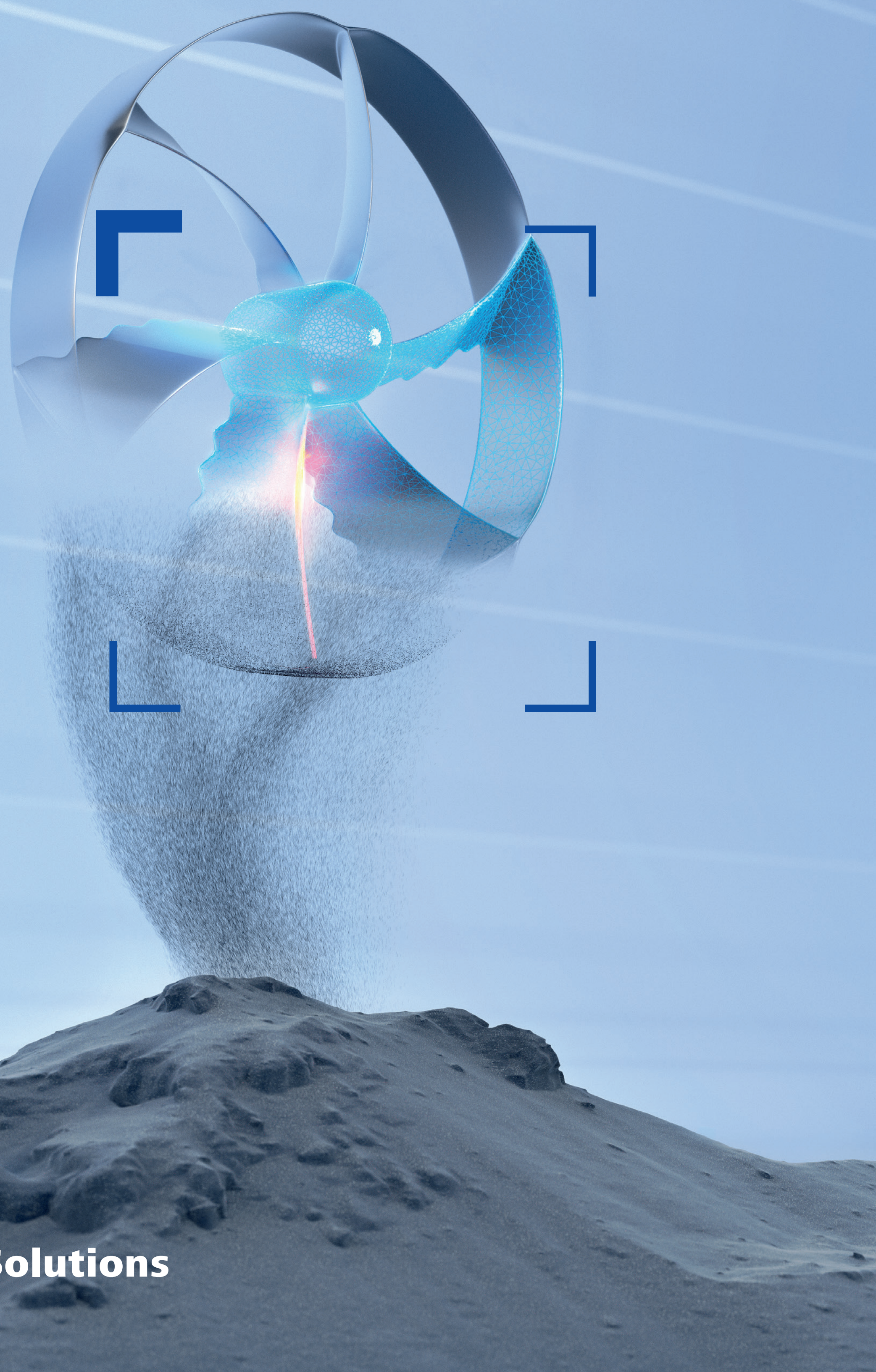
From Powder to Performance

Seeing beyond



ZEISS Additive Manufacturing Solutions

ZEISS Additive Manufacturing Solutions
Holistic Integrated Process for Quality Improvement

Powder and Material Characterization

SEM, LM, X-ray CT

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In-Process Metrology and Data Analysis

