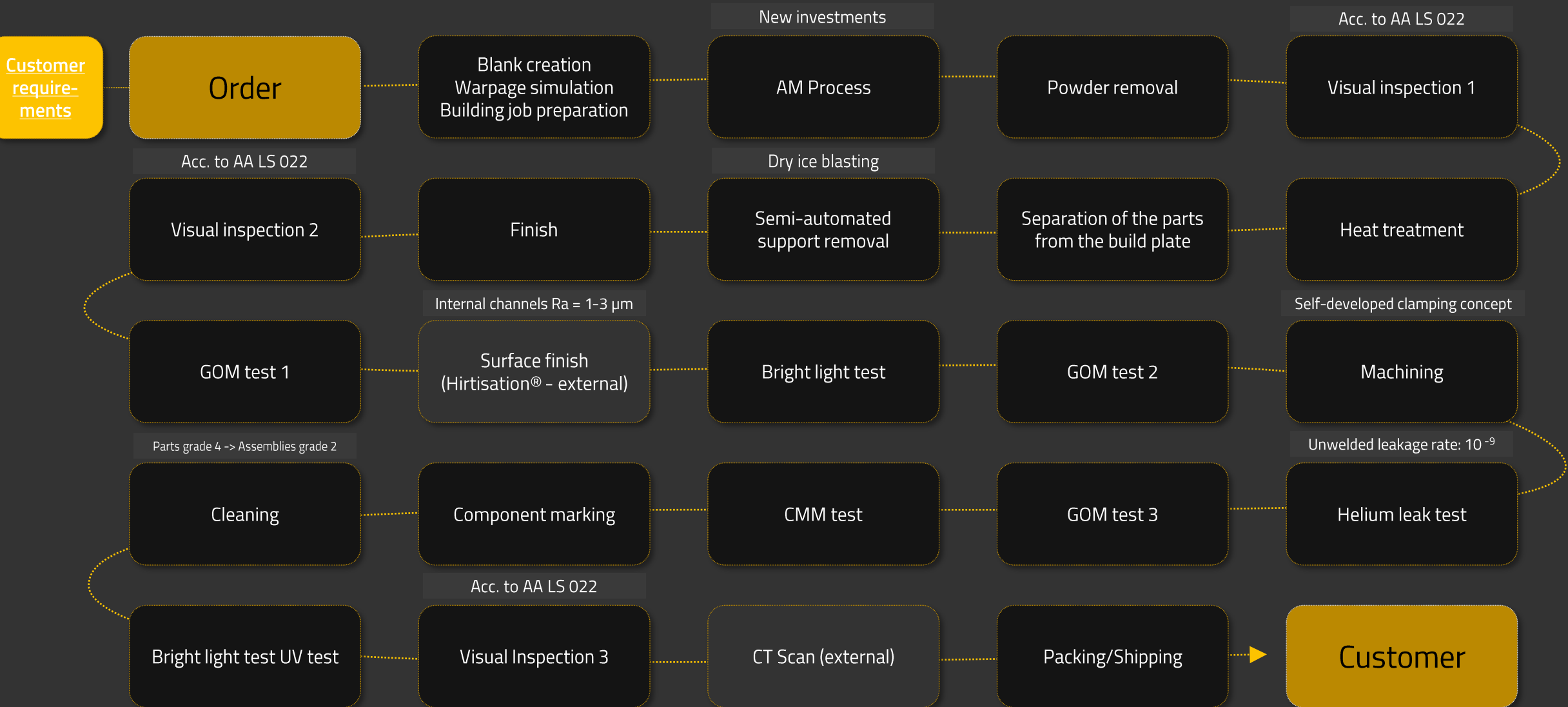
PROCESS CHAIN OF THOSE 21 AM-COMPONENTS



KEY FACTORS

FOR THE HIGH-END PROCESS CAPABILITY & THE RESULTING SUCCESSFUL AUDITS

PROCESS CHAIN OF THOSE 21 AM-COMPONENTS



CUSTOMER REQUIREMENTS & INTERNAL LAB

Possible customer requirements:

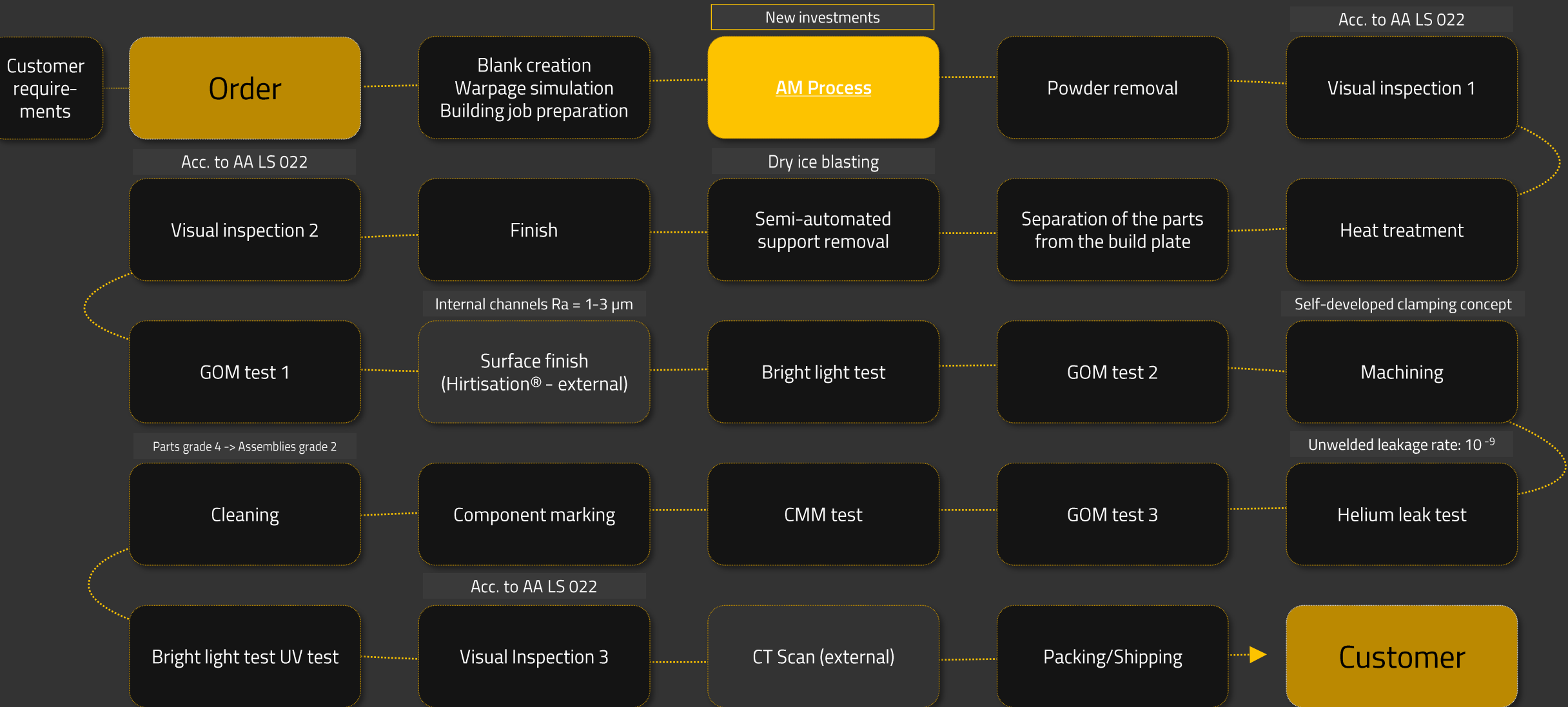
- Certification of the service provider
- Compliance with AM norms/standards
- Technical drawing/3D model
- AM-specific customer specification: e.g., accompanying sample analysis

Necessity of a certified in-house laboratory to meet these requirements

- Powder qualification: e.g., particle shape and size distribution
- Process qualification: e.g., microstructure, mech. properties
- Component qualification: e.g., accompanying samples, NDT

