American Gear Manufacturers Association®

AGMA EMERGING TECHNOLOGY WEBINAR

June 5, 2024

Laser Powder DED – Technical Overview

NIDEC Machine Tool America
Dwight Smith, VP Additive Manufacturing and Marketing
Tobias Dornai, Application Engineer

Please make sure to have your microphone on mute. We will begin shortly.

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Gear Grinding Technology

NIDEC MACHINE TOOL CORPORATION

Introduction of LAMDA
Powder DED Metal 3D Printer

Ritto Plant, Japan

NIDEC MACHINE TOOL CORPORATION

NIDEC Kyoto Tower

Nidec Machine Tool Corporation - Products

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Gear Manufacturing Solutions

Machining System

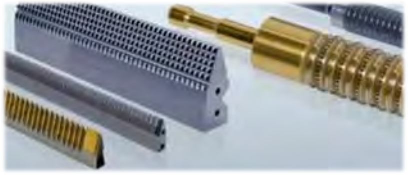
- Hobbing Machines

- Grinding Machines

Cutting Tools

- Gear Cutting Tools

- Broaches



General Purpose Machines

- Large Machines
  (HBMs) (DCMs)

Micro Machining Solutions

- Additive manufacturing

- Wafer Bonding

Global Operations

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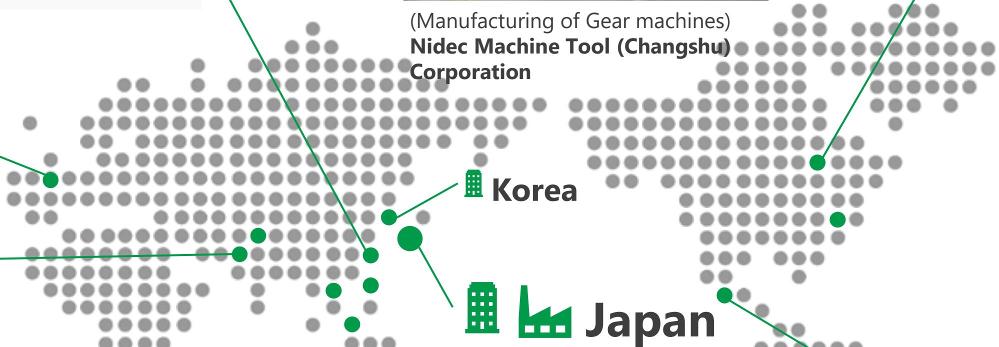
4 factories

13 sales & service offices

1383 Number of employees including overseas bases



Germany

India

Delhi

Ranipet

(Manufacturing cutting tools)
Nidec India Precision Tools, Ltd.

China

Shanghai

Changshu

(Manufacturing of Gear machines)
Nidec Machine Tool (Changshu) Corporation

Korea

Japan

USA

Wixom, MI

(Machine Tool Sales & Service)
Nidec Machine Tool America LLC

Harrison, MI, Greer, SC

(Manufacturing, Sales & Service of Machines and cutting tools)
Federal Broach Holdings (FBC & SEB)

Mexico

Brazil

History

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Mitsubishi Heavy Industries → Nidec

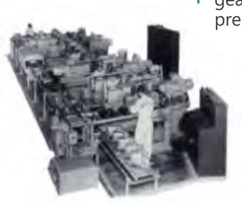
Kyoto plant

1944

Established as Mitsubishi Heavy Industries (MHI) Kyoto plant

The commencement of production: tools and jigs to manufacture aircraft engines; special purpose machines to manufacture automotive engines; gear cutting machines and precision cutting tools

Japan's first NC gear hobbing machine



Japan's first transfer machine for processing crankcases of agricultural machinery

Precision cutting tools

Ritto Plant

1983
Establishment of Ritto plant to shift cutting tools production from Kyoto

1986
The commencement of production of gear cutting machines and special purpose machines in Ritto

2000
Consolidation of production sites into Ritto

The completion of plant relocation from Kyoto

2003
The completion of plant relocation from Hiroshima

2015
Establishment of MHI Machine Tool Co., Ltd. focusing on machine tool and cutting tools business

2021
Becoming part of NIDEC group as NIDEC MACHINE TOOL CORPORATION

Hiroshima plant

1939
Established as Toyo Machine Tool Co., Ltd. for production of lathes

Bestselling model

1941
Toyo Machine Tool joined Mitsubishi Heavy Industries

Japan's first Horizontal Boring Mill

1943
The company name changed to Mitsubishi Machine Tool Co., Ltd.

The commencement of large machines to supply suitable production equipment to meet MHI's in-house manufacturing requirements

1945
Absorption by MHI

The world's largest-class NC milling-and-boring combined machine (gate width: 13 m).

History of our metal 3D printer development

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We are one of the few machine tool manufacturers in Japan that can develop and manufacture laser optics units in-house

Technology background

We were Laser technology development division in **Mitsubishi Heavy Industries**

2014~
1st prototype
DED machine

2017~
Release monitoring feedback technology

2019~
LAMDA200

2020～
Large scale part metal 3D printer
LAMDA2000

2022
5-Axis metal 3D printer
LAMDA500

LAMDA DED System

Line up from Small Research Machines to Large Production Machines

<table>
<tr><th></th><th>LAMDA 200</th><th>LAMDA 500</th><th colspan="3">LAMDA 2000/LAMDA5000</th></tr>
<tr><td>Maximum printing size [mm]</td><td>200 x 200 x 200</td><td>500 x 500 x 500</td><td>2,000 x 1,500 x 1,600</td><td>2,500 x 900 x 1,000</td><td>5,000 X 2,500 X 1,600</td></tr>
<tr><td>Laser power [kW]</td><td colspan="5">1, 2, 4, 6</td></tr>
<tr><td>Local gas shielding</td><td colspan="5">Available</td></tr>
<tr><td>Cutting head (Hybrid)</td><td colspan="2">N/A</td><td colspan="2">Standard</td><td>N/A</td></tr>
<tr><td>NC axis table</td><td>1-axis or 2-axis tables Available</td><td>2-axis tables Standard</td><td colspan="3">1-axis or 2-axis tables Available</td></tr>
<tr><td>Machine Size (installation space) [mm]</td><td>4,000 × 2,600</td><td>4,000 × 6,000</td><td colspan="2">12,000 × 6,500</td><td>7,000 × 5,500</td></tr>
<tr><td>Printing materials</td><td colspan="5">Titanium alloys, Inconel, Stainless steel, Maraging steel, Cobalt-chromium alloys, Invar alloys, Aluminum alloys</td></tr>
</table>

LAMDA5000

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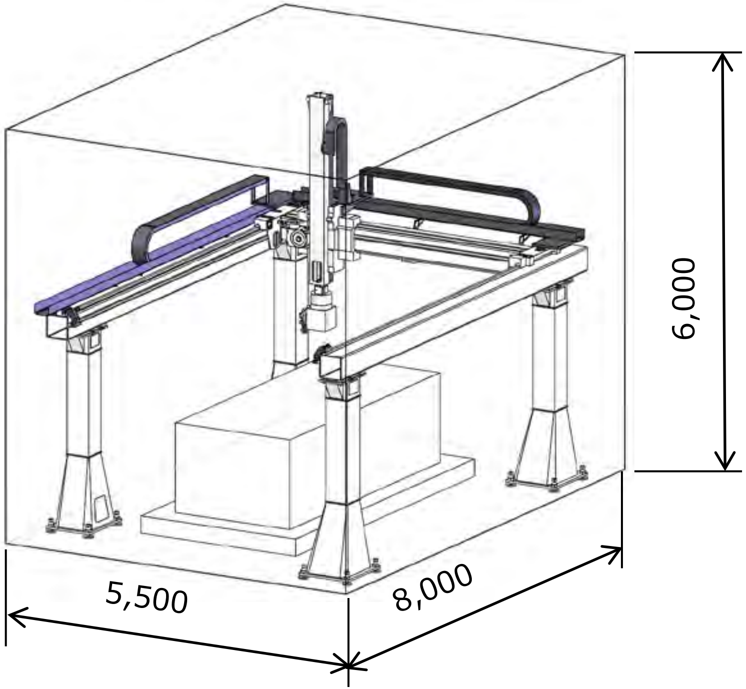
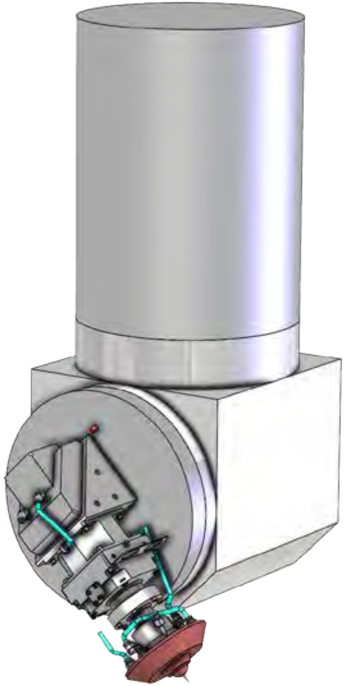
Gantry type, with two rotating axes on the DED head.

LAMDA5000 Specifications

Gantry type, with two rotating axes on the DED head.



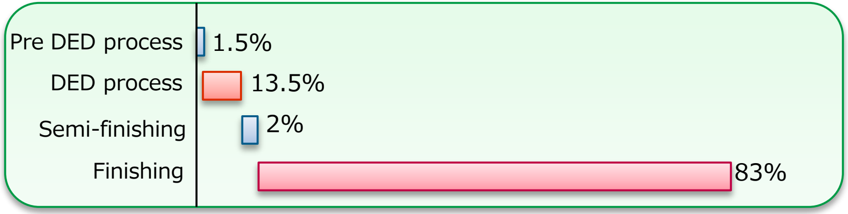
Stroke X: 5,000 mm, Y: 2,500 mm, Z: 1600 mm
Footprint 5,500 mm x 8,000 mm



With simultaneous 5-axis DED with 2 turning axes on the DED head for printing on complex free-form surfaces

LAMDA5000 Specifications

We will support the construction of an optimal production line while utilizing the current equipment, such as adding a DED system to the existing APC station.

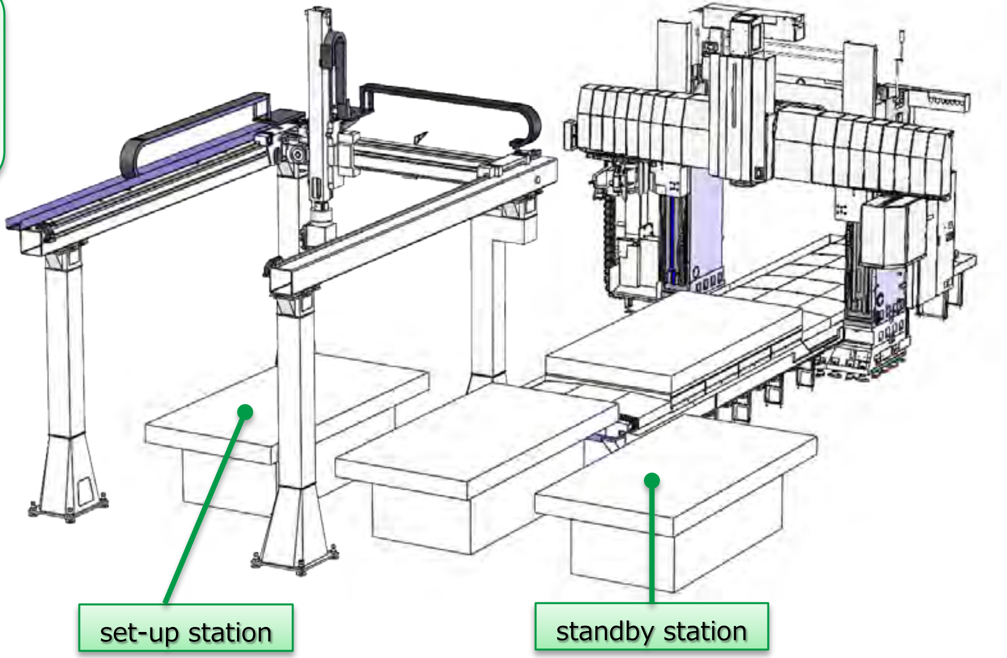


Die & molds repair process and its time ratio

For repair operations, the time required for finishing occupies about 80% of the total process.

Other processes such as heat treatment are also required depending on the request.