In-Process Powder Bed Inspection

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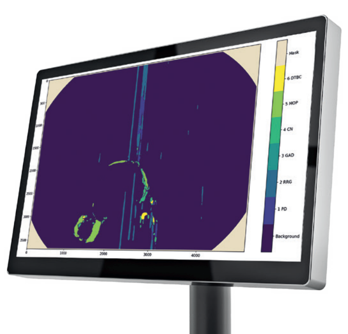

Post-Print Heat Treatment and Part Removal

CMM, 3D Scanning

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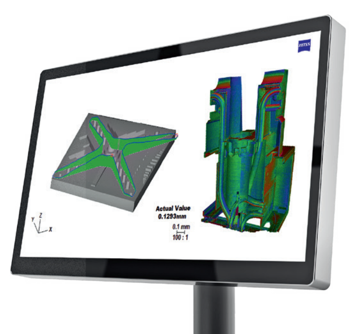

Internal Defect and Structural Inspection

X-ray CT, LM

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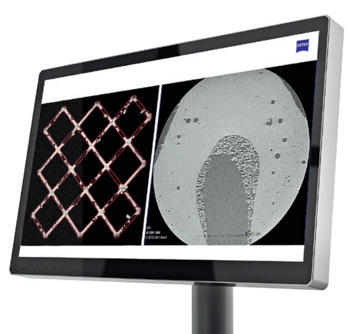

Post-Print Material Quality Inspection

SEM, LM, X-ray CT, 3D Testing

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Dimensional and Surface Quality Inspection

CMM, X-ray CT, 3D Scanning, LM

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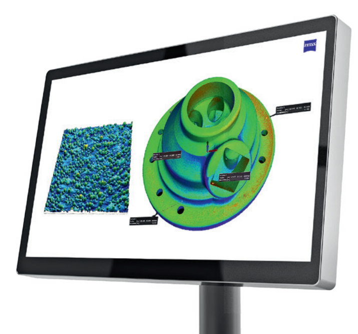

Process Data Statistics and Analytics

PiWeb, Analytics and Correlation Tools

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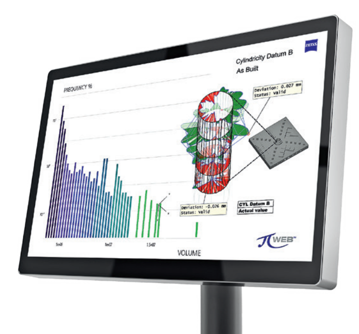
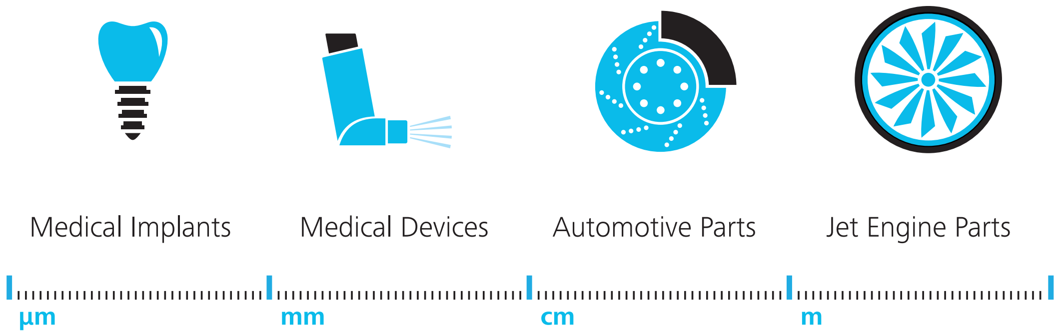


Improving Yield in Additive Manufacturing

3D printing processes – additive manufacturing – are becoming increasingly a part of the industrial production chain. Medical, aerospace, and automotive industries are leading the innovation and implementation of additive manufacturing.

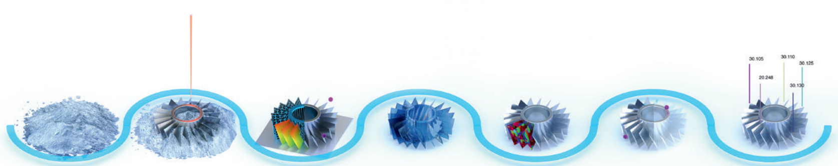


ZEISS AM Solutions features a selection of products from the ZEISS portfolio, as well as new solutions dedicated for additive manufacturing. This unique holistic inspection solution for additive manufacturing focuses on:

+ MATERIAL COMPOSITION ANALYSIS
+ POWDER ANALYSIS
+ IN-PROCESS ANALYSIS
+ POST-BUILD ANALYSIS INCLUDING DE-POWDERING, HEAT TREATMENT, PART REMOVAL AND CLEANLINESS
+ METALLOGRAPHIC ANALYSIS
+ DEFECT ANALYSIS
+ SURFACE METROLOGY – EXTERNAL AND INTERNAL
+ DIMENSIONAL METROLOGY – EXTERNAL AND INTERNAL

This integrated process brings the most reliable knowledge and, thus, certainty about the reliability of 3D printed parts.