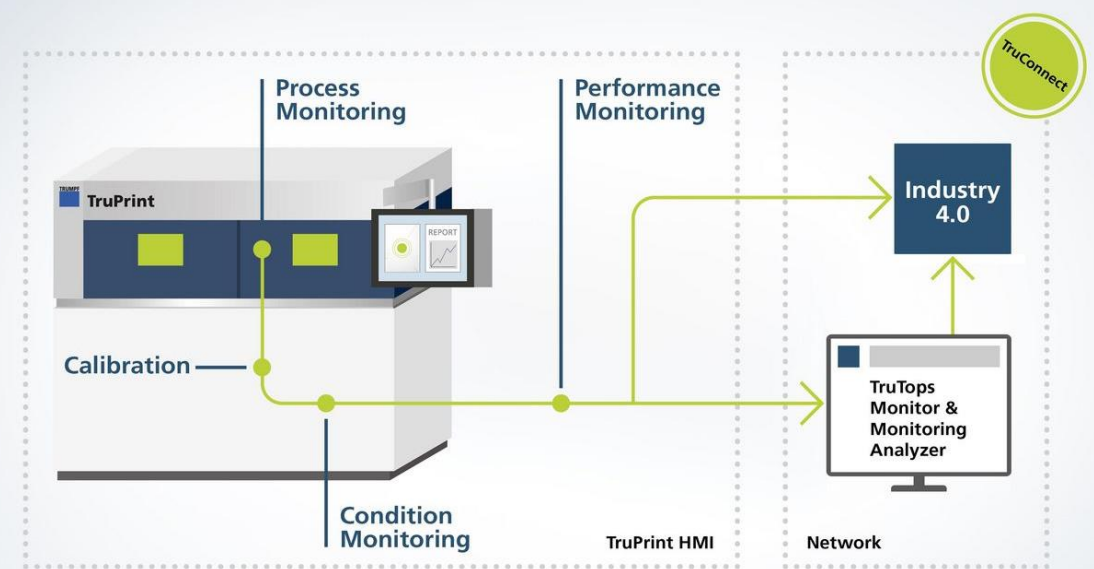


PROCESS CHAIN OF THOSE 21 AM-COMPONENTS

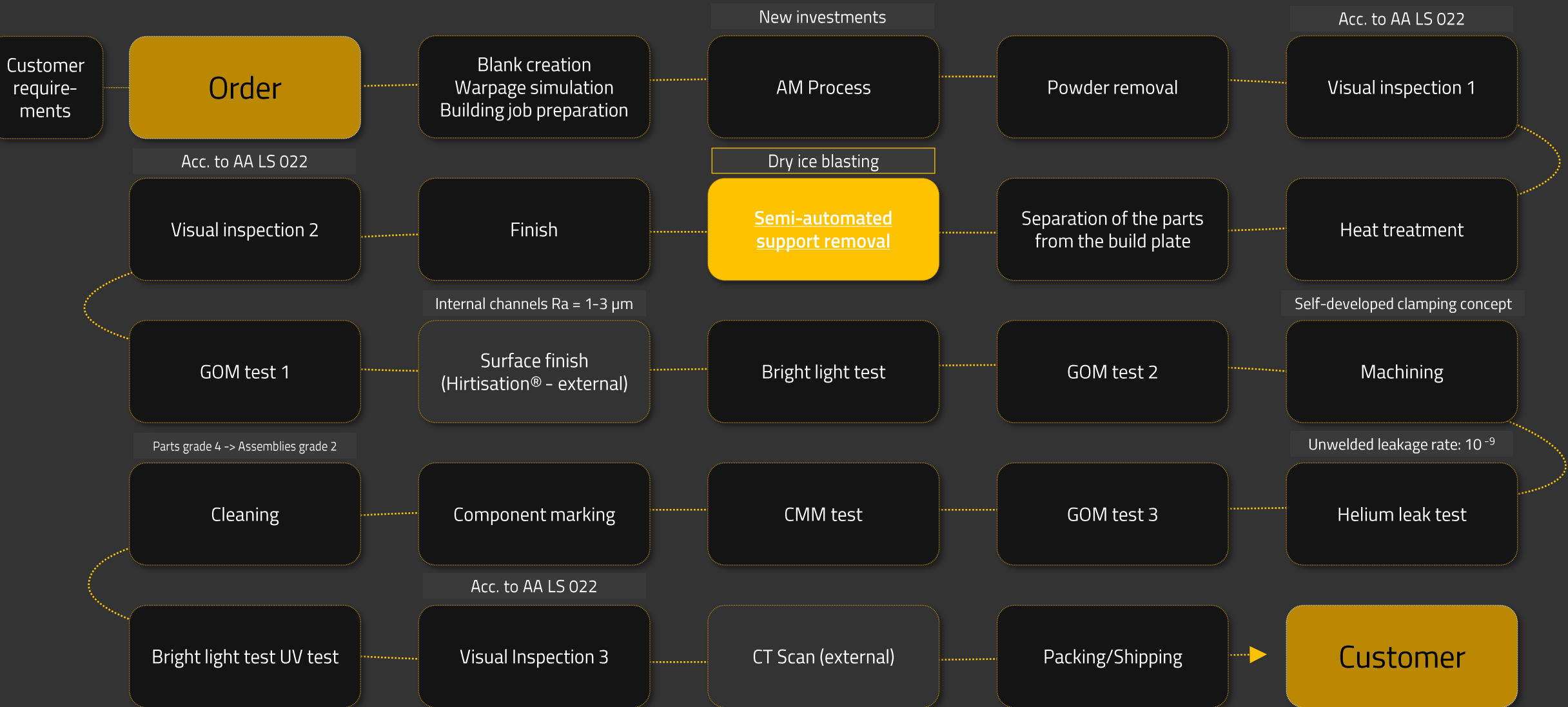


OUR INVESTMENT: TRUPRINT 3000 ML

- Available since **January 2024**
- Processed material: **1.4404**
- Build volume (Cylinder): \varnothing 300 mm x 400 mm (z)
- Full-field **multilaser** 2 x 700 watts
- Newly developed shielding gas concept (primary and secondary gas flow)
- Extensive industrial **monitoring** for quality assurance
 - Identification of temperature hotspots
 - Early detection of deviations in the laser metal melting process by integrated sensors
 - Fully automatic evaluation
 - **Potential to avoid CT scan costs**