A machine configuration that can accommodate flexible line configurations is the best



Additive Manufacturing Technologies

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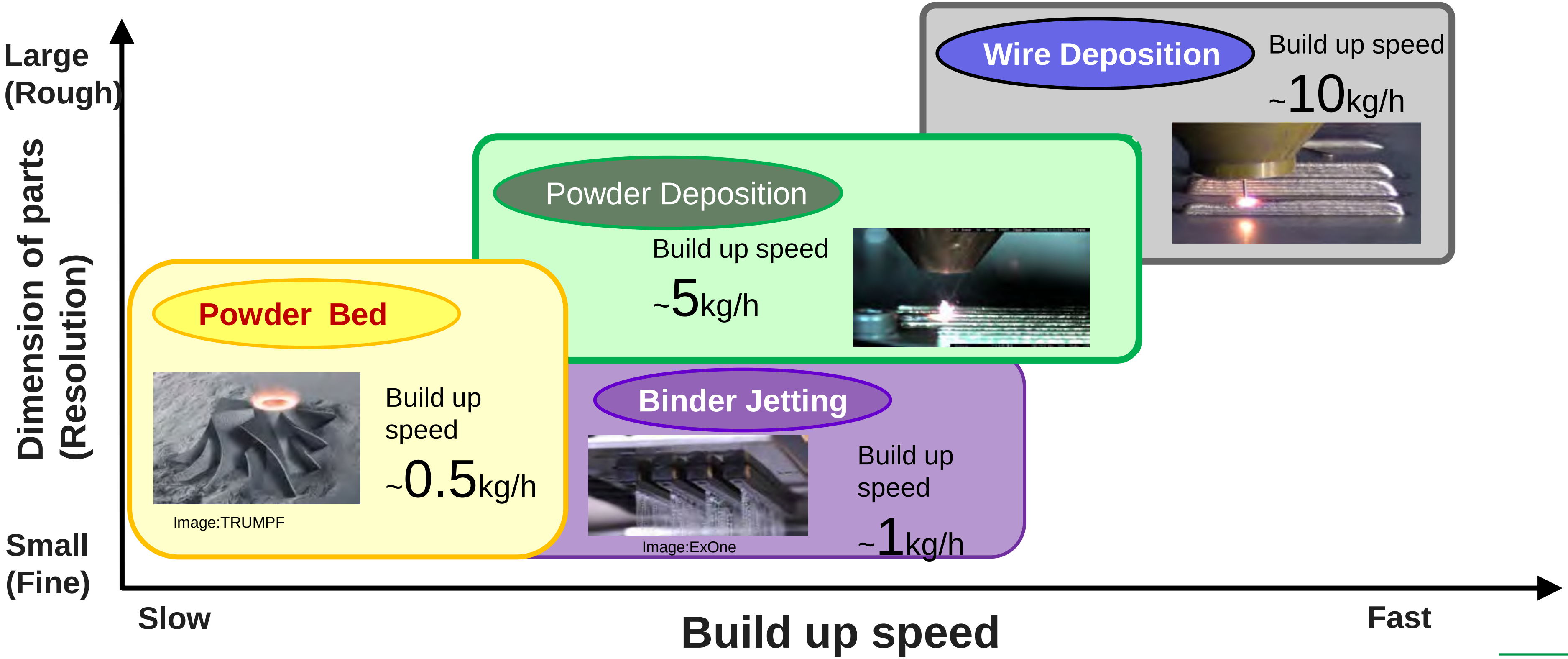
Specific types of technology are used for specific parts



The official name of the powder deposition method is Directed Energy Deposition (DED）.

Large
(Rough)

Dimension of parts
(Resolution)

Powder Deposition

Build up speed
~5kg/h

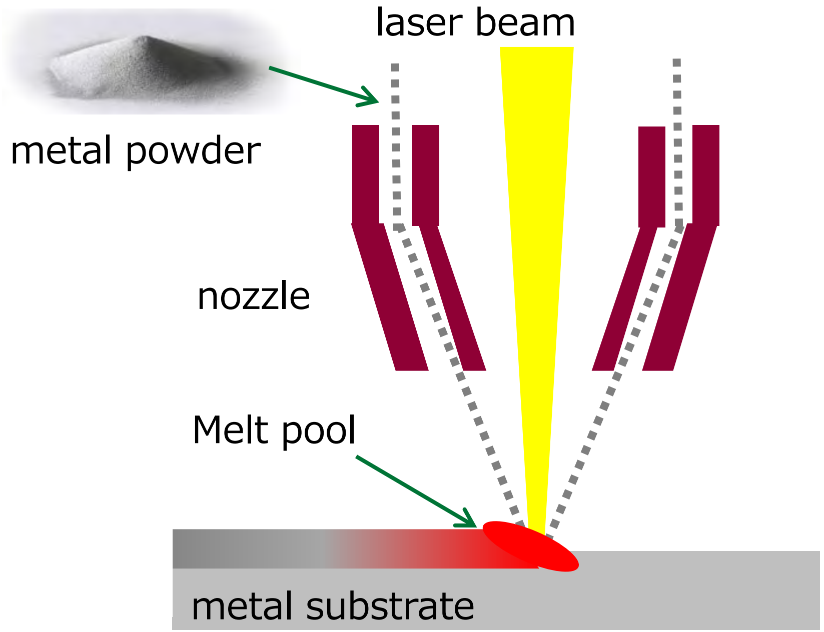
Small
(Fine)

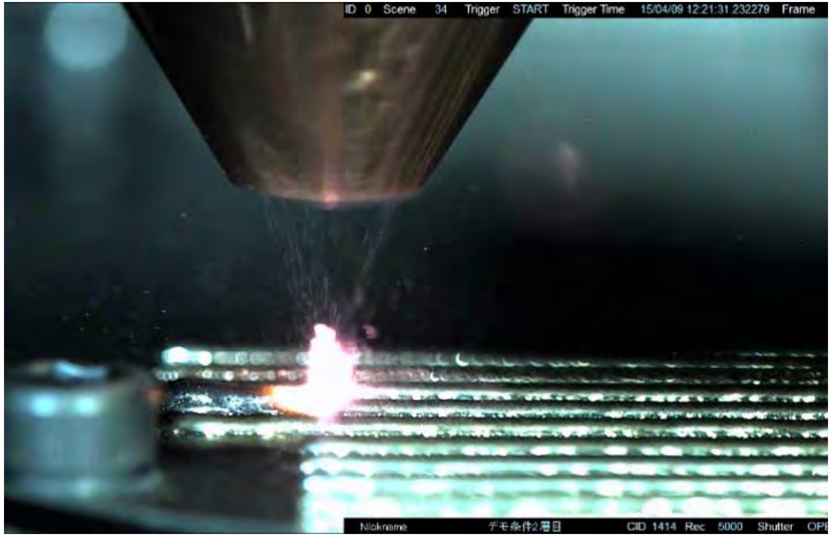
Slow

Build up speed

Fast

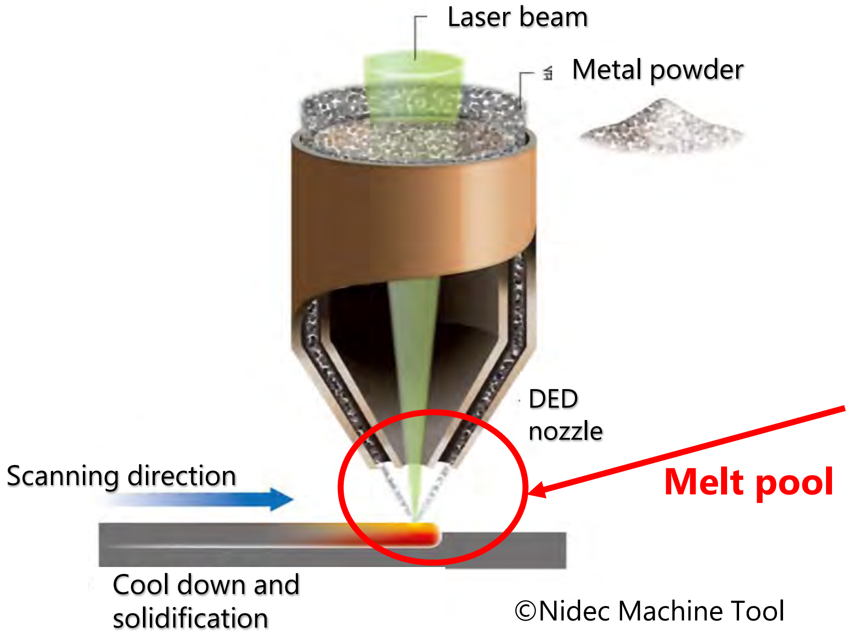
Characteristics of powder DED

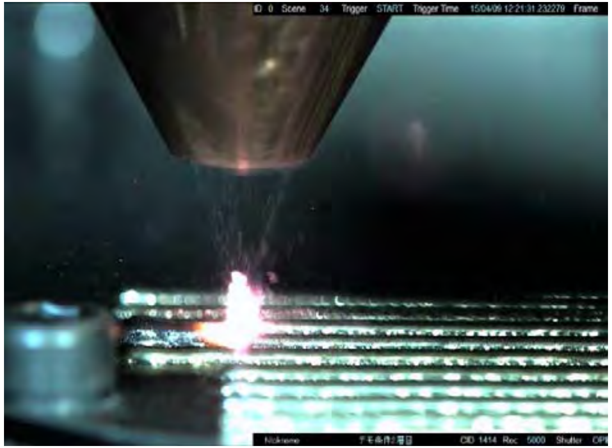




Directed Energy Deposition (DED) method features

Advantages	Challenges
No limit on printing size	Inert gas atmosphere in a large space
Multi-material printing	Traceability of printing material quality and active stabilization control





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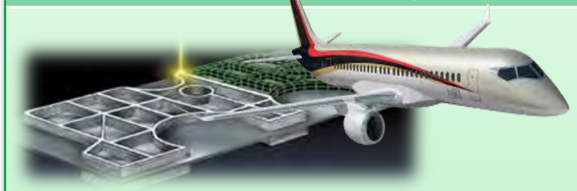
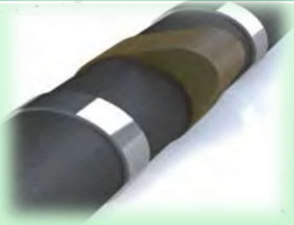
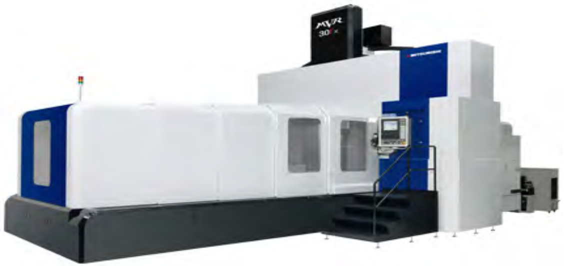
Video

DED Applications

Aerospace	Energy, Oil & Gas	Automotive
Near net Shape of Titanium Alloy	Repair of larger parts	High function component with several materials
 Quote : Additive Manufacturing of Aerospace Alloys for Aircraft Structure (Air Force Research Laboratory))		
Reduction of cost/delivery	Reduction of life cycle cost	Light weight/High Function
 LAMDA2000 DED System	 LAMDA 500 DED System	 LAMDA 200 DED System

Titanium alloy parts with DED

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Aerospace, military and space applications

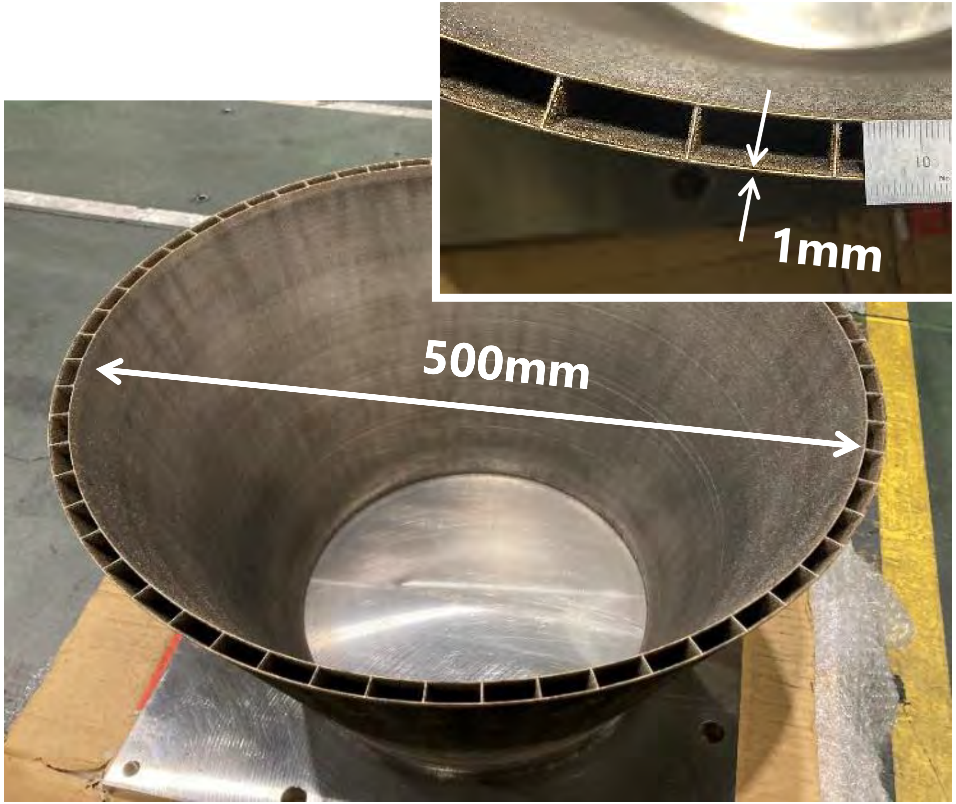
Wing parts

Body parts

Plate parts

Printed parts by LAMDA

LAMDA system is capable of long hours of finely precise printing.

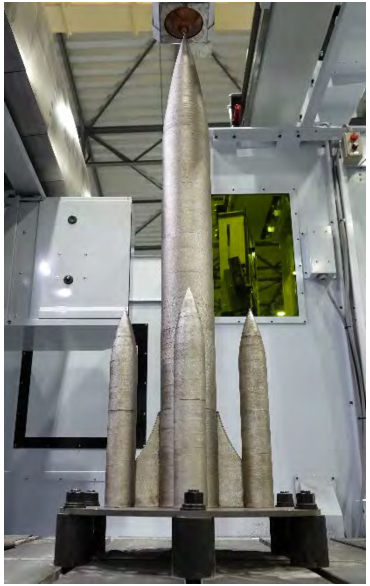


Printed parts by LAMDA

LAMDA system is capable of long hours of finely precise printing.