ZEISS AM Solutions Knowledge Hub



ZEISS AM Application Lab

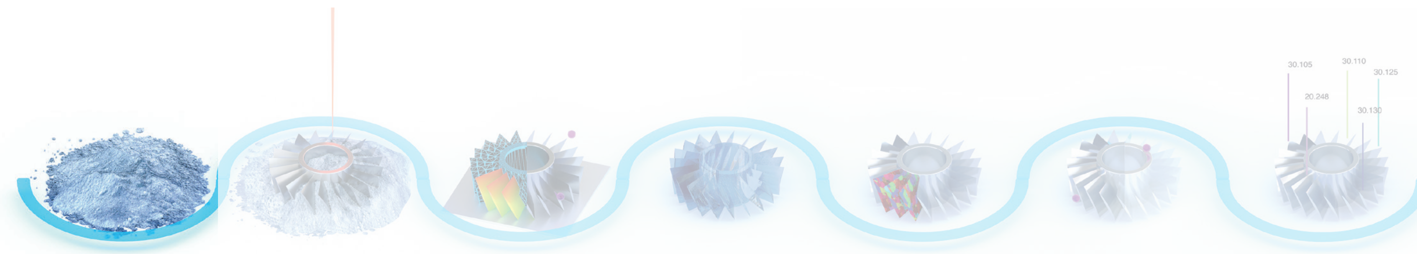
ZEISS has established a globally unique application lab dedicated completely to additive manufacturing. The lab is open for joint customer projects, scientific studies and demonstrations and serves as a hub for learning as well as knowledge distribution for customers and ZEISS.

ZEISS and ORNL Collaboration

The Manufacturing Demonstration Facility at Oak Ridge National Laboratory (ORNL) is a leader in additive manufacturing focused on translating cutting edge scientific research into industrial applications, making it an ideal partner and location for the ZEISS AM application lab.

Fast AM Material Parameter Development

Combining the additive manufacturing know-how of ORNL and the metrology knowlegde of ZEISS, a new approach for holistic optimization of AM process parameters was derived which can reduce the time for process development from years or months to only weeks or even days.



Powder and Material Characterization

Light Microscope (LM)

Scanning Electron Microscope (SEM)

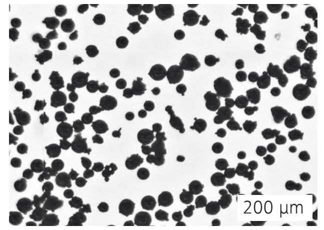
X-ray Computed Tomography (X-ray CT)

Powder is the building block of additively manufactured parts. Size distribution and shape influence spreadability and hence possible defects formed during the process. The defect density is among other factors also a function of recycling and aging of the powder. LM, SEM and X-Ray CT help to continuously define the powder quality.

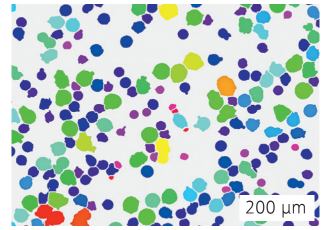
Powder and Material Characterization

Light Microscope (LM)

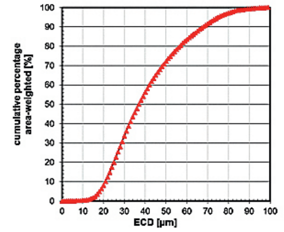
Optical microscopes offer the possibility of quick powder sampling and reliable analysis of particle size distribution.