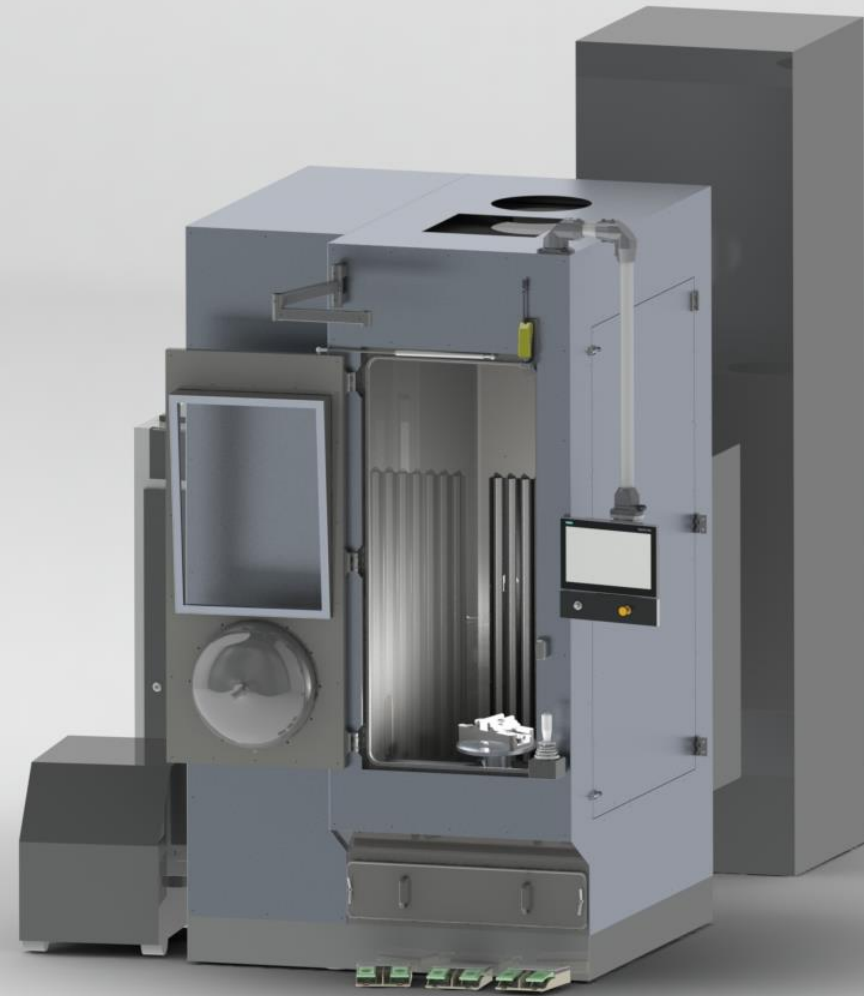


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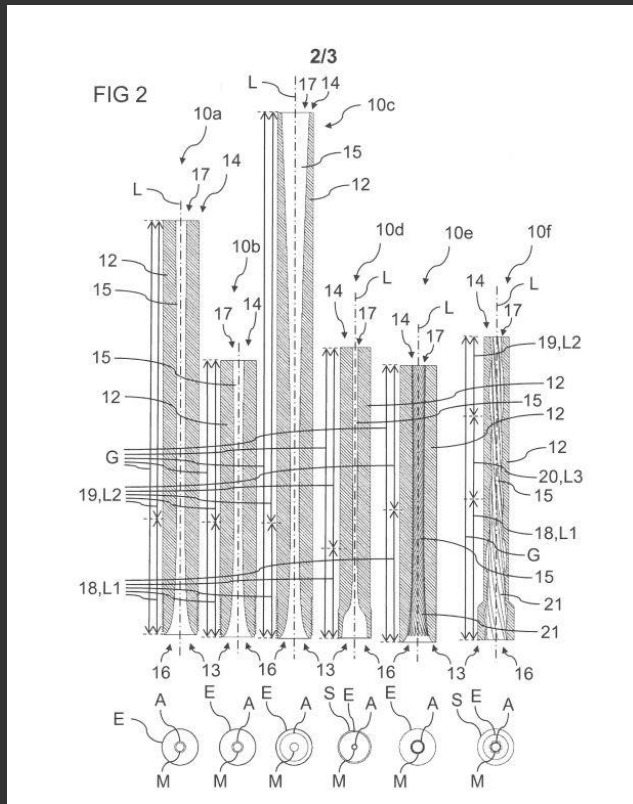
SEMI-AUTOMATED SUPPORT REMOVAL

- Registered utility model
- Functional principle: **Dry ice blasting**
- Currently processable materials:
 - Aluminum, titanium, stainless steel
 - Inconel (in final development)
 - More in development
- Footprint: 3000 mm x 4200 mm x 3000 mm
- Cabin interior dimensions: 800 mm x 1490 mm
- Clamping surface: \varnothing 280 mm
- Maximum part weight: ~16 kg