AlSi10Mg
0.6mm wall

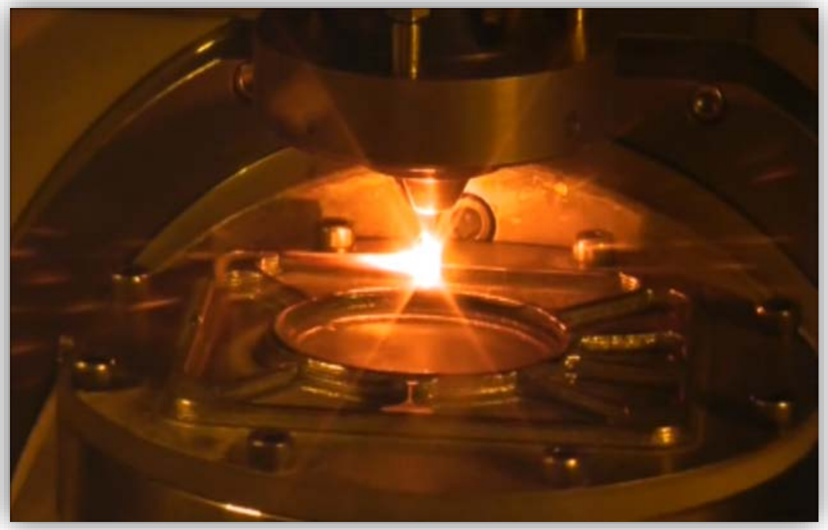
Ti6Al4V Rocket Model



AlSi10Mg
2.0mm±0.2mm
Height：1,160mm
Printing time：
approx. 11h

Printed parts by LAMDA

LAMDA system is capable of long hours of finely precise printing.



<u>DUCT SAMPLE MODEL</u>

- ■ Material Ti6Al4V
- ■ Local shield nozzle
- ■ Surface finished by machining
- ■ Size 100×100×100mm
- ■ 5-axis

- ■ Printing Titanium alloy parts in the atmosphere
- ■ Improving production efficiency with near net printing
- ■ Hybrid processing with printing head and machining head.

Cladding and Repair

Coating high-hardness materials where necessary by DED process, it is possible to reduce material costs and extend the life of die & molds.

SKH40

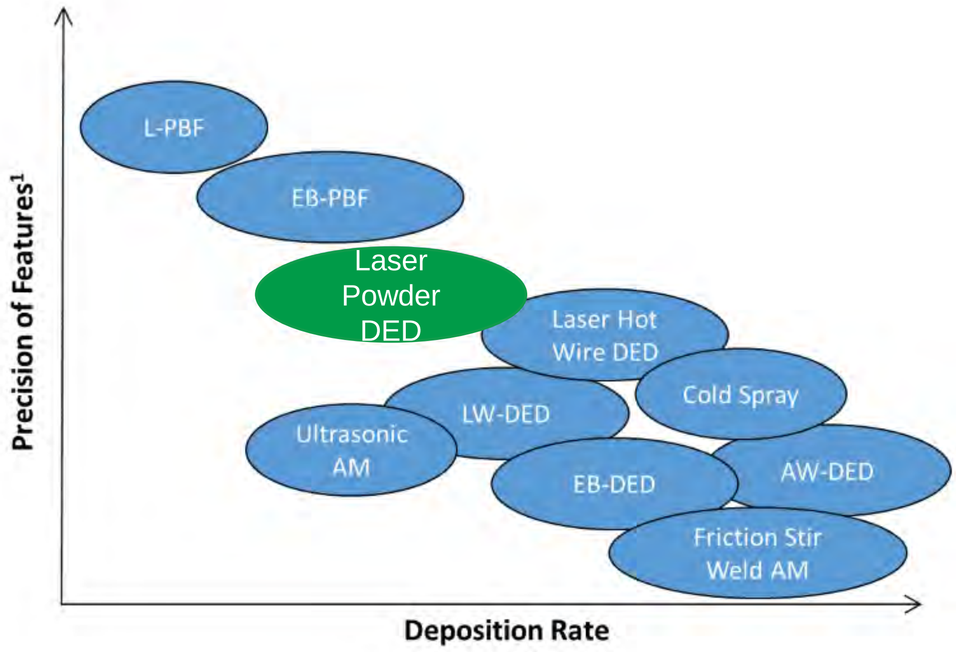
High speed tool steel. An alloy with high hardness and excellent wear resistance and toughness.

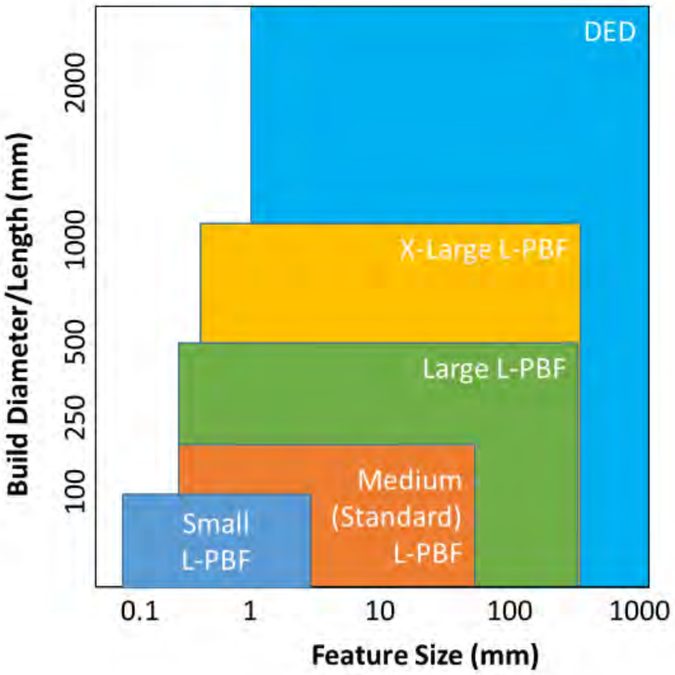
Stellite No. 6

A cobalt-based alloy with excellent wear resistance, corrosion resistance, and heat resistance.

Where DED fits into the 3D mix

Size versus precision

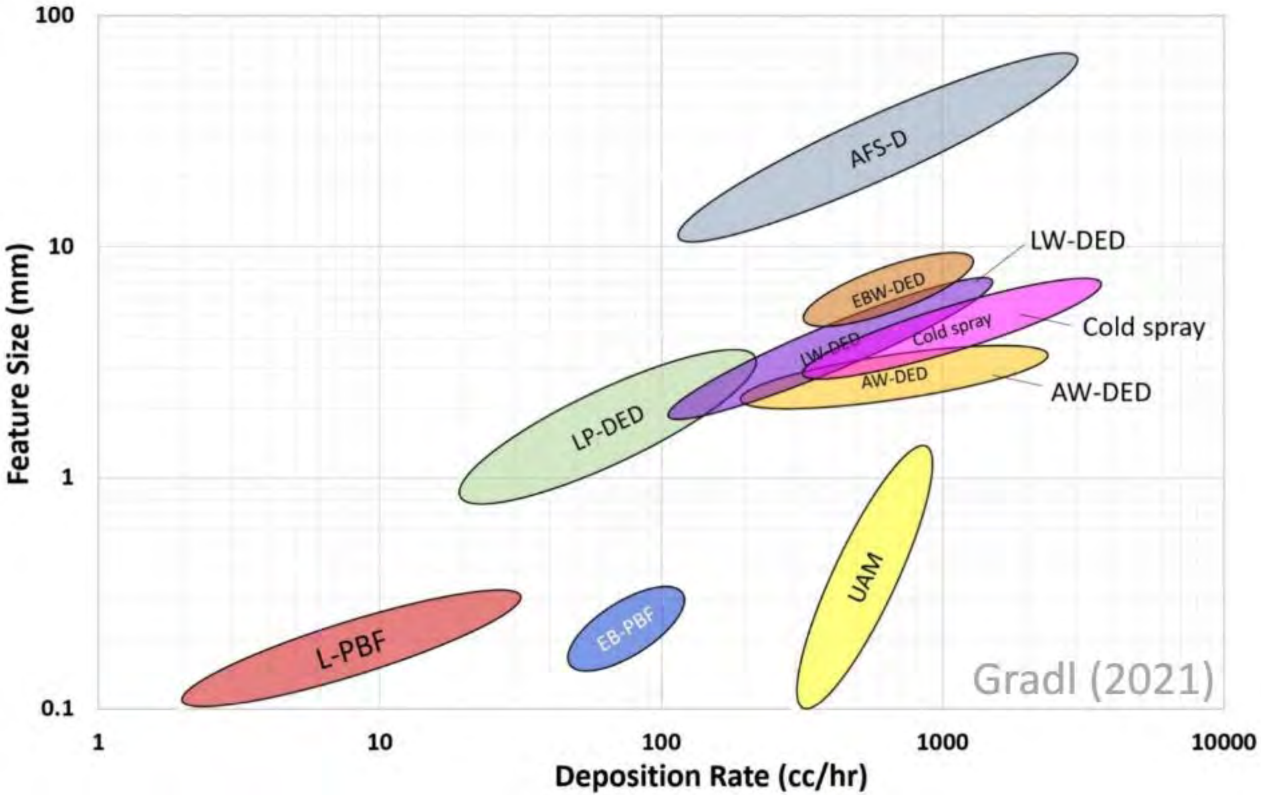




Gradl, P. R. – Metal Additive Manufacturing for Propulsion Applications
Gradl, P.R., Mireles, O., Andrews, N. "Introduction to Additive Manufacturing for Propulsion Systems"

Where DED fits into the 3D mix

Speed of deposition versus feature size



Gradl, Paul R. – Metal Additive Manufacturing for Propulsion Applications

Where DED fits into the 3D mix

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Use cases for additive manufacturing

- Higher complexity – AM becomes a better choice
- Lower production volumes (prototypes) – AM becomes a better choice
- Creates “near net” parts - some post processing usually required

Where DED fits into the 3D mix

Quality and design considerations

- Material structures and qualities are greatly dependent on what parameters are used and are difficult to keep consistent– monitoring/feedback system helps with this
- AM process benefit from DFAM (Design for Additive Manufacturing) for lightweighting, multimaterials, structural optimization

All for dreams

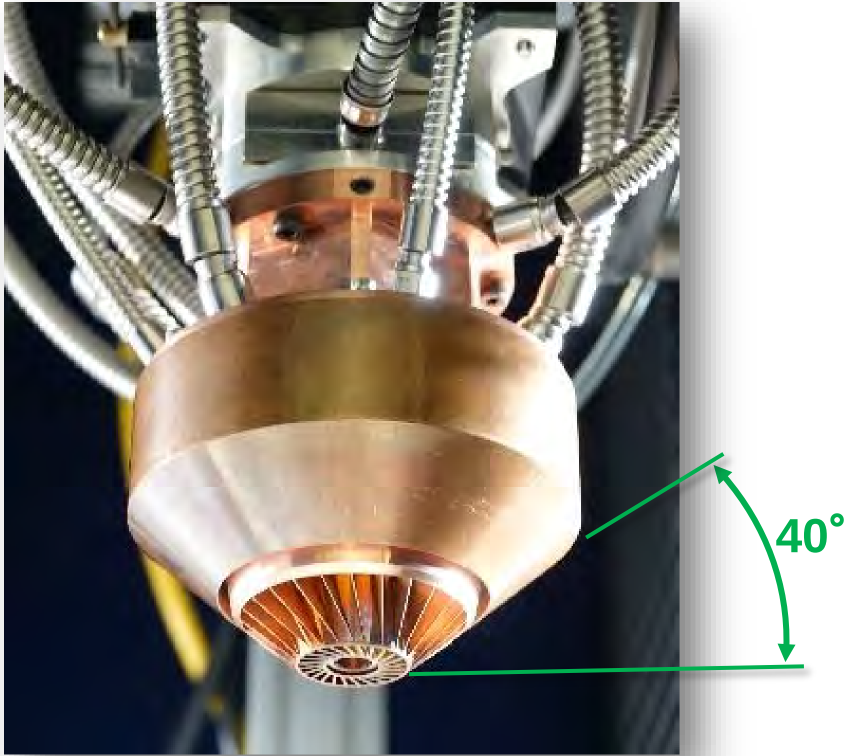
NIDEC MACHINE TOOL CORPORATION

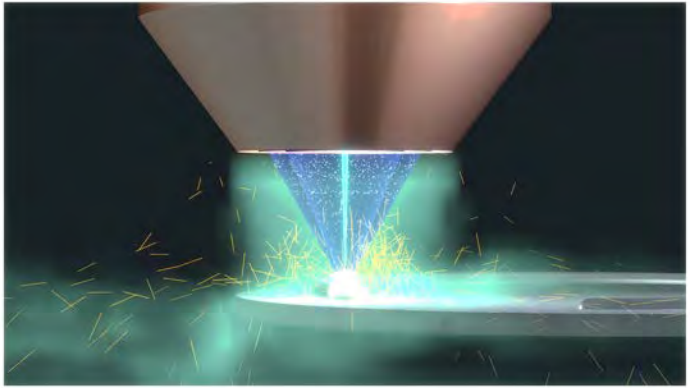
Introduction of LAMDA Local Shield Nozzle