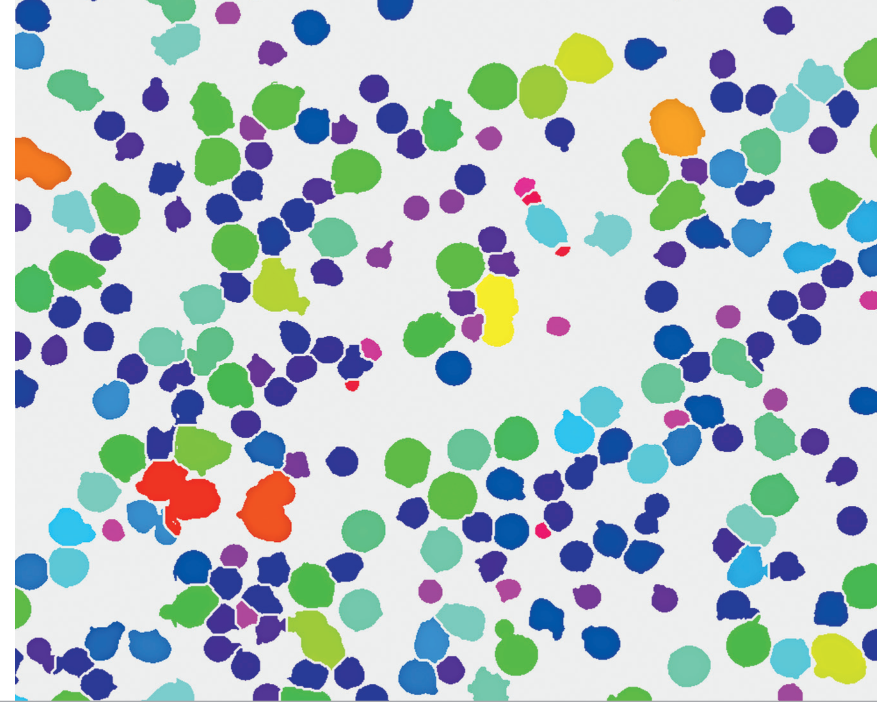
Light microscopy image of metal powder



Automated segmentation

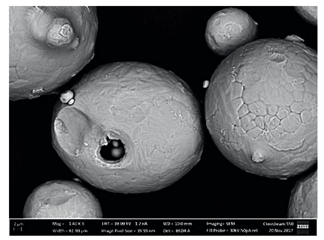


Particle size distribution

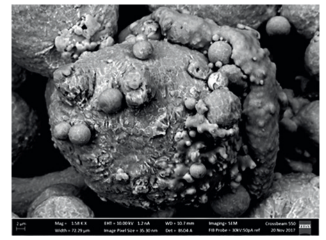


Scanning Electron Microscope (SEM)

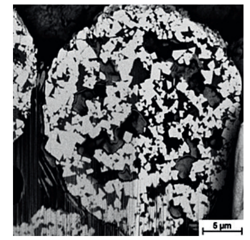
Powder particles are fairly small in size, typically ranging from few micrometers to tens of microns in diameter. Scanning Electron Microscopes (SEM) offer nanometer level resolution and the ability to examine batch or each individual particle to help engineers better understand the build ingredients for additive manufacturing.