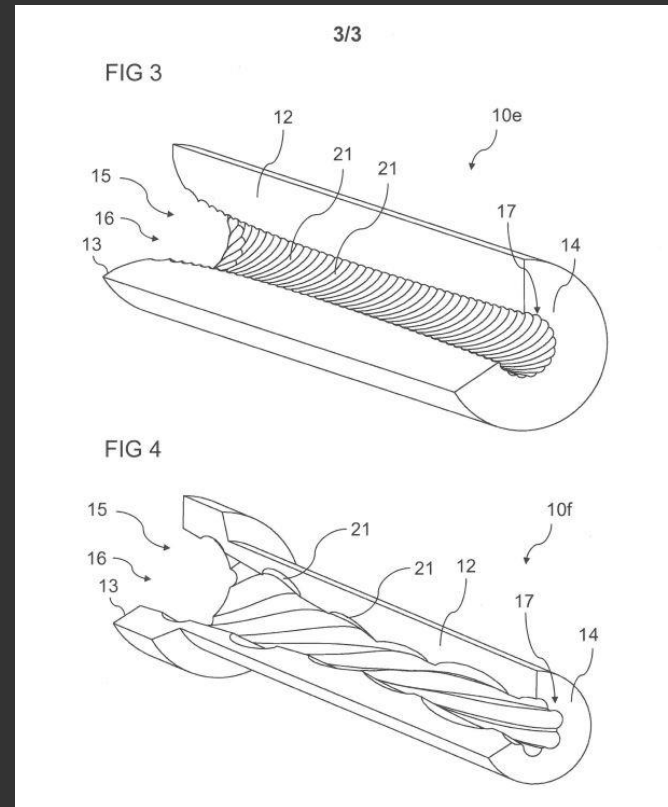


DRY ICE BLASTING: REGISTRATION OF UTILITY MODELS

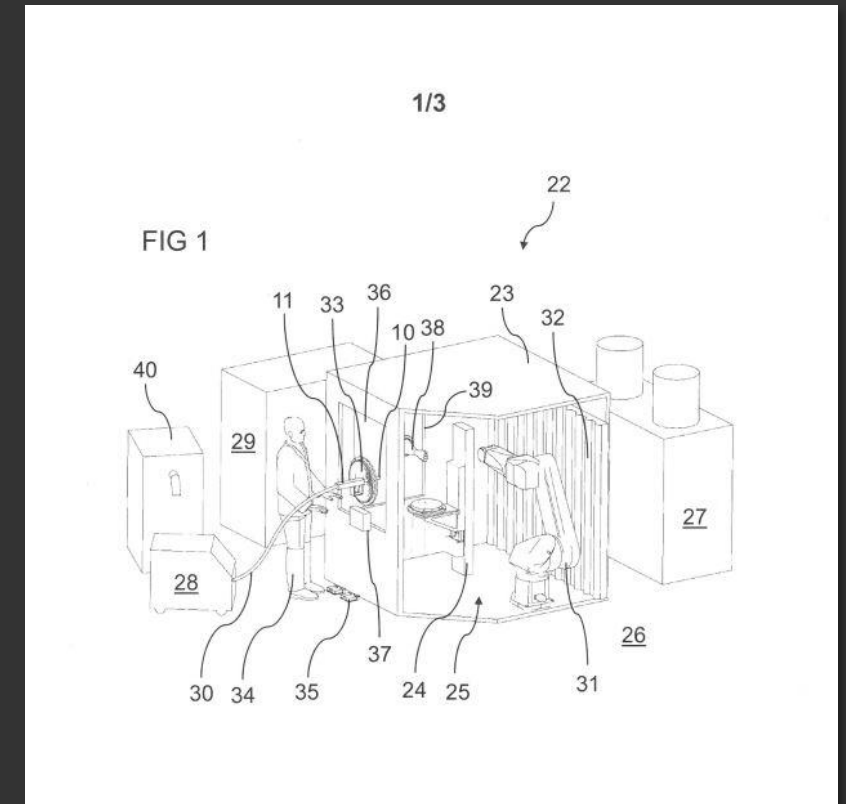
Internal nozzle geometry



Surface structure



Automation



DRY ICE BLASTING: EFFICIENT SUPPORT REMOVAL

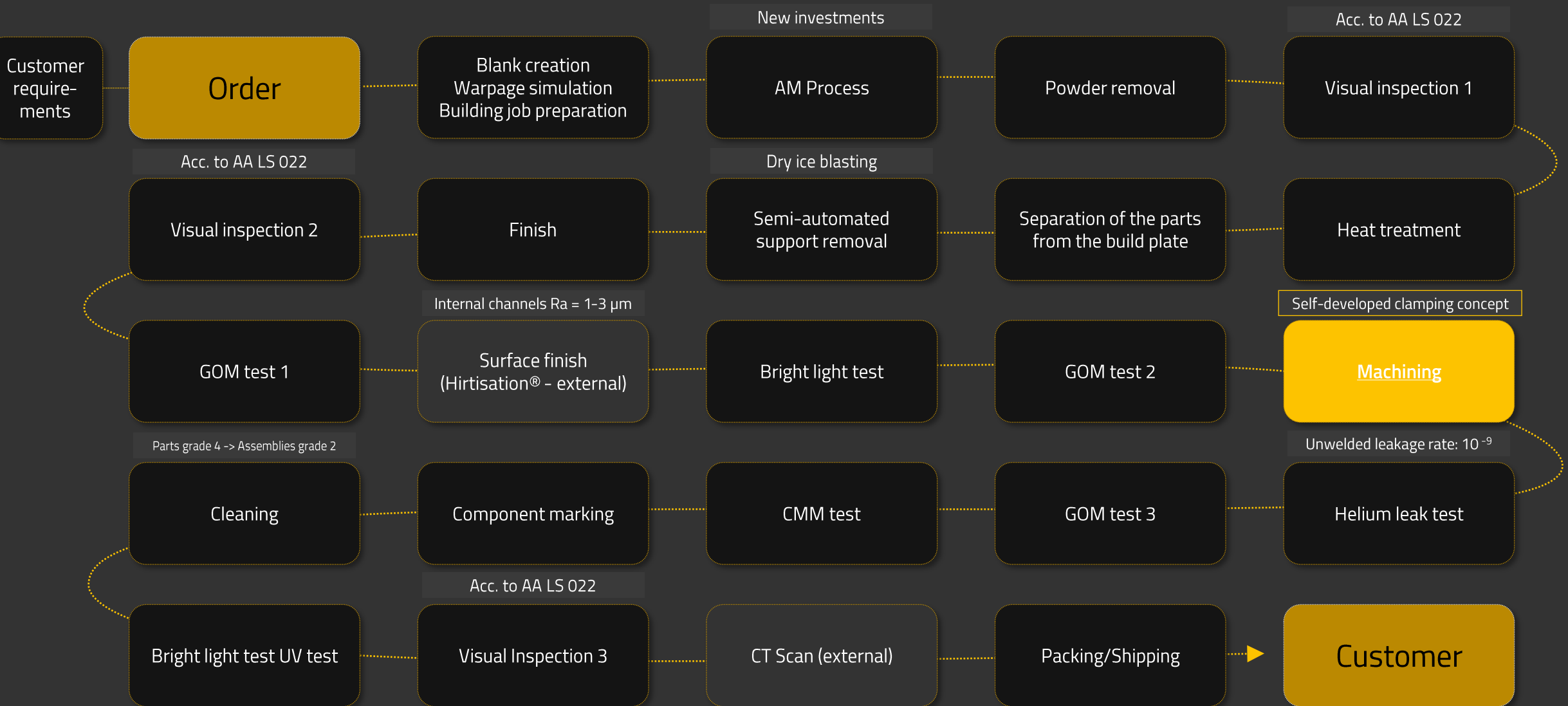
Before removal
(Component in clamping)



After removal

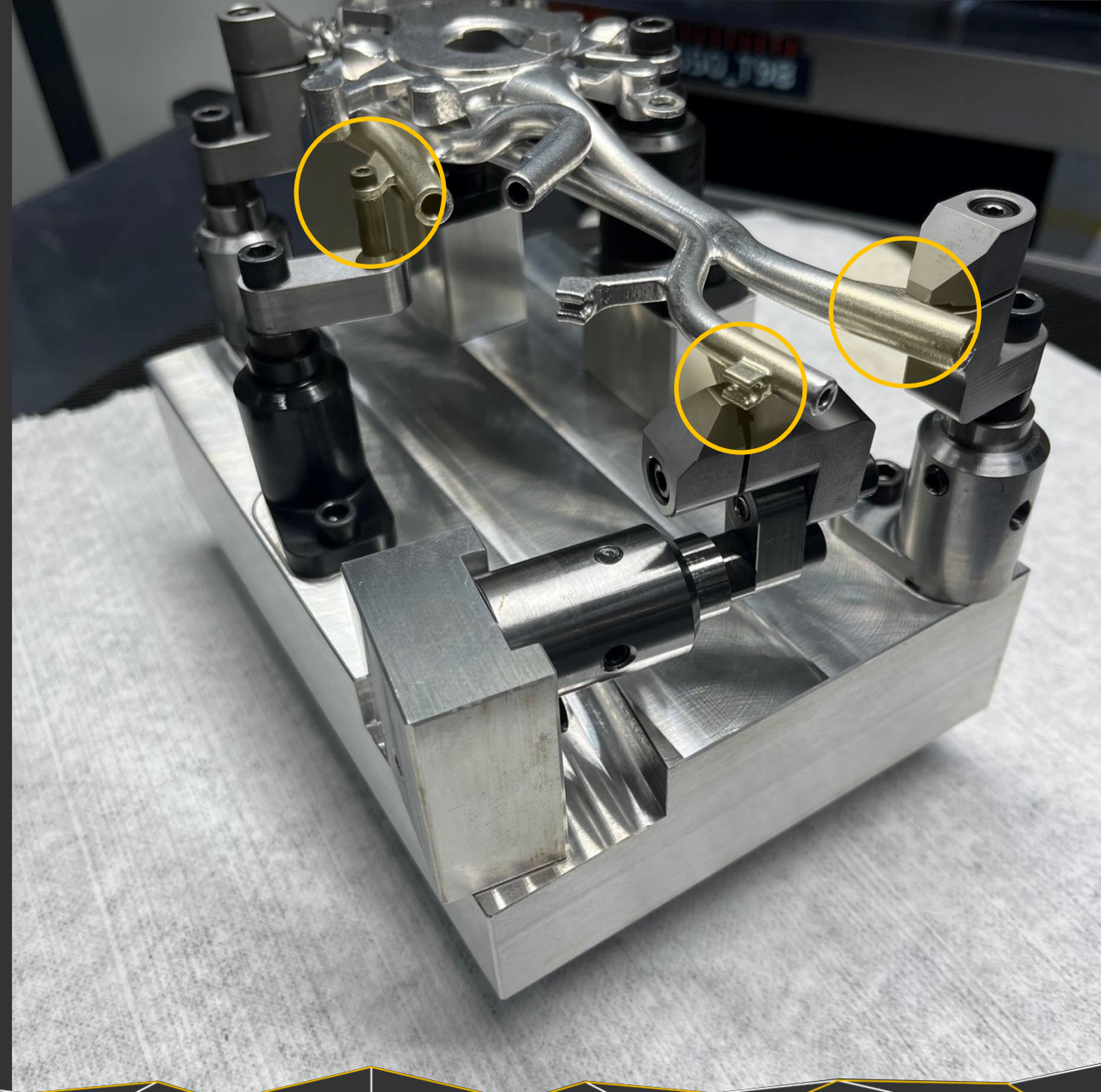


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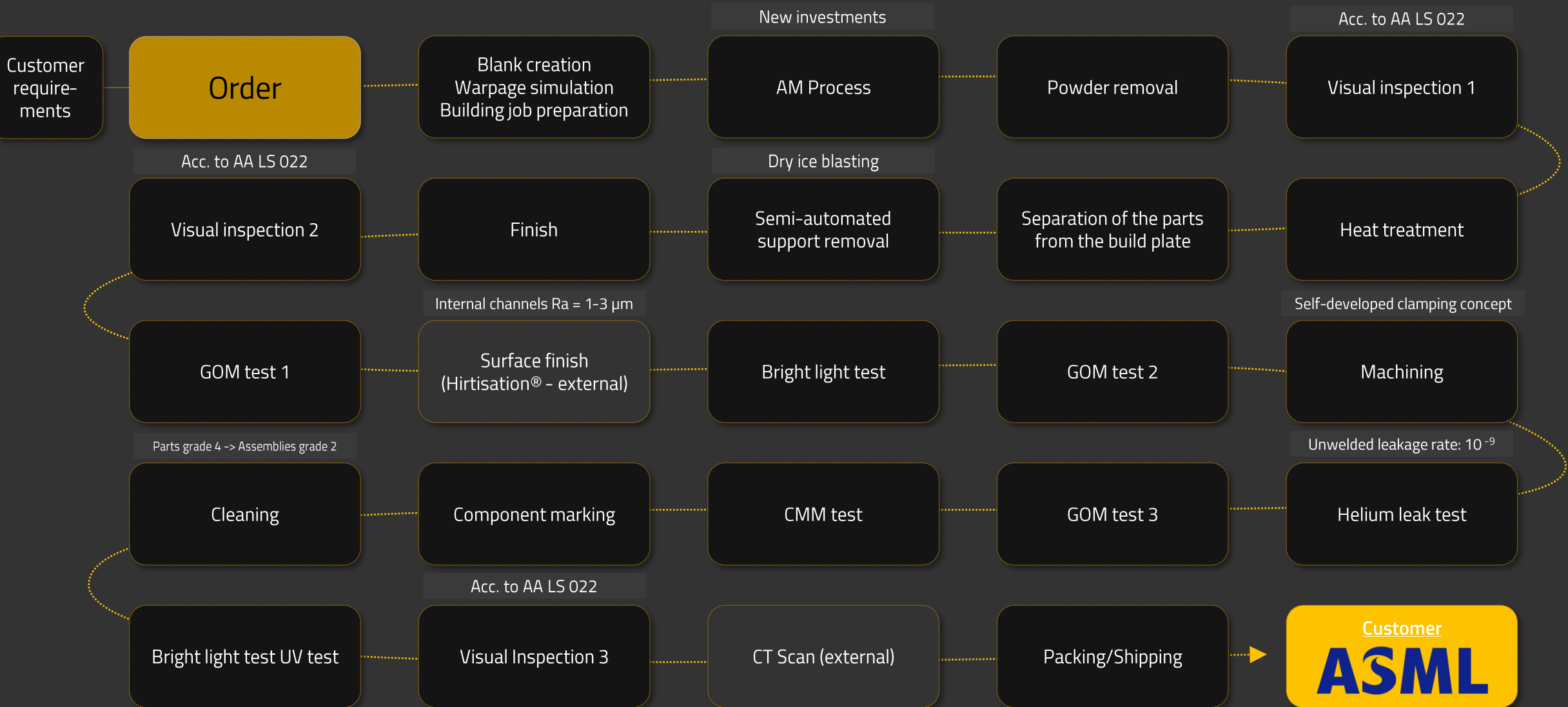