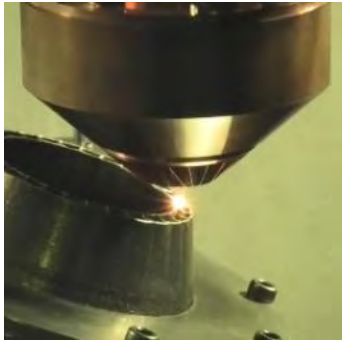
Development Headquarters

Local Shield Nozzle

Local shielding performance prevents oxidation during printing







Large approach angle of 40 degrees enables 5-axis printing

Advantage of Nidec LAMDA system

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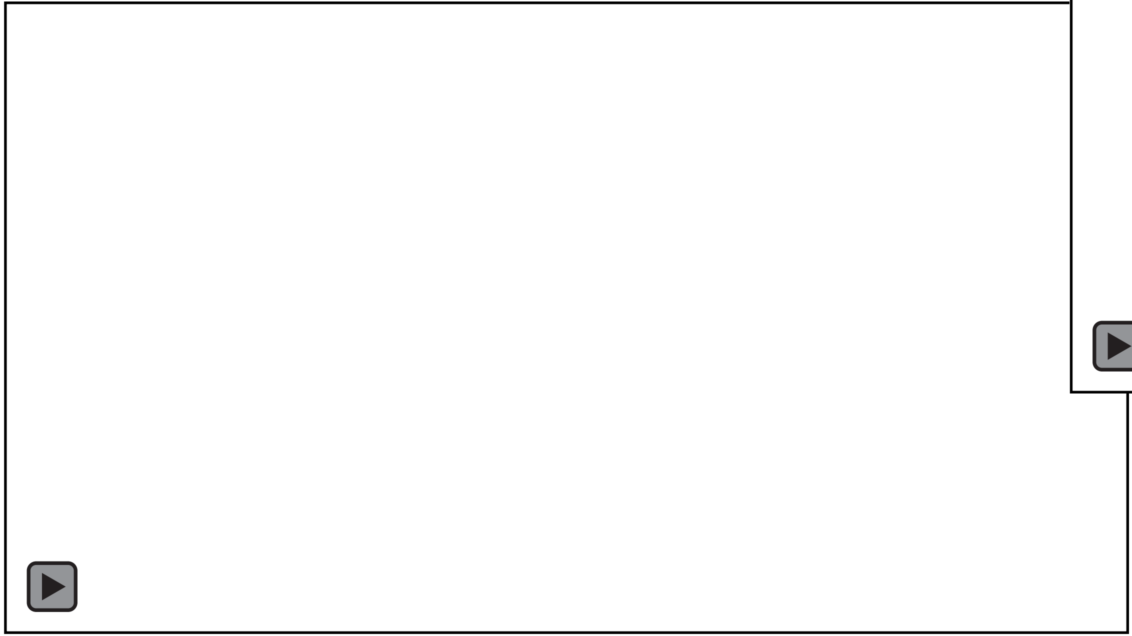
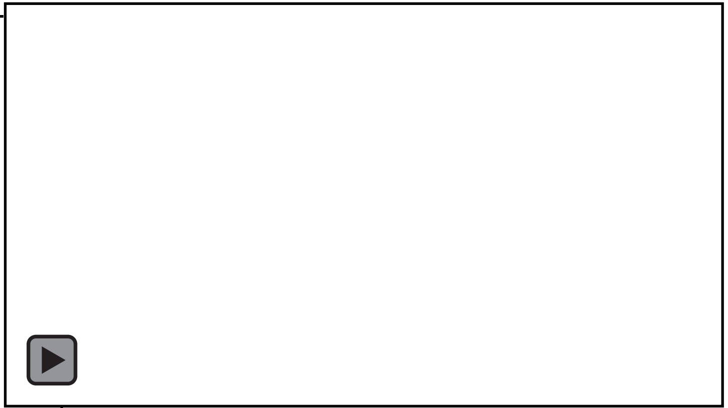
By creating an inert gas environment locally, reactive material can be printed in an atmospheric environment.

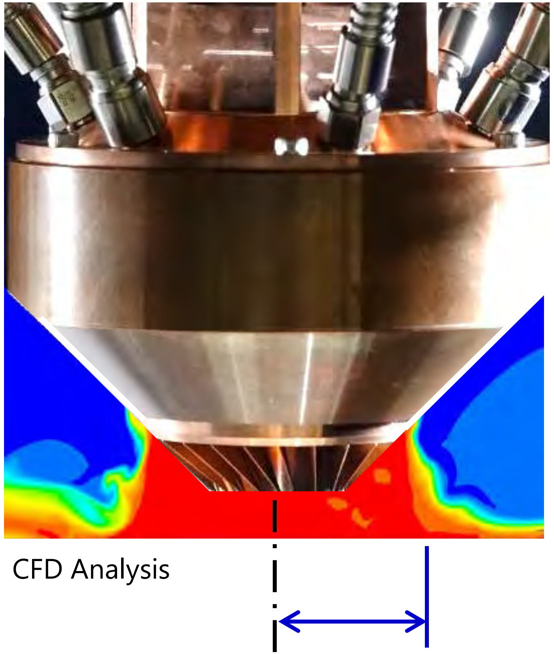




Material： Ti-6Al-4V
Hight：1,430 ㎜
Printing time：100 Hours

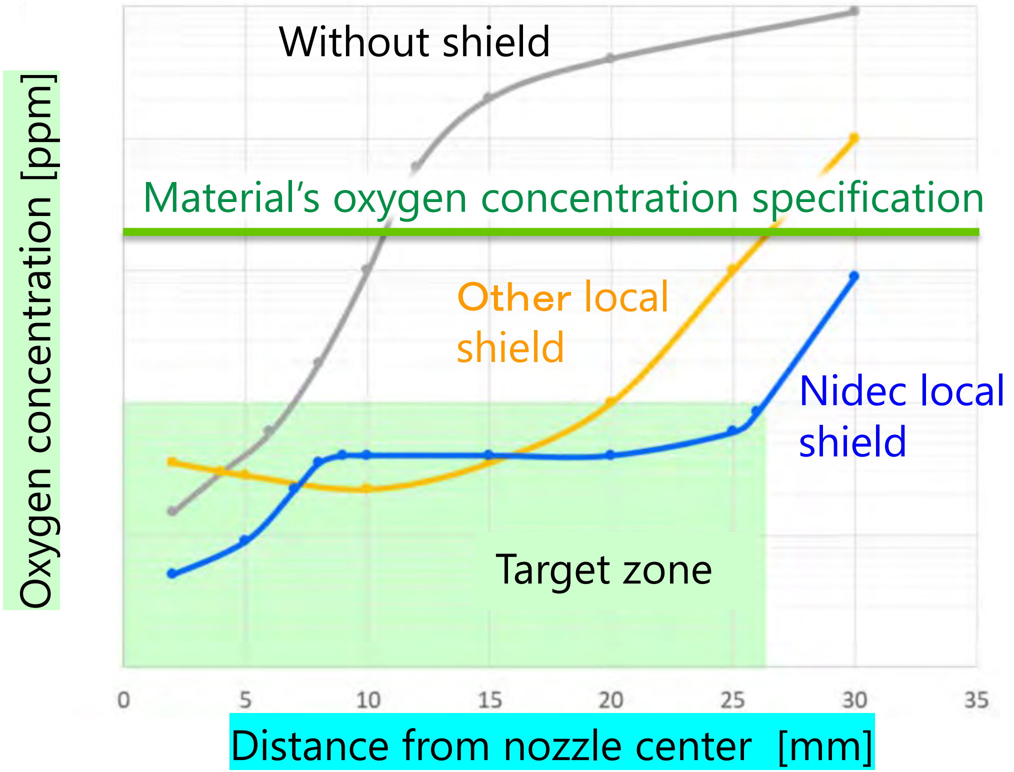
The Most Effective Shield Function

The shield nozzle was designed by simulation to provide the widest shielding in the world.



CFD Analysis

Distance from nozzle center



The Most Effective Shield Function

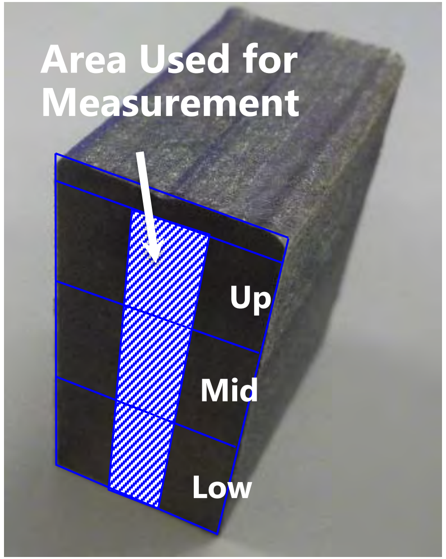
The effect of the shielded nozzle can be seen in the difference in the amount of spatter generated.

Without local shield

With local shield

Measurement result of Oxygen Concentration

The results of printing titanium alloys using the shielded nozzle fully satisfied general aircraft material standards.



Measurement Result (64 Titanium Block) unit [ppm]

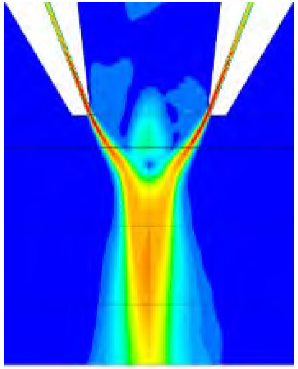
Gas	Up 1	Up 2	Mid 1	Mid 2	Low 1	Low 2
O	**880**	**861**	**828**	**893**	**858**	**854**
N	386	401	327	331	467	405
H	18	13	10	16	6	16

Measurement Conditions/ Notes

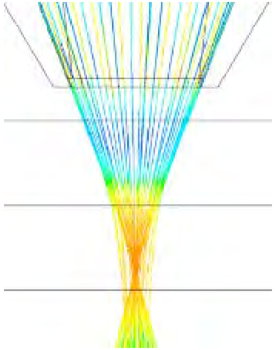
1. **Material (64 Titanium Powder)'s Oxygen concentration was around 810ppm.**
2. Oxygen Concentration has been calibrated before measurement.
   (For Nitrogen and Hydrogen, calibration has not been done, so the values may have some error and are for reference only.)
3. Two positions each at Upper/Middle/Lower area has been measured.

Coaxial nozzle powder converging diameter

By analyzing gas and powder motion and visualizing powder flow
The nozzle performance was improved, and the convergence pass of 0.6 mm was achieved.

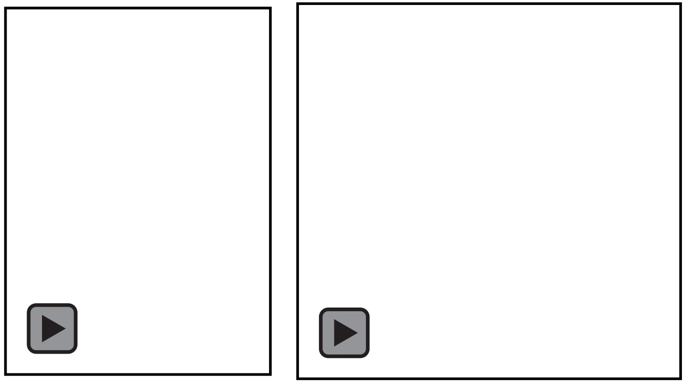


Carrier Gas Flow
CFD

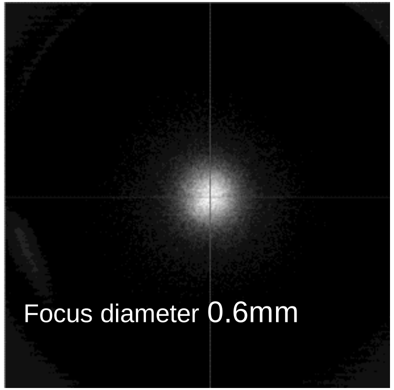


Powder Flow
DPM

Simulation



Powder Flow Validation



LAMDA nozzle
Powder focusing
measurement data

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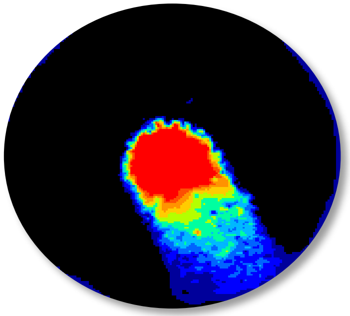
LAMDA Monitoring and Feedback System



NMTJ

5 JUN 2024

Advantage of Nidec LAMDA system

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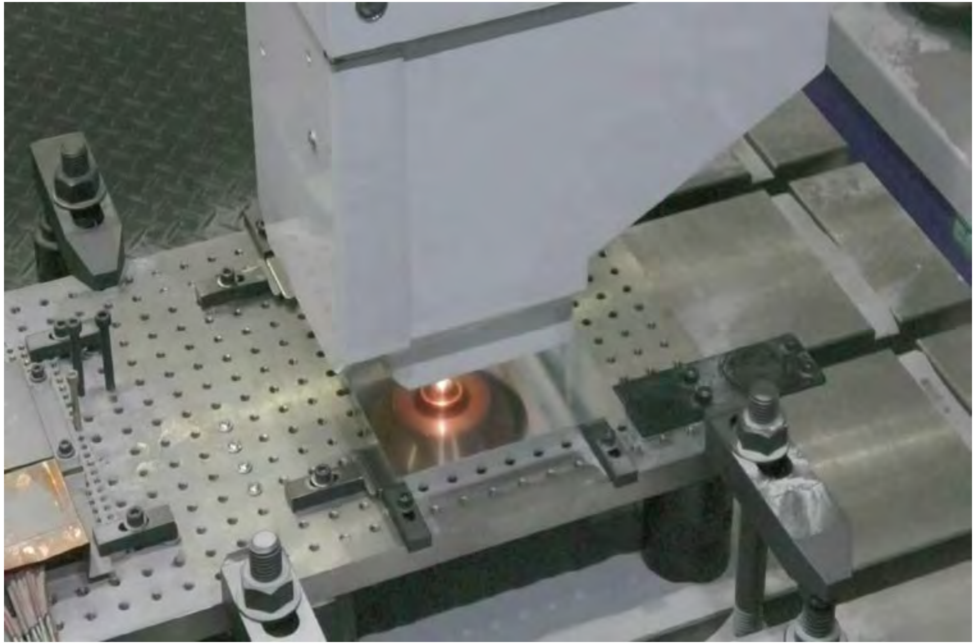
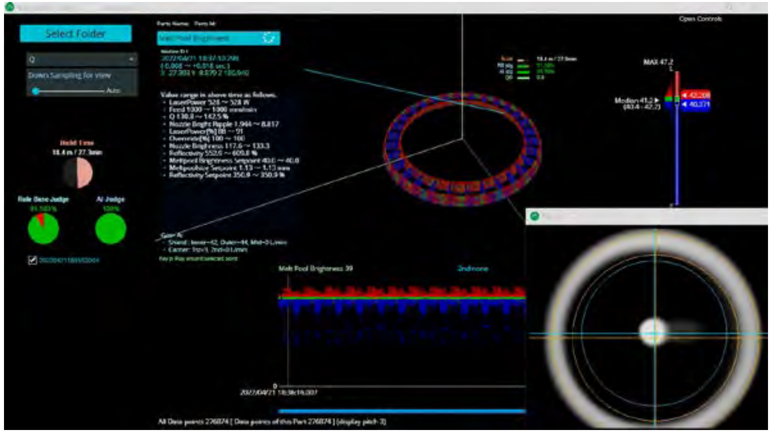
A monitoring feedback system based on high-speed image processing technology allows for stable, long-term modeling.