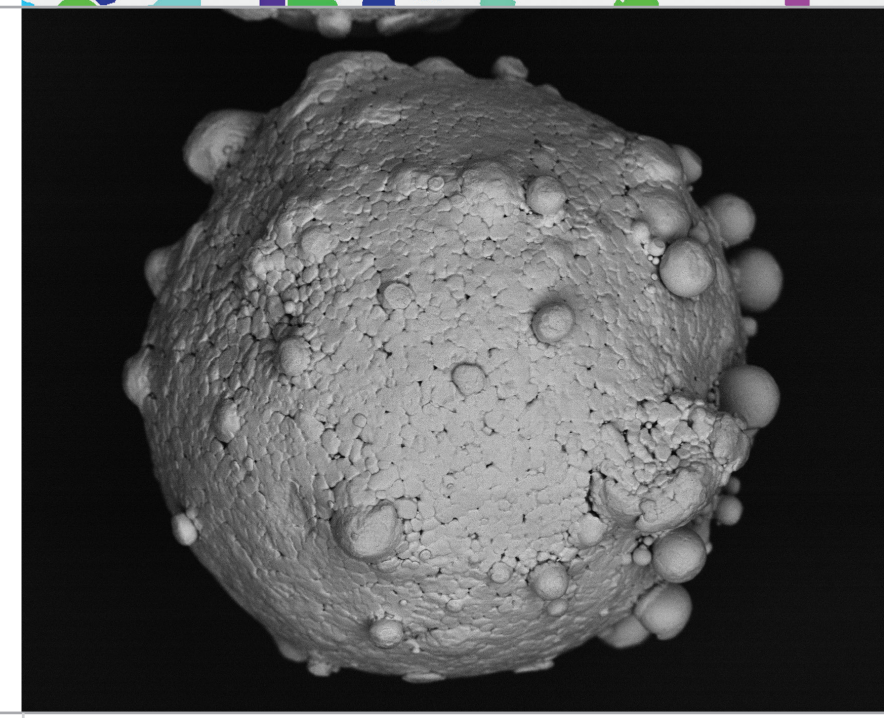
New powder



Recycled powder



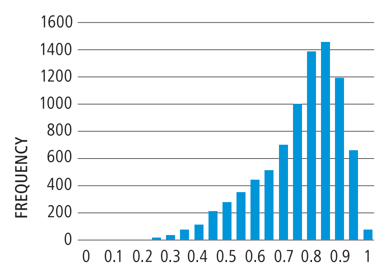
Powder with porosity



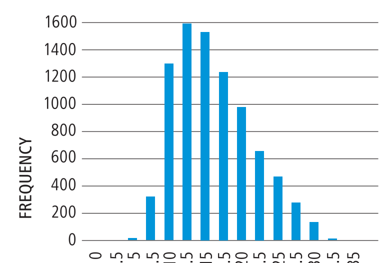
X-ray Computed Tomography (X-ray CT)

High resolution X-ray CT allows for detailed analysis of particle shape, and size. The pore volume fraction inside particles, and contaminants can also be identified by measuring particle density

Aspect ratio

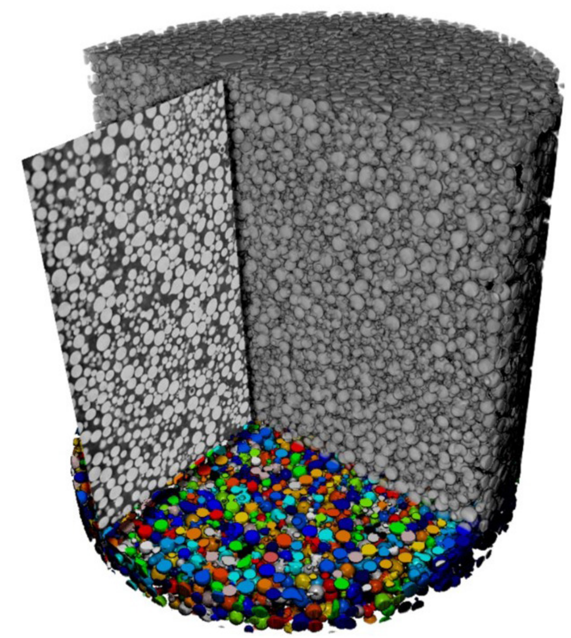


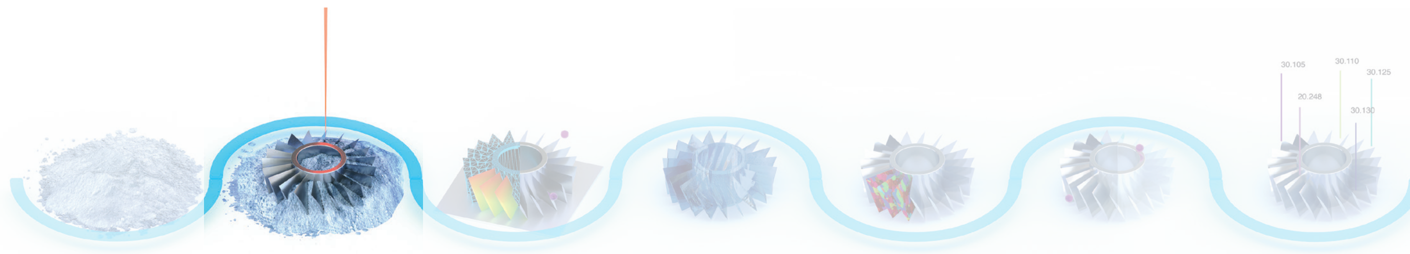
Particle diameter



8500+ particles analyzed for aspect ratio and diameter

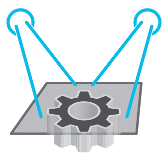
>
Imaging of additive manufacturing powder X-ray CT