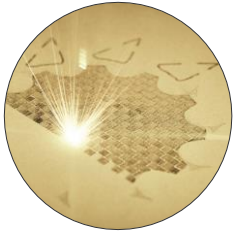
SELF-DEVELOPED CLAMPING CONCEPT

- + Challenge: Clamping concept for filigree, thin-walled AM components
- + Solution: Self-developed clamping elements
- + Standard parts catalog with modular structure deposited in Siemens NX CAD
- + Matching clamping straps for fixing the clamping elements integrated in NX library
- + Fast, uncomplicated design, changes and representation of the clamping concept realizable within NX



PROCESS CHAIN OF CS MF C1, PPL MF C2, FLOWMETER MF C1, ...





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LASER METAL DEPOSITION (LMD) - POWDER

INTRODUCTION AND INDUSTRIAL CASE STUDIES

Scan the QR code to watch the video



SECURITY-PROJECT „L-PBF + LMD“

Components with L-PBF

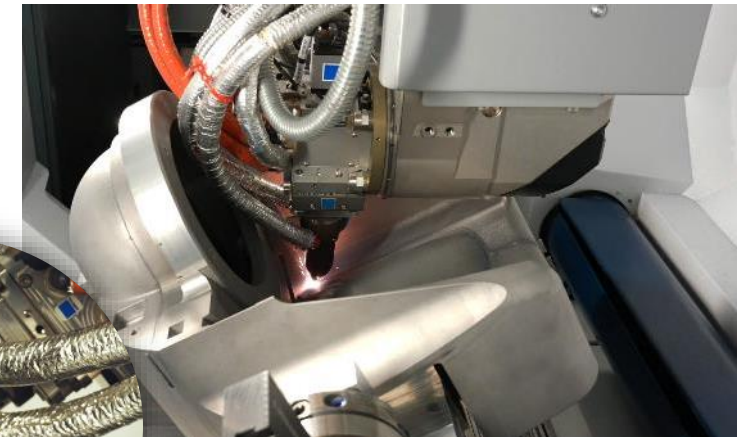
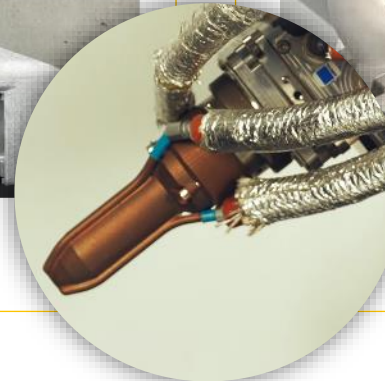
Joining Process with LMD

+ TECHNOLOGY:
Additive Manufacturing

+ USE IN:
Security

+ INDUSTRY:
Security

+ MATERIAL:
Aluminum alloy



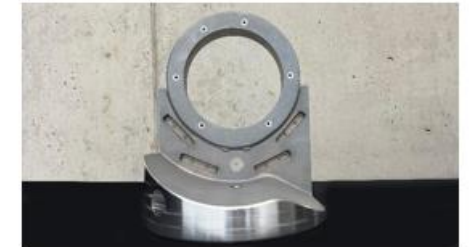
SECURITY-PROJECT „L-PBF + LMD“

INITIAL SITUATION

- + Compactness (small installation space)
- + Low weight with a high ammunition supply at the same time
- Conventional design / manufacturing not expedient

WITH ADDITIVE MANUFACTURING

- + Functional cable feeds (cannot be produced conventionally)
- + High long-term availability of spare parts
- + High speed in the development of the carrier element





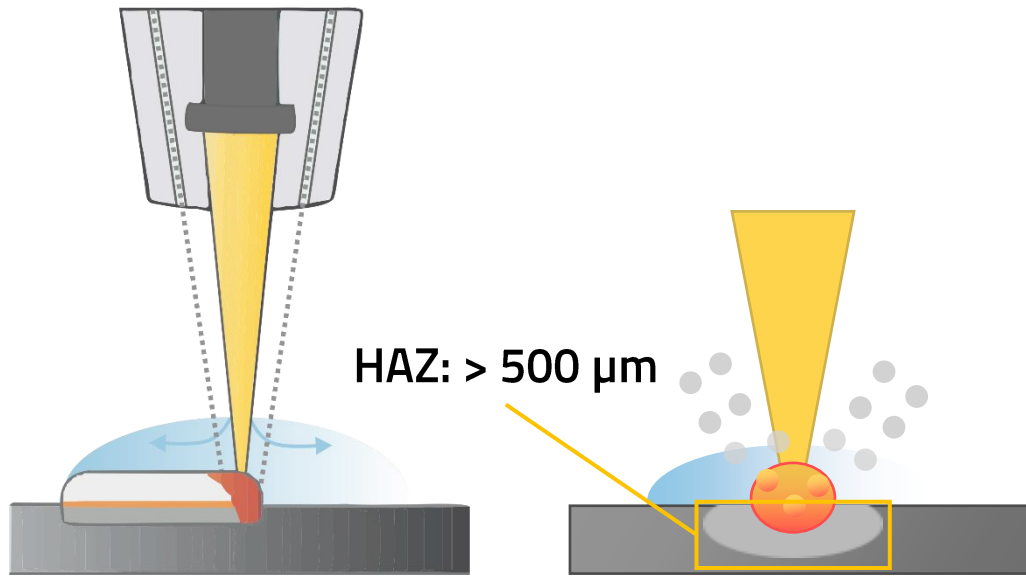
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EXTREME HIGH-SPEED LMD