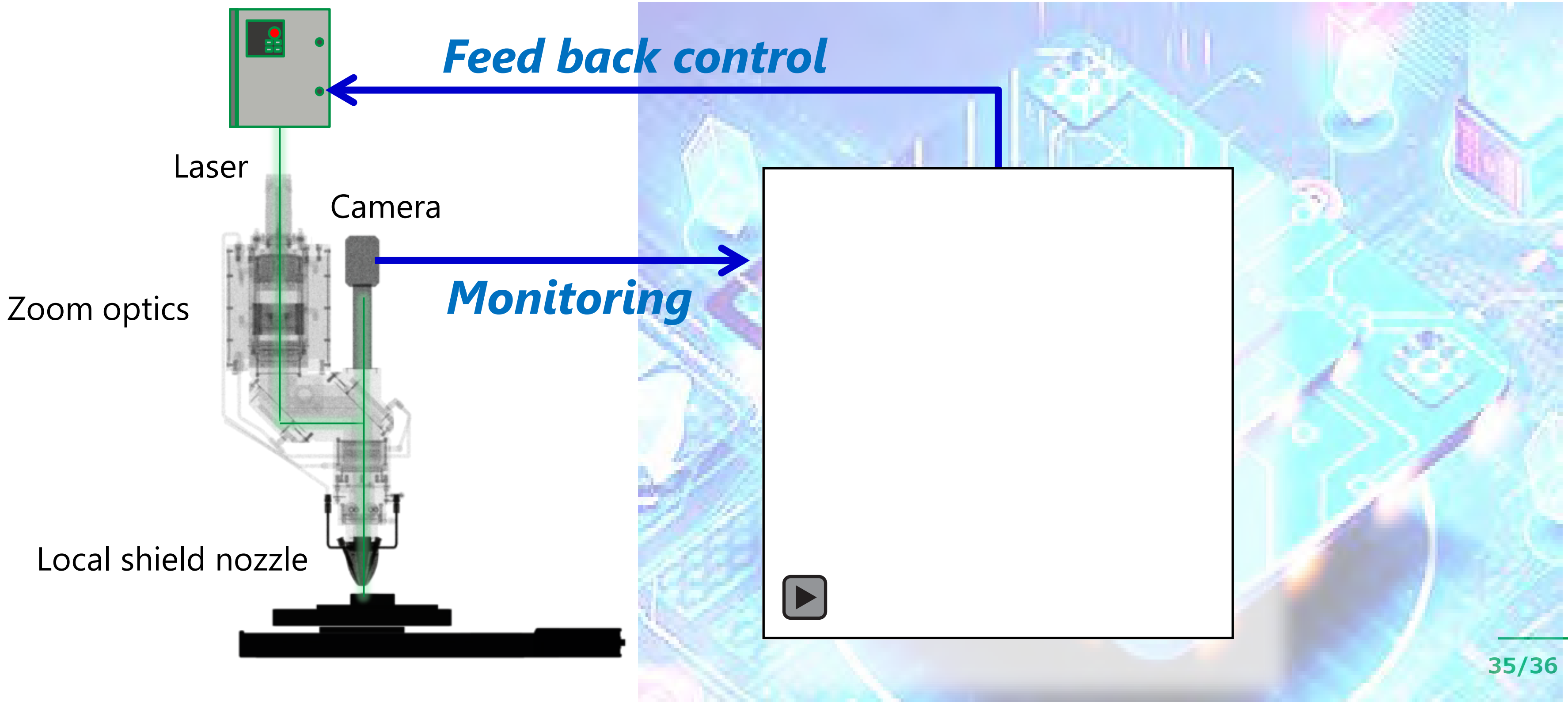


Material： AlSi10Mg
Height：1,160 ㎜
Printing time：11 Hours

LAMDA
Directed Energy Deposition AM System

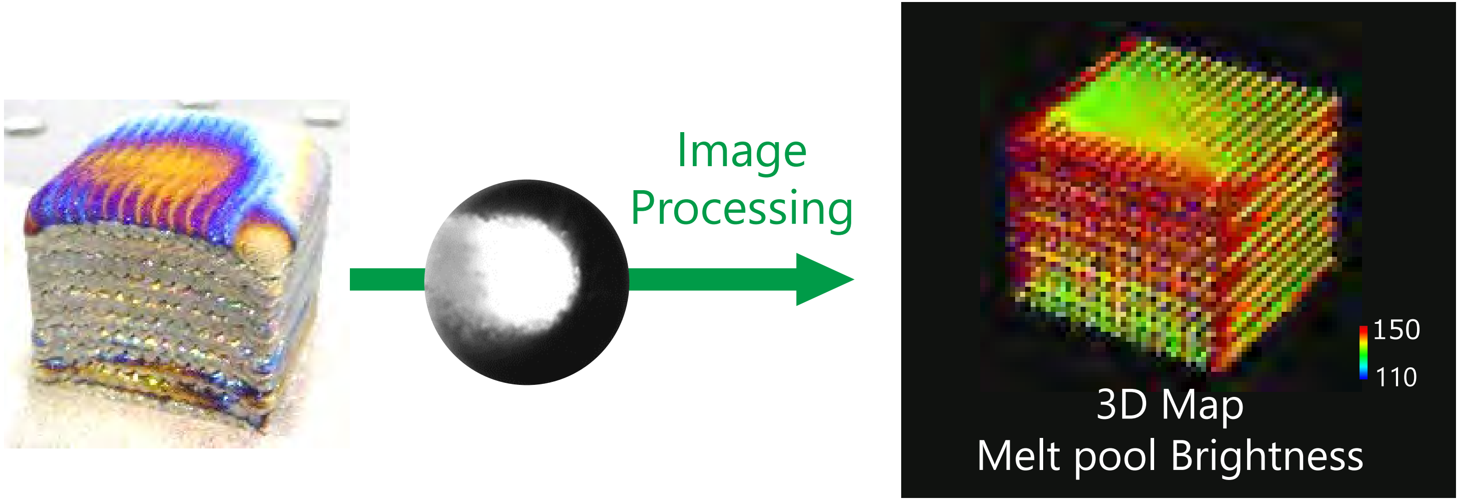
LAMDA Monitoring and FeedBack (MFB) System

A high-speed image processing algorithm developed in-house enables feedback control of printing conditions in real time (340fps).



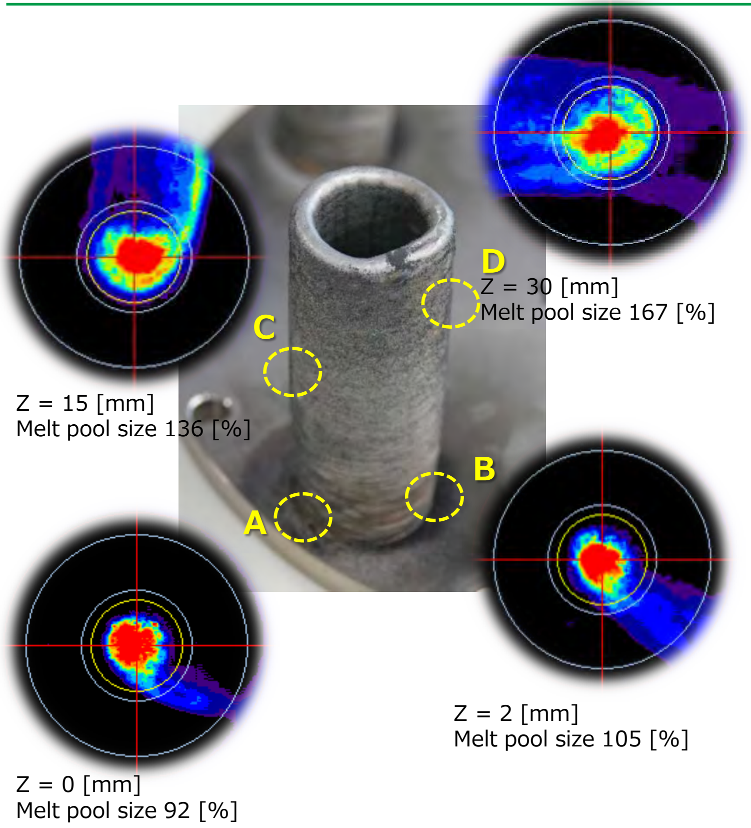
Key feature of LAMDA MFB System

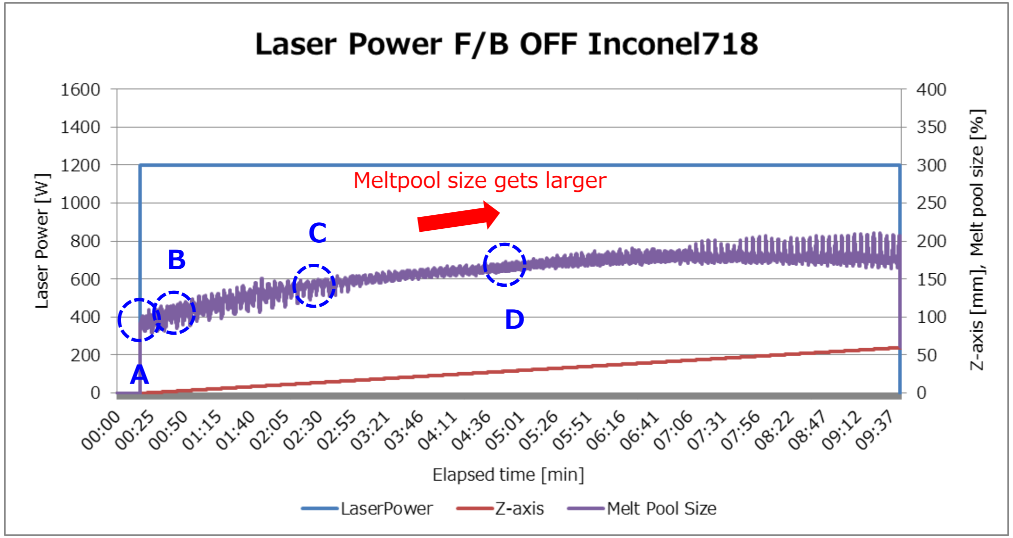
Visualization of the printing process results.



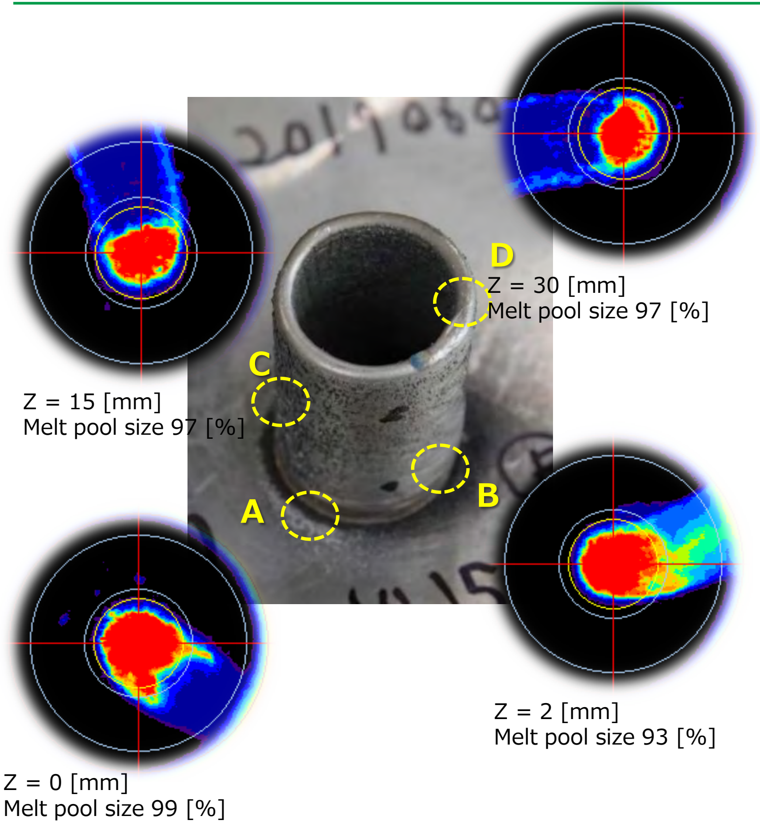
The brightness of the melt pool measured during printing can be converted to color and further visualized on the 3D shape data. Anomalies in the molding process can be visually captured.