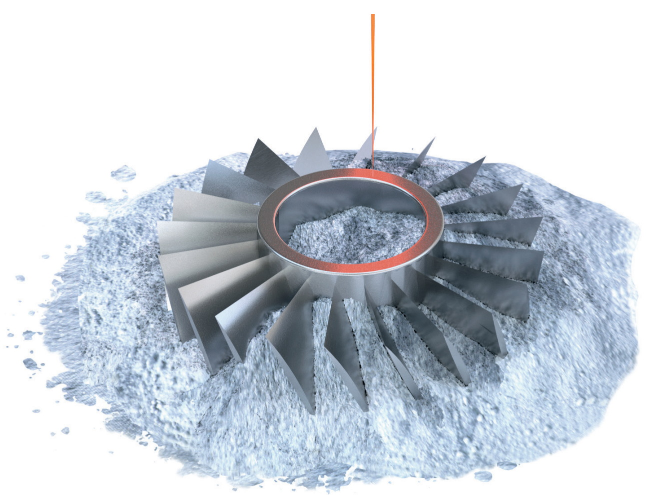


In-Process and Post-Print Powder Bed Analysis

A uniformly distributed powder bed is the essential basis for a stable and reliable AM process. Therefore, the surveillance of the powder bed during the printing process or afterwards enables the identification of sources for quality issues. Defective parts can be identified during the build, even fixed, which avoids down-stream costs and increases yield.



Powder Bed Inspection

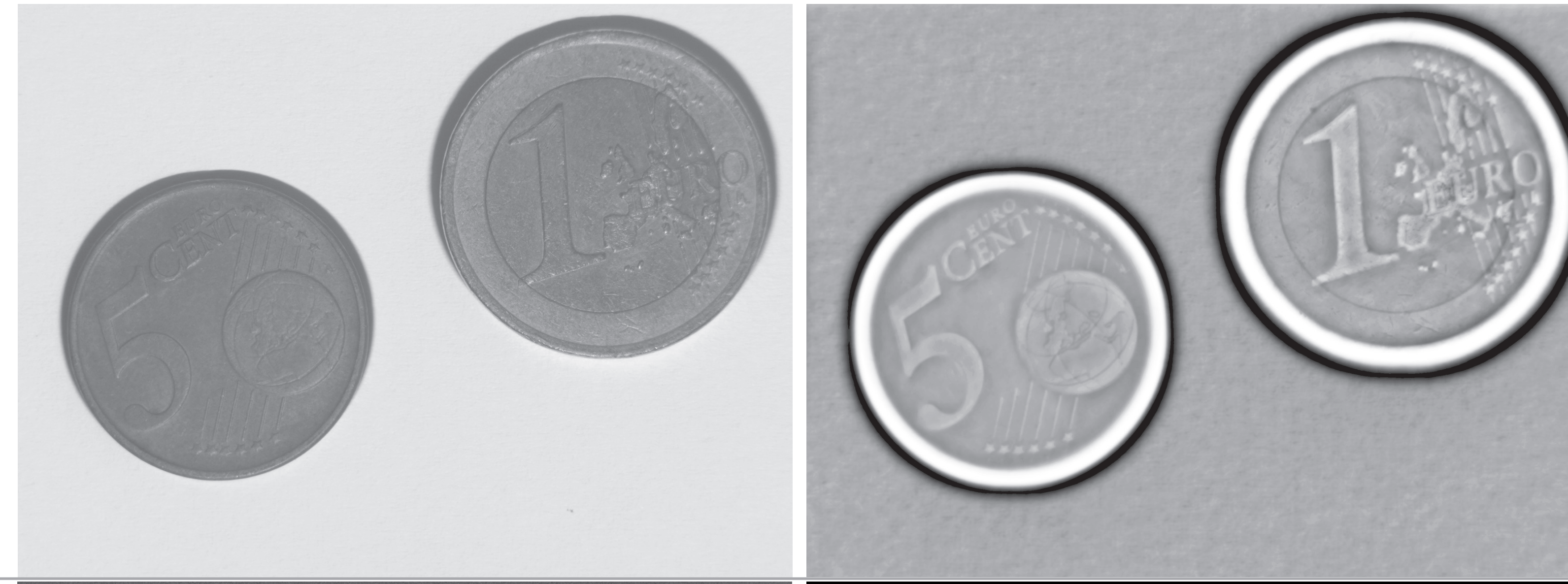


In-Process and Post-Print Powder Bed Analysis