INTRODUCTION AND INDUSTRIAL USE CASES

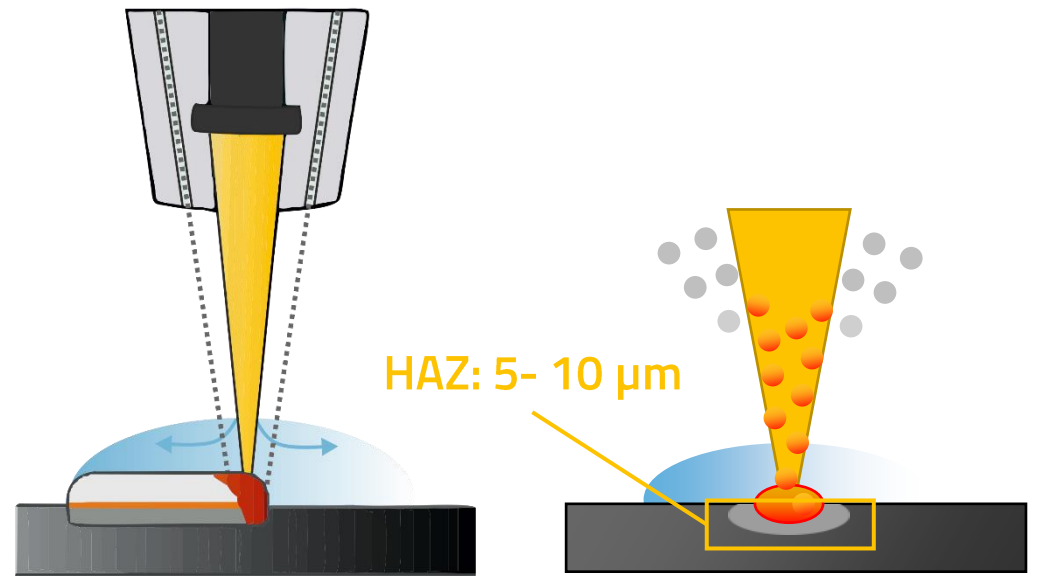
EHLA: EXTREME HIGH-SPEED LMD

Conventional LMD



The powder particles only begin melting in the melt pool

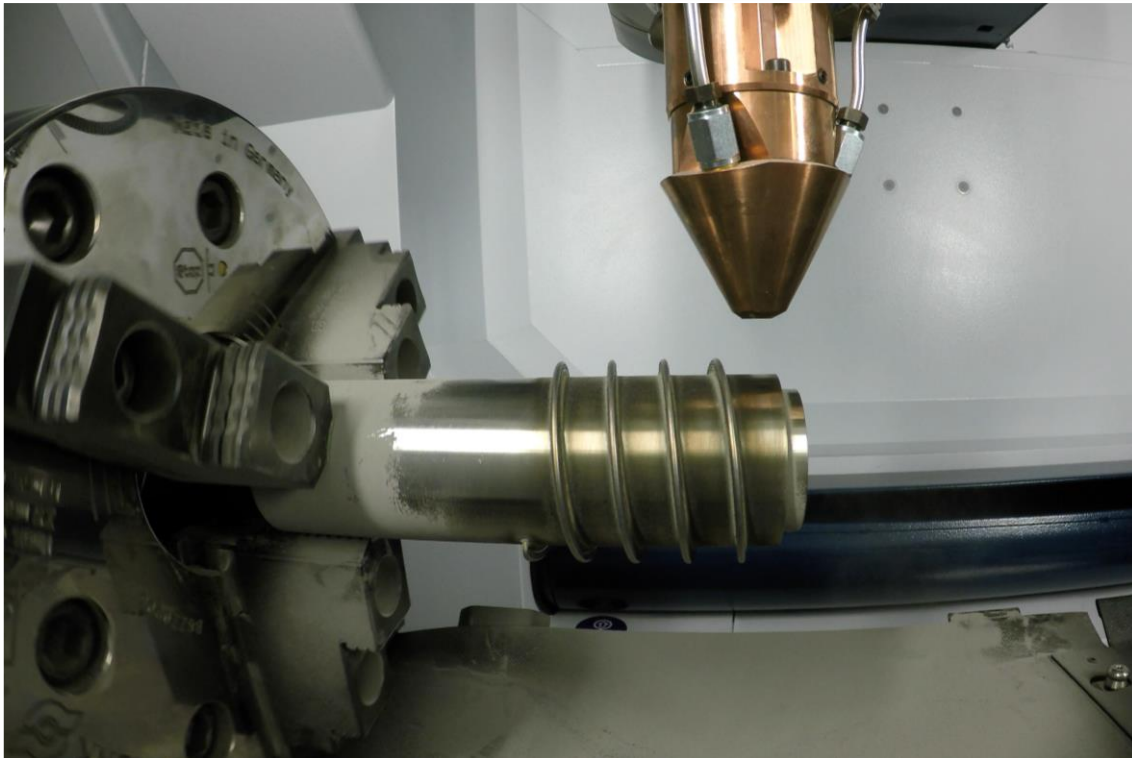
EHLA



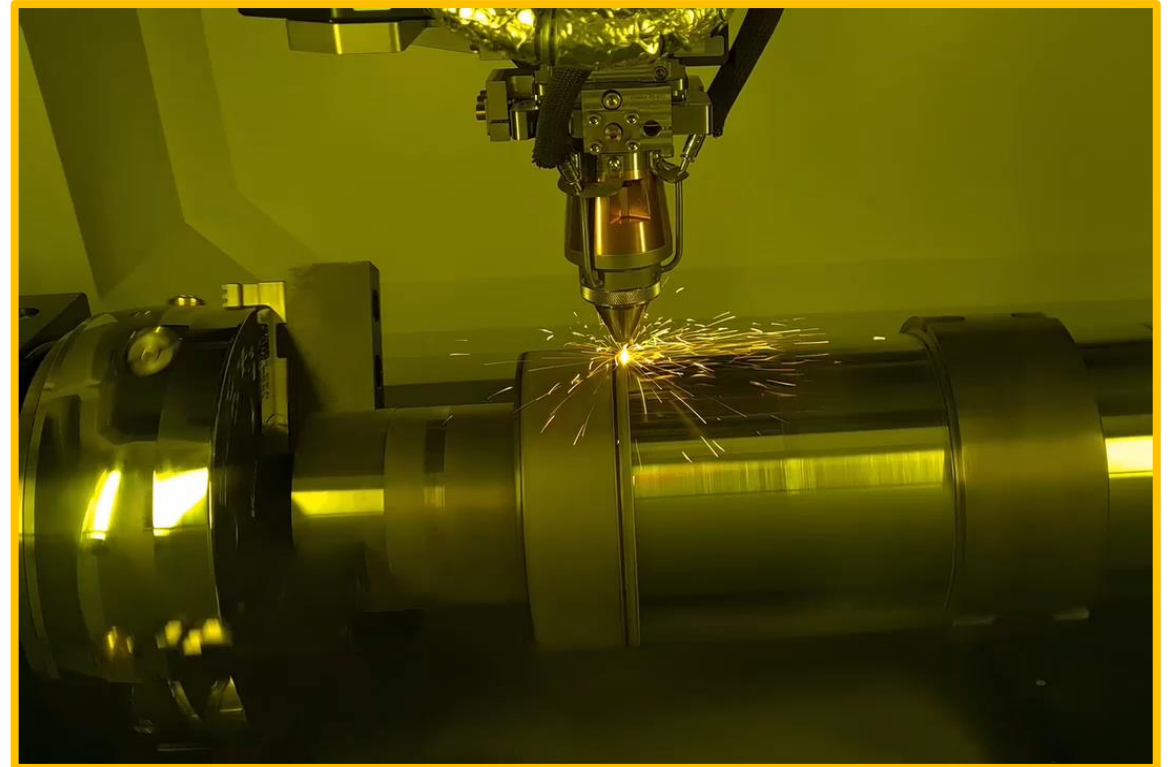
The powder particles are melting above the melt pool

EHLA: EXTREME HIGH-SPEED LMD

LMD – Process (additive)



EHLA – Process (coating)



Improvement of productivity + Powder efficiencies above 90%

EHLA 3D – MAIN FACTS

- + Based on Slim3n milling machine
- + Light-weight casting for increased acceleration (> 2 g)
- + 5-axis RWH
- + Processing area: 500 x 400 x 400 mm
- + Max. weight on table: 60 kg
- + Control unit: Siemens Sinumerik One
- + Processing Head
 - 4kW Diode-Laser
 - Variable Laser focus (1-3 mm)
 - Annular gap powder nozzle (>1 mm)
 - Dual powder feeder