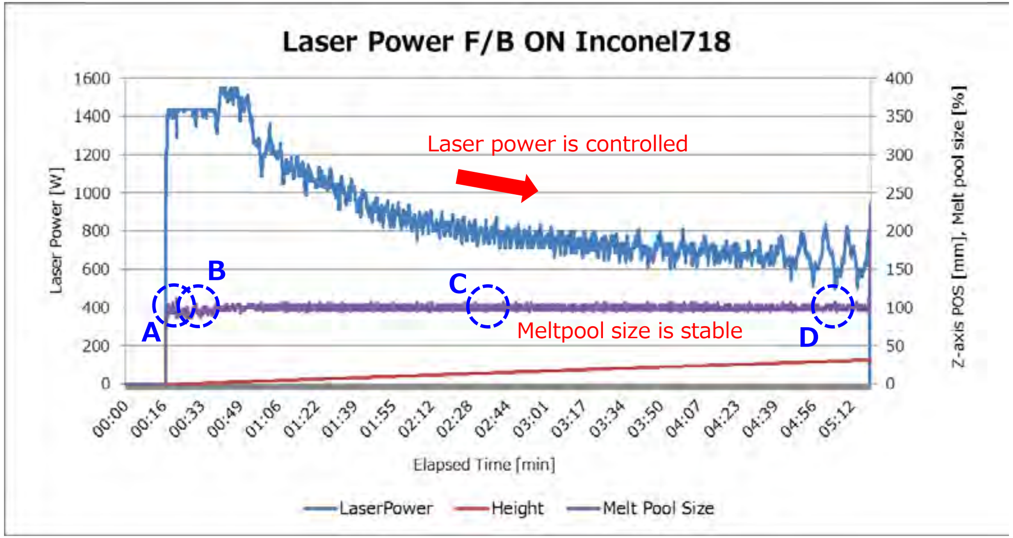
In-process Monitoring / Feedback OFF





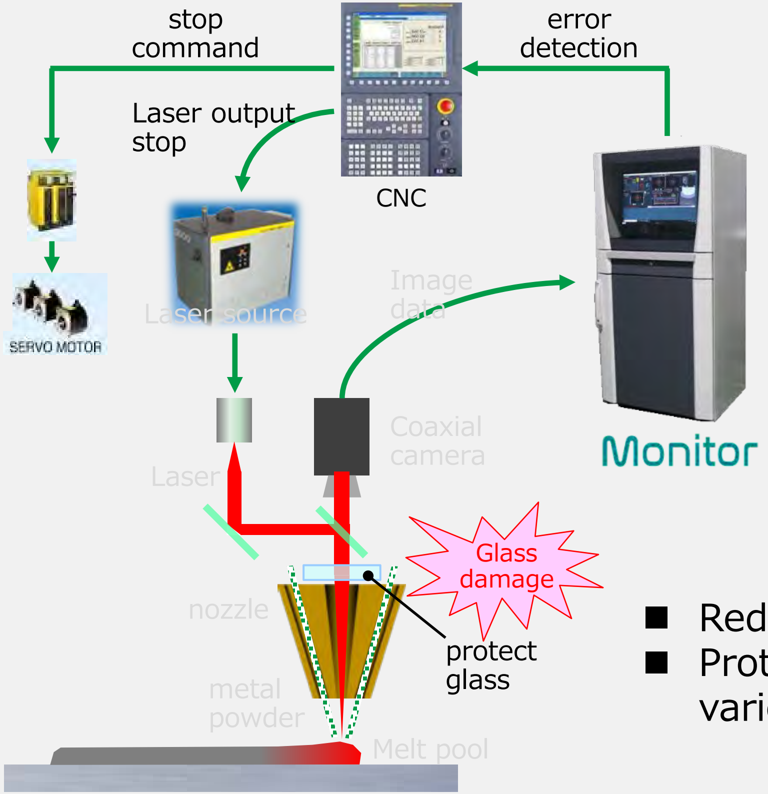
In-process Monitoring / Feedback ON

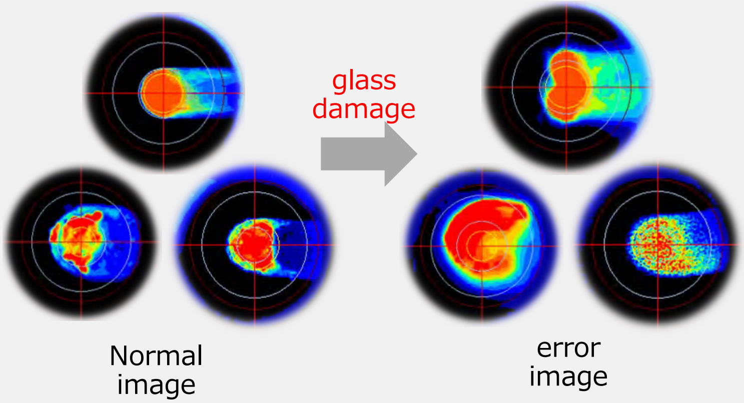




In-process monitoring and control system

Protect glass error detection by deep learning





- Reduce downtime
- Protect laser head from various damage

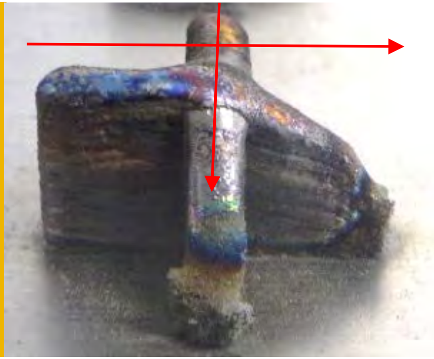
damaged glass

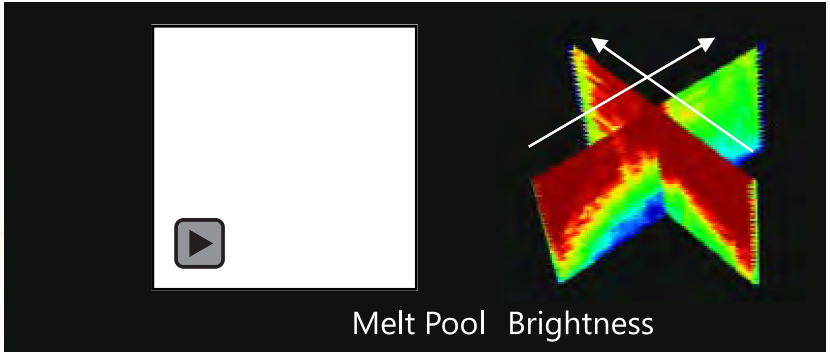
Real value of LAMDA MFB System

LAMDA MFB System provide a contributes to shape stabilization at orthogonal sections and corners.

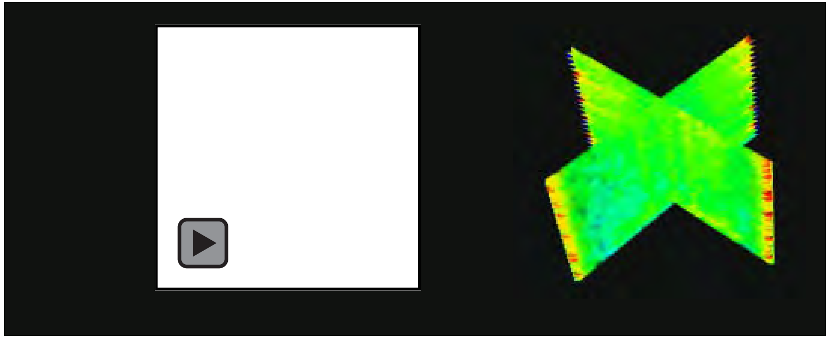
With out
Feed back Control

Ti64



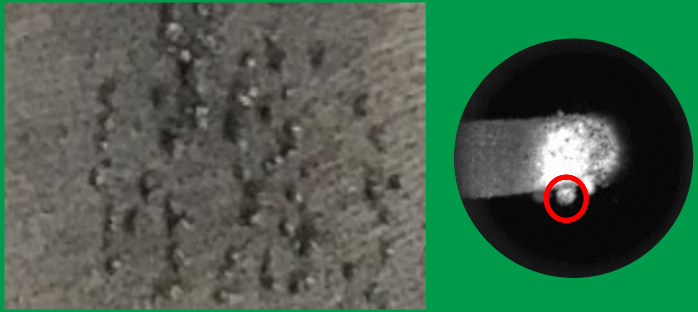


With
Feed back Control

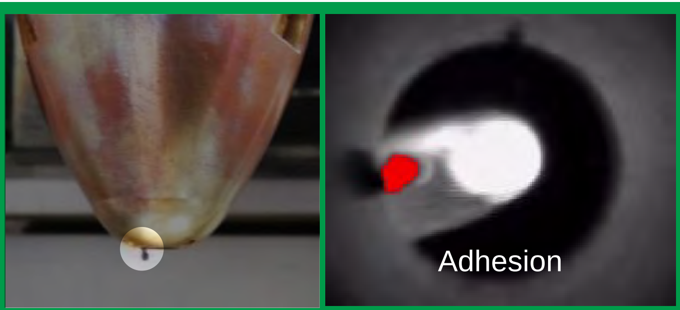


Ai Anomaly Detection

AI can detect various abnormalities and stop molding automatically.

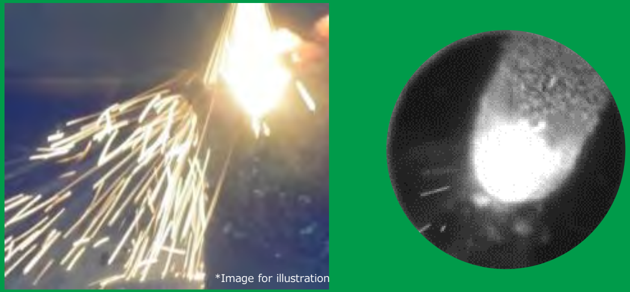


Unmelted Powder



Adhesion of foreign matter to nozzle tip

Protective glass stain

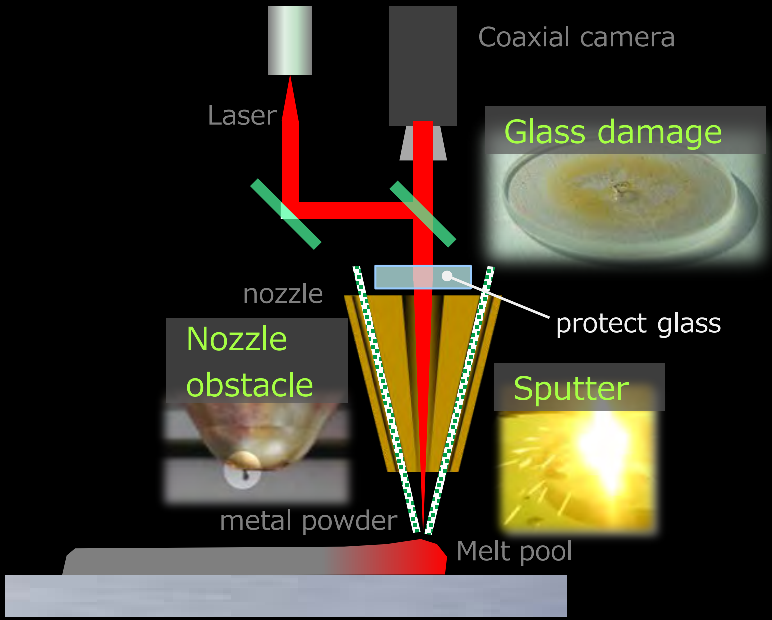


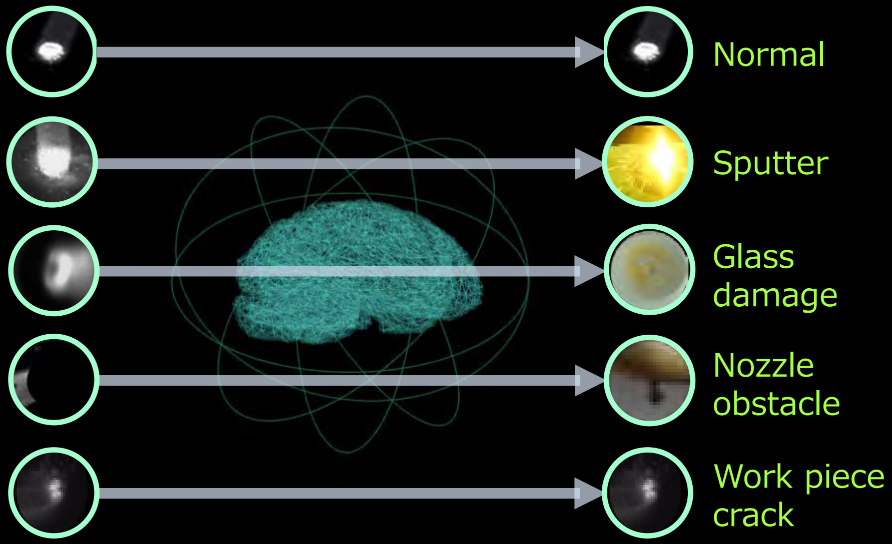
Sputter generation

Monitoring System

In-process monitoring control system with AI

- Reduce downtime
- Protect laser head from various damage





LAMDA’s Unique technology

Materials

Near net may appropriate for your application

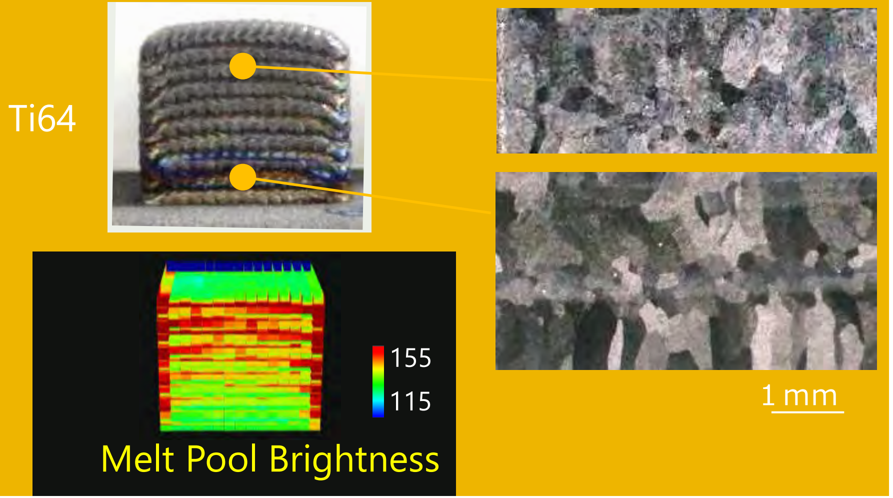
Use cases for additive manufacturing

Image from Relativity Space

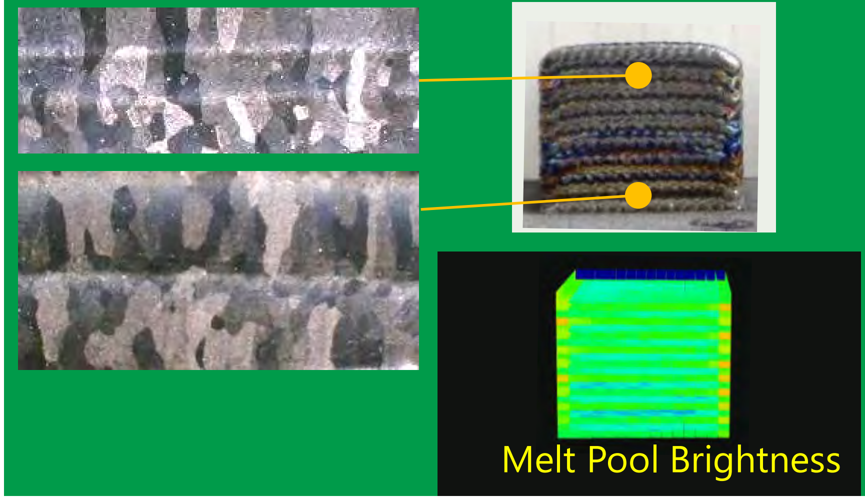
Real value of LAMDA MFB System

Stabilization of melting and solidifying also leads to homogenization of metallurgical structure.

without Feed back control



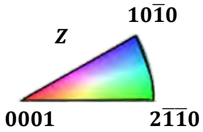
With Feed back control



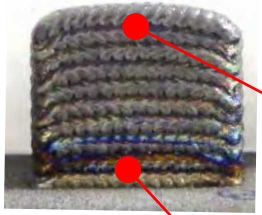
Comparison of α/α’ grains by EBSD

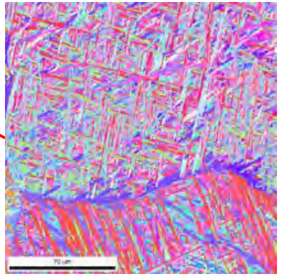
Ti6Al4V	FB OFF	FB ON

W=H=20mm

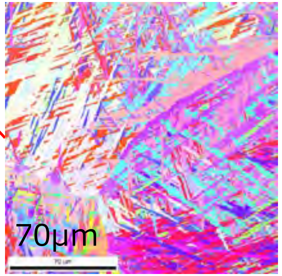


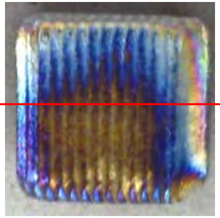
FB OFF



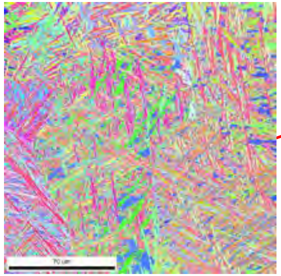


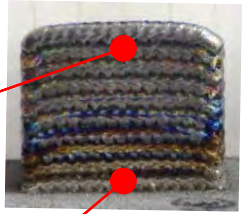
Grain size in the bottom is bigger than that in the top



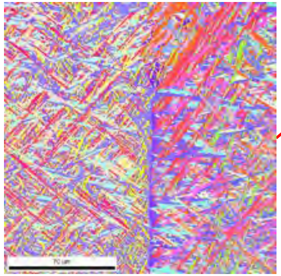


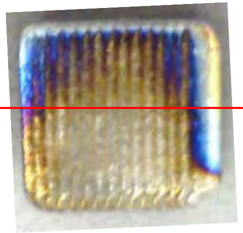
FB ON





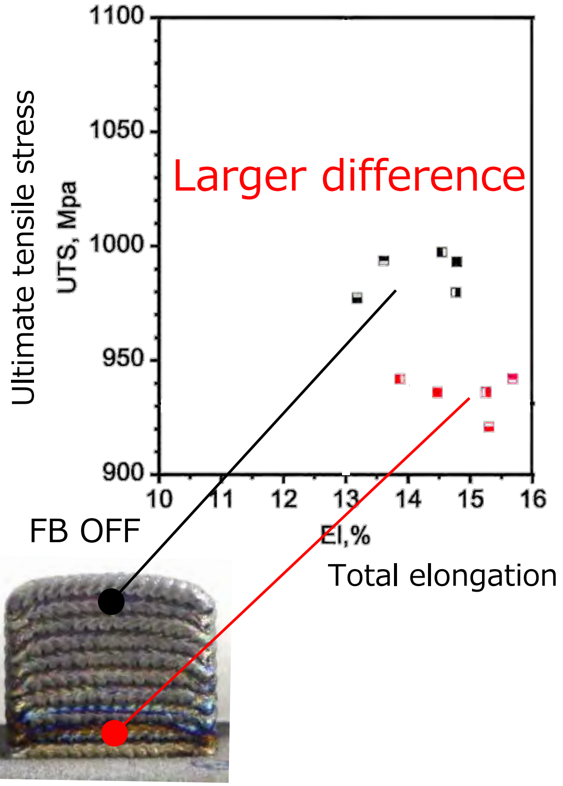
Little difference between top and bottom

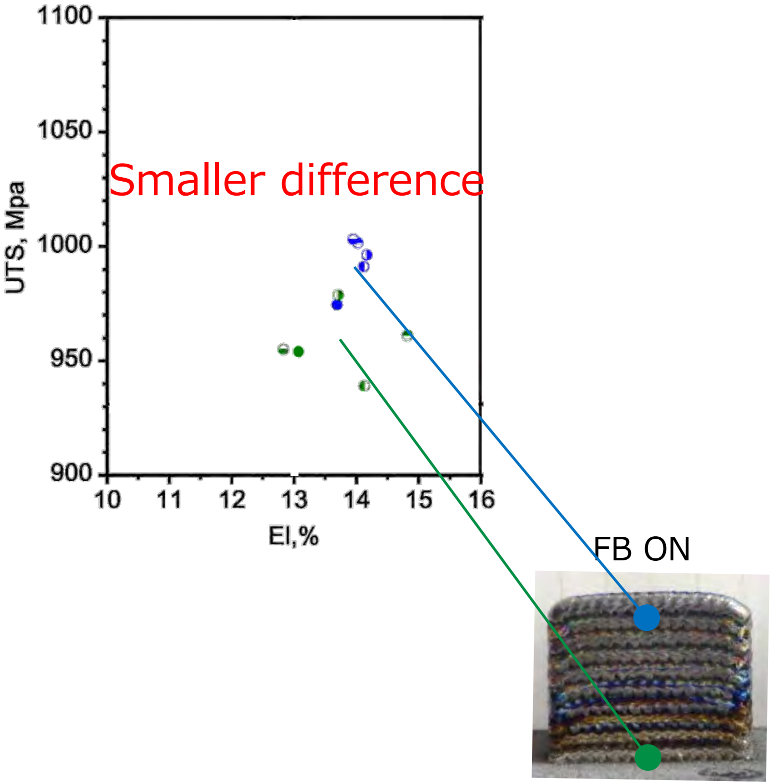




Comparison of tensile strength

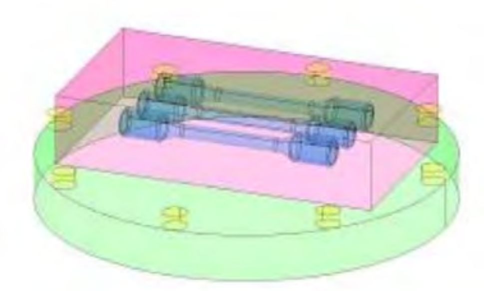
W=H=20mm



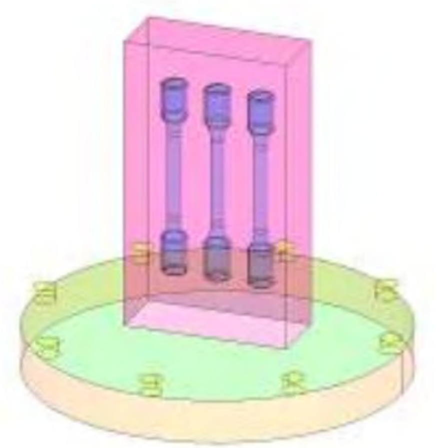


*these are reference values because the tensile test is not based on the standards.