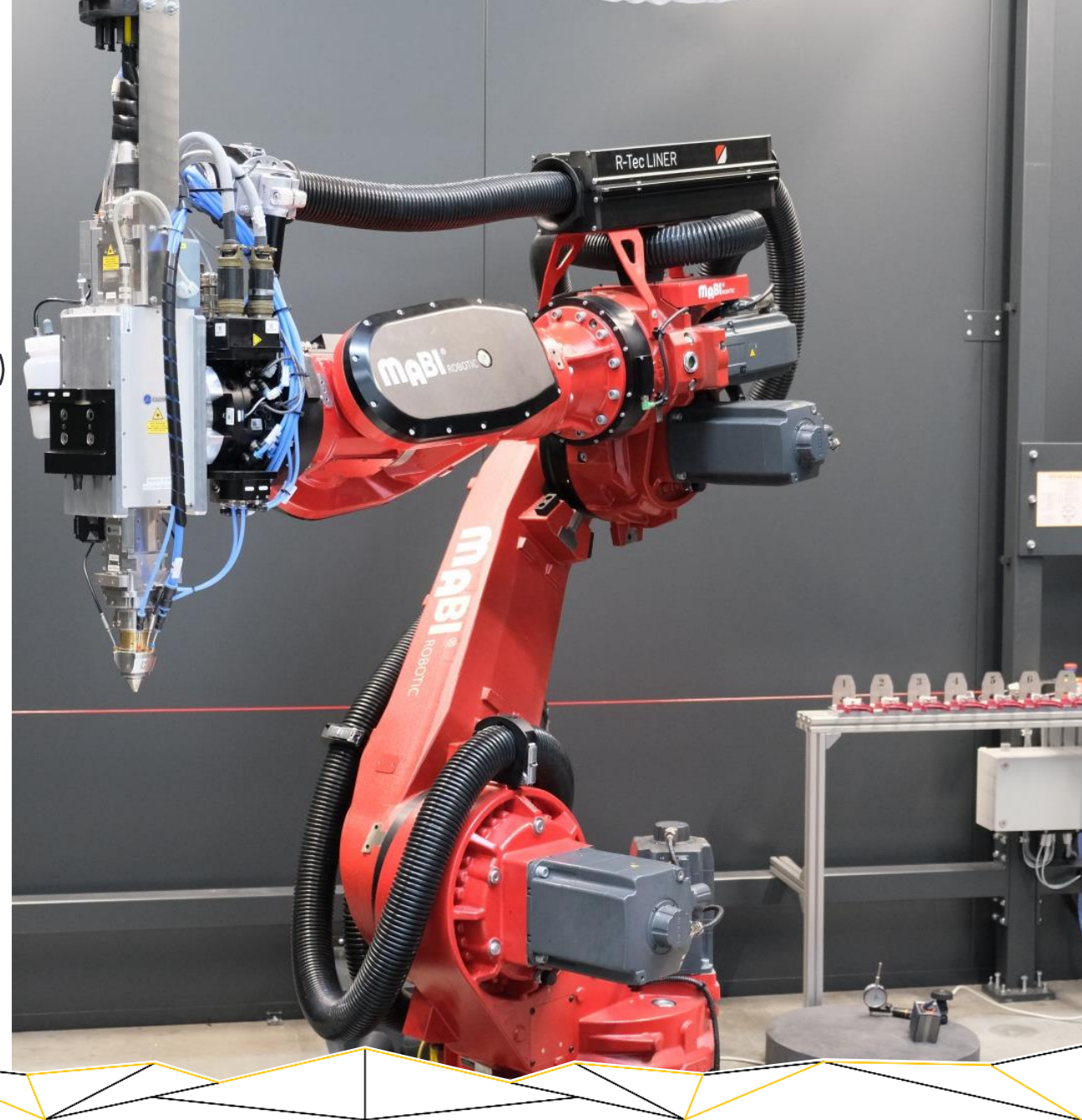


SELF-DEVELOPED ROBOT CELL

FOR HYBRID ADDITIVE MANUFACTURING

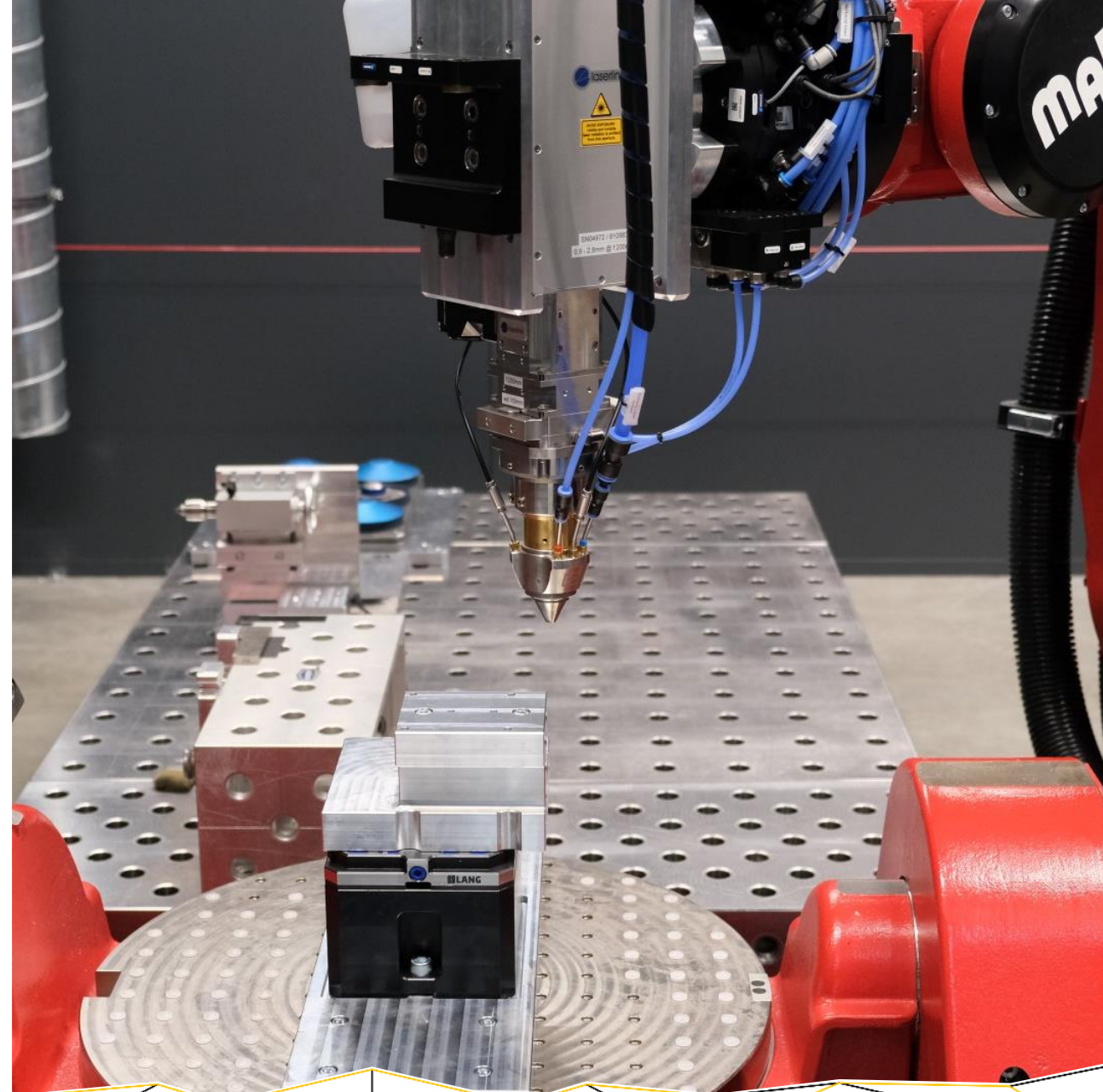
TECHNICAL DATA – ROBOT CELL

- + Robot manufacturer: **MABI Robotic AG** (load capacity: 100 kg)
- + **Adaptive spindle**
 - Spindle fixture: HSK63 E
 - Spindle speed: 16,000 rpm
 - Number of tools: 7
- + **Adaptive laser head: Laserline OTZ-5-VC**
 - Laser power: 8 kW
- + **Rotary tilt table** - load capacity: 500 kg
- + **Machining table** (heavy load): 2000 x 1200 mm
- + Exhaust system, laser protection cabin, multifunctional construction