SUS304

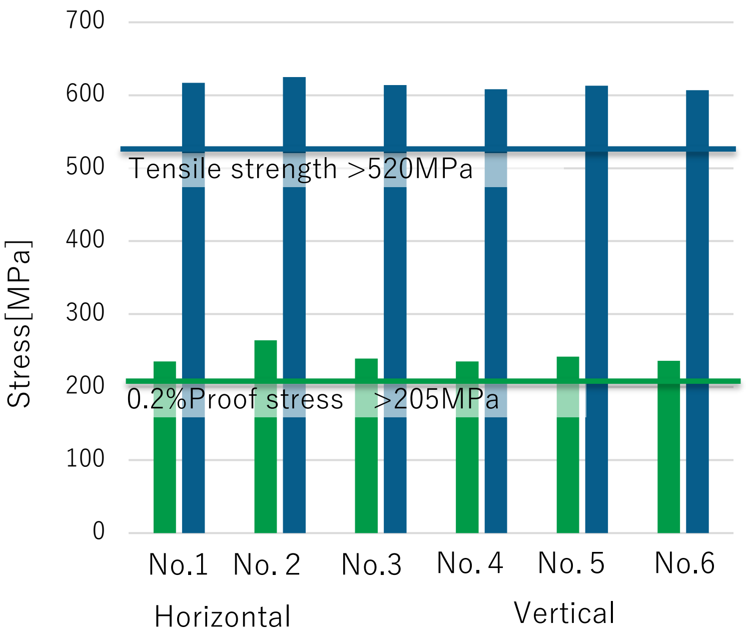


Horizontal

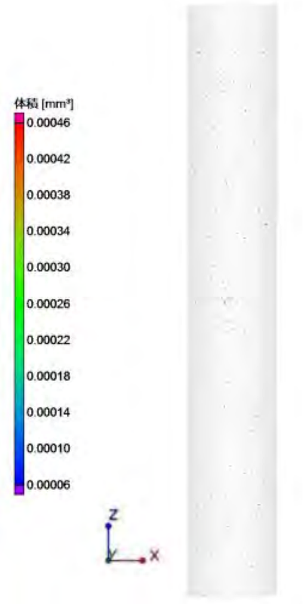


Vertical

Tensile strength test result

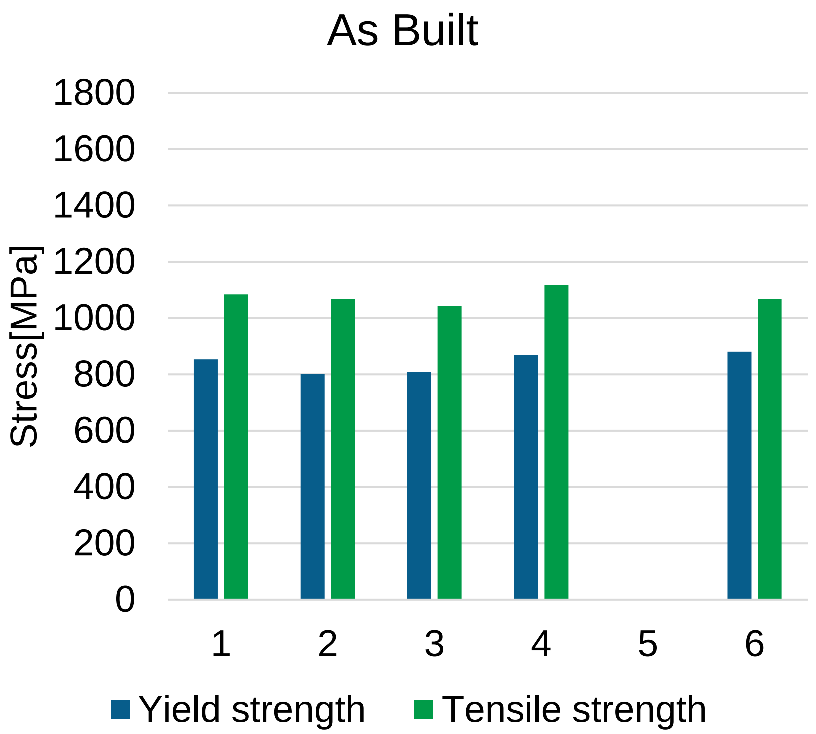


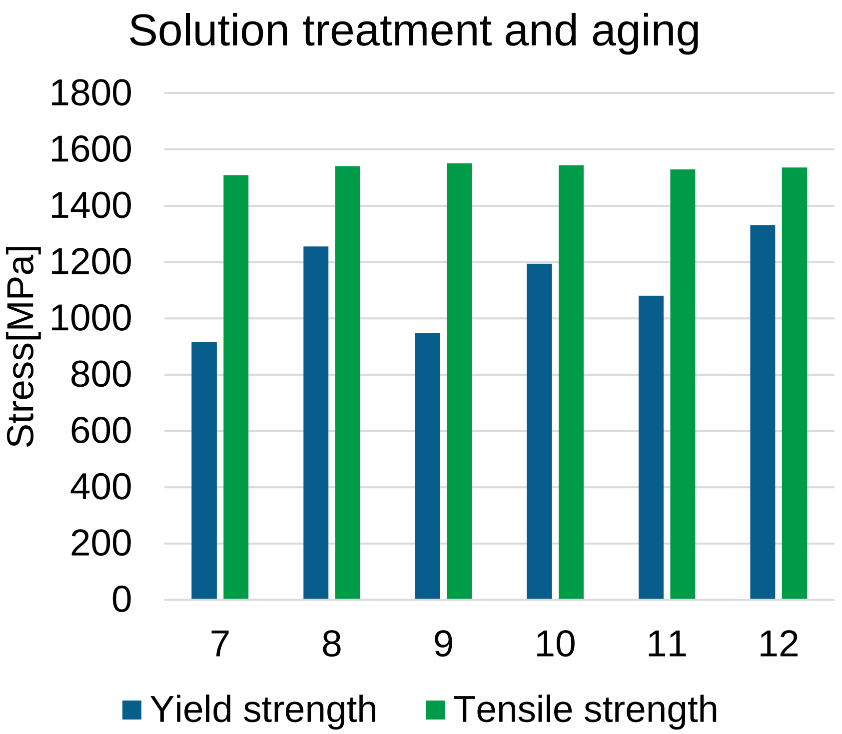
X-ray CT inspection results



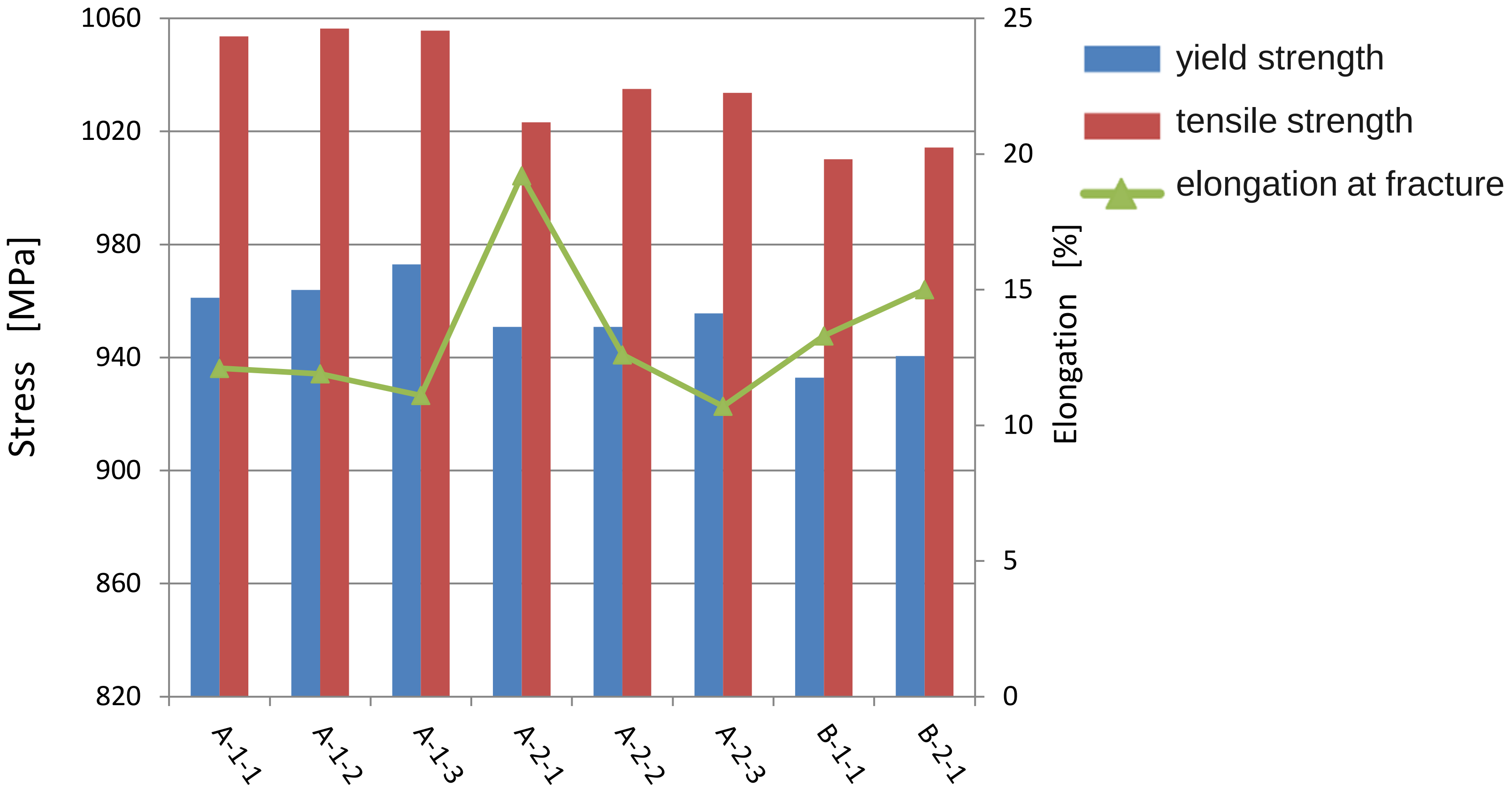
defect volume fraction
< 0.01%

Maraging steel





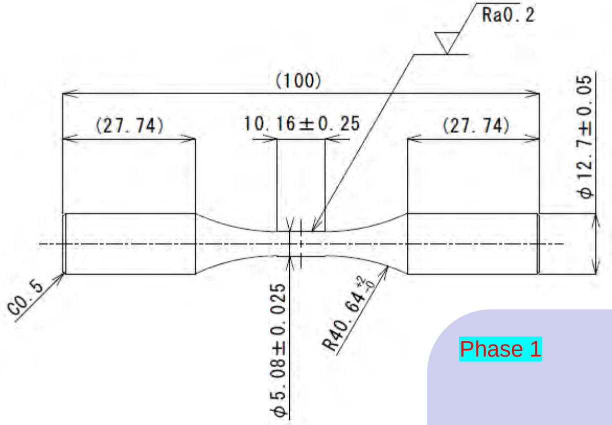
Ti 6Al 4V

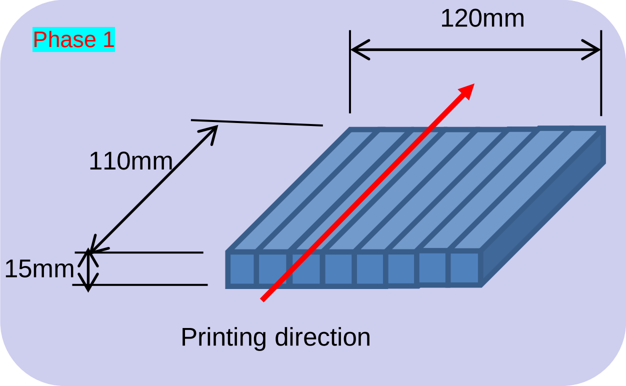


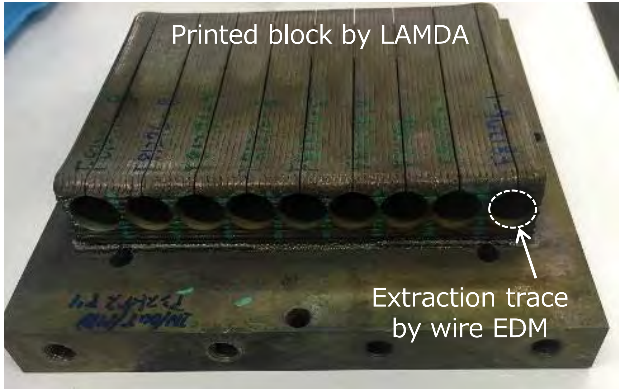
1060
1020
980
940
900
860
820
Stress [MPa]
25
20
15
10
5
0
Elongation [%]
A-1-1
A-1-2
A-1-3
A-2-1
A-2-2
A-2-3
B-1-1
B-2-1
yield strength
tensile strength
elongation at fracture

Ti 6Al 4V

Powder: Ti6Al4V(45/105)
Specimen size: Both ends φ12.7x100mm L
 ⇒ Print size per specimen □ 15 x 110mm L
*Specimen is extracted by cutting from the printed block

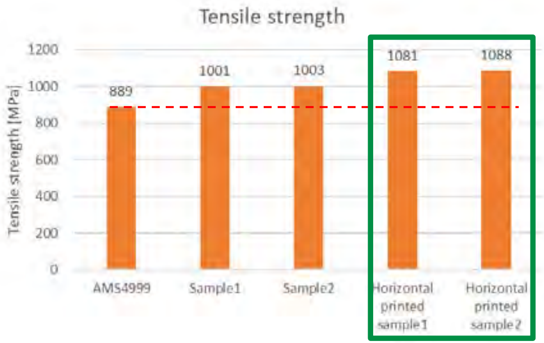


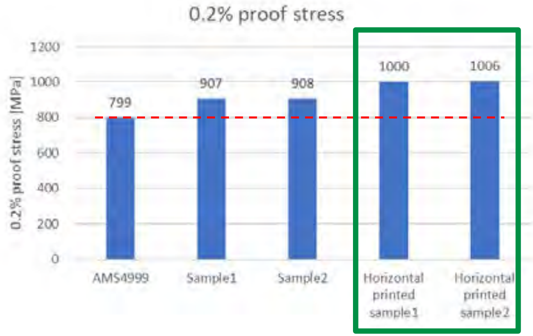


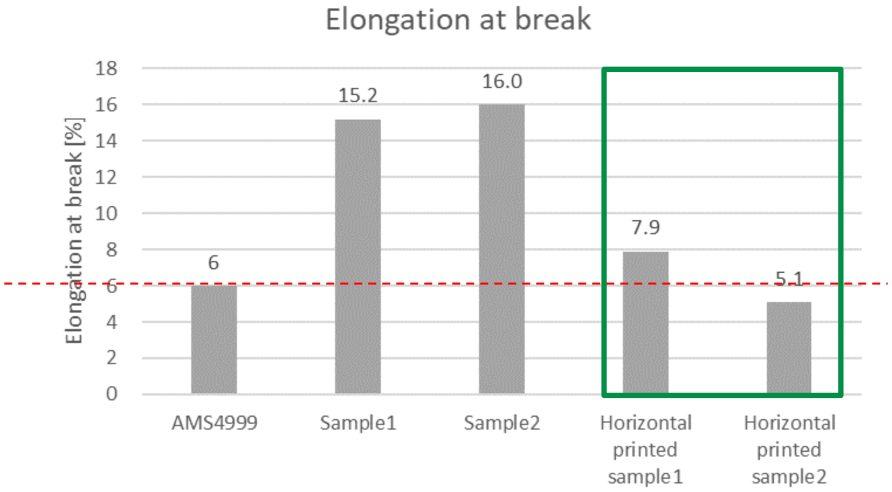


Tensile test and fatigue test of printed titanium

Tensile strength generally satisfies the AMS4999 standard, and elongation tends to be slightly lower. Also, high cycle fatigue testing tends to be slightly inferior to commercial materials.
It is desirable to design according to the characteristics of the DED material.







Maximum stress [MPa]

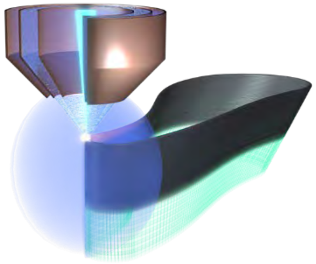
"→" means unbroken

Summary

Nidec
All for dreams

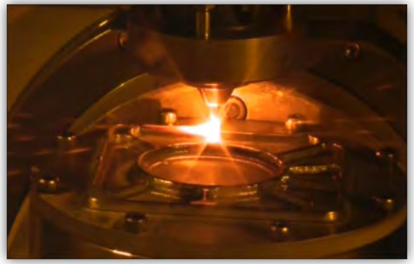
- The LAMDA series can produce up to large scale parts with DED, with our unique features
- It is confirmed that local shield nozzle can reduce titanium oxidization in the atmosphere during 3D printing
- In-process monitoring was confirmed to be effective for stabilization and quality improvement of the DED process

LAMDA



Local Shield

Monitor



Titanium alloy parts

Nidec

All for dreams