PROS AND CONS – ROBOT CELL

- + Multifunctional: **Additive and subtractive**
- + Large machining radius
- + Good accessibility due to **8 axes**
- + Expandable
- + **EHLA process** for rotary components
- + For small and large components (**up to 1.5 m in length**)
- **Accuracy:**
 - Machining center: ± 0.01 mm
 - vs.
 - **Machining with robot: ± 0.20 mm**





tolcraft

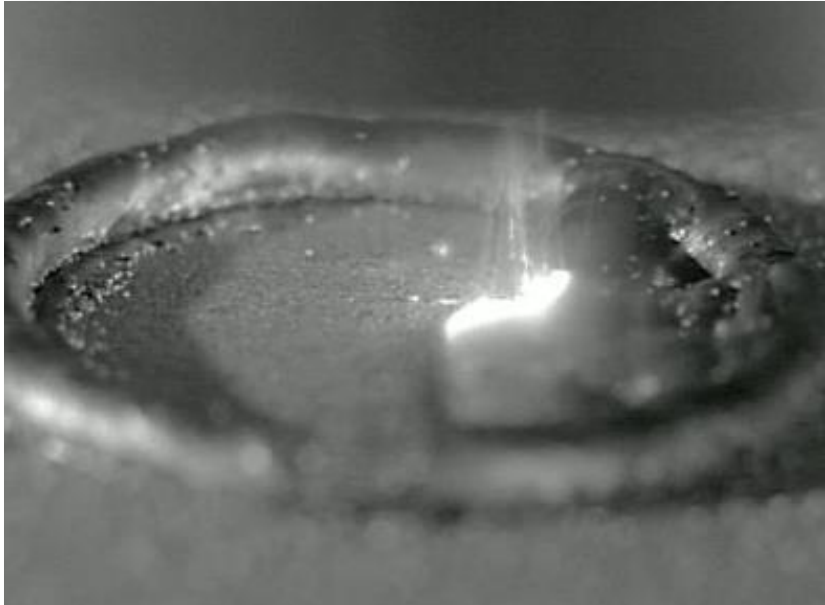


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HIGHER DEPOSITION RATES THROUGH WIRE APPLICATION

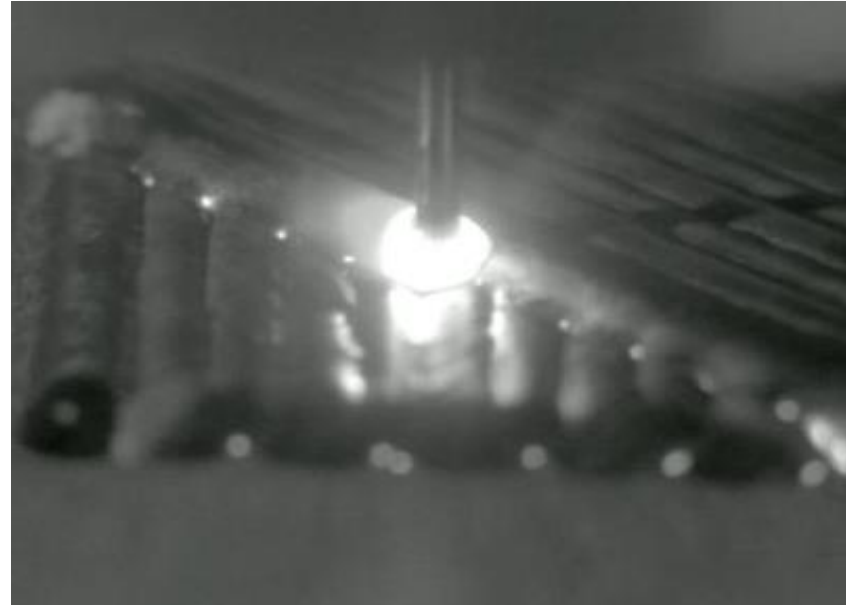
OUTLOOK

LMD-WIRE: POWDER VS. WIRE APPLICATION



Powder application:

- + Maturity level
- + Process accuracy
- + Process control



Wire application:

- + Higher deposition rate (up to 1 kg/h)
- + More cost-effective



Component:

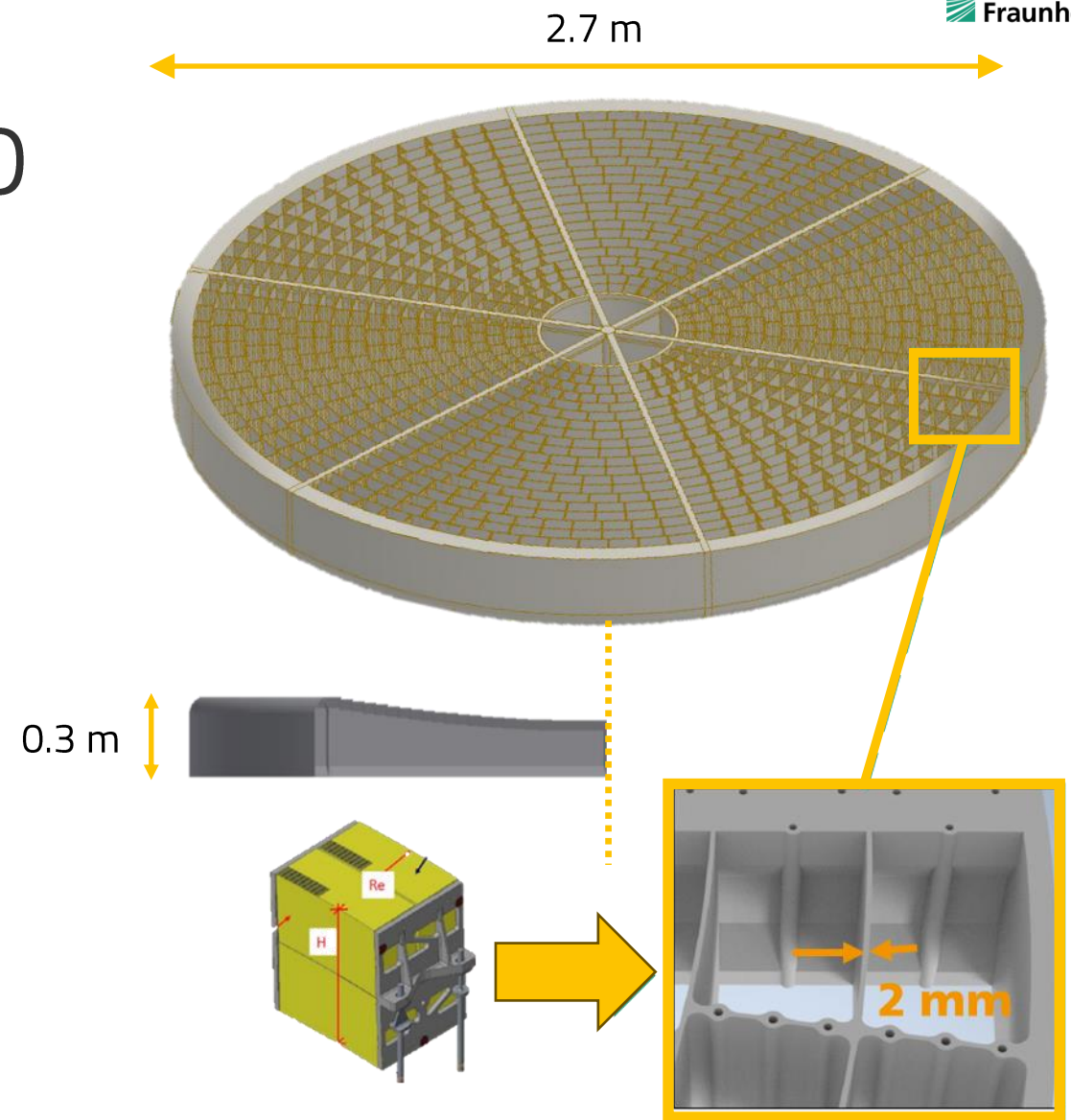
Double-sided structural component

Material: TiAl6V4 / as-build

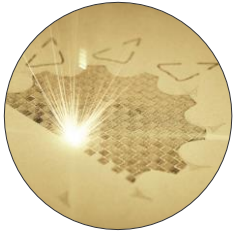
Base plate: 500 mm x 400 mm x 10 mm

ADDITIVELY MANUFACTURED STRUCTURAL COMPONENTS

- + Main mirror: > 600 silicon pore X-Ray modules to be embedded
- + KPIs include high specific stiffness
- + **Hard to machine** in terms of material properties, volume, geometry and required wrought material
- + Filigree cellular structure
- + High aspect ratios (300 mm height vs. 2 mm width)
- + First prototype: 1,5 m; **currently demonstrator: 2,7 m**
- + **Material: TiAl6V4**
- + Manufactured with a **hybrid approach** combining additive material build-up and subtractive machining



Source: Appendix 1 to AO/1-8607/16/NL/LvH



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FINAL SUMMARY: AM WITH **toolcraft**, & **ASML**

1

More and more AM-adapted standards and certifications are emerging with a focus on process capability

2

Process capability can be achieved:

- With the right **system**, the right **system tools**, the right **equipment** and the right **team**
- Through **close partnerships** and **regular feedback loops** between manufacturer and user
- Through **innovation**



toolcraft will continue to be innovative:

- Further **investments** in our machine park (wire optics in Robot Cell)
- Future processing of **high-temperature plastics** such as PEEK, PEI, ULTEM...

Pace Maker for High-End Precision Parts



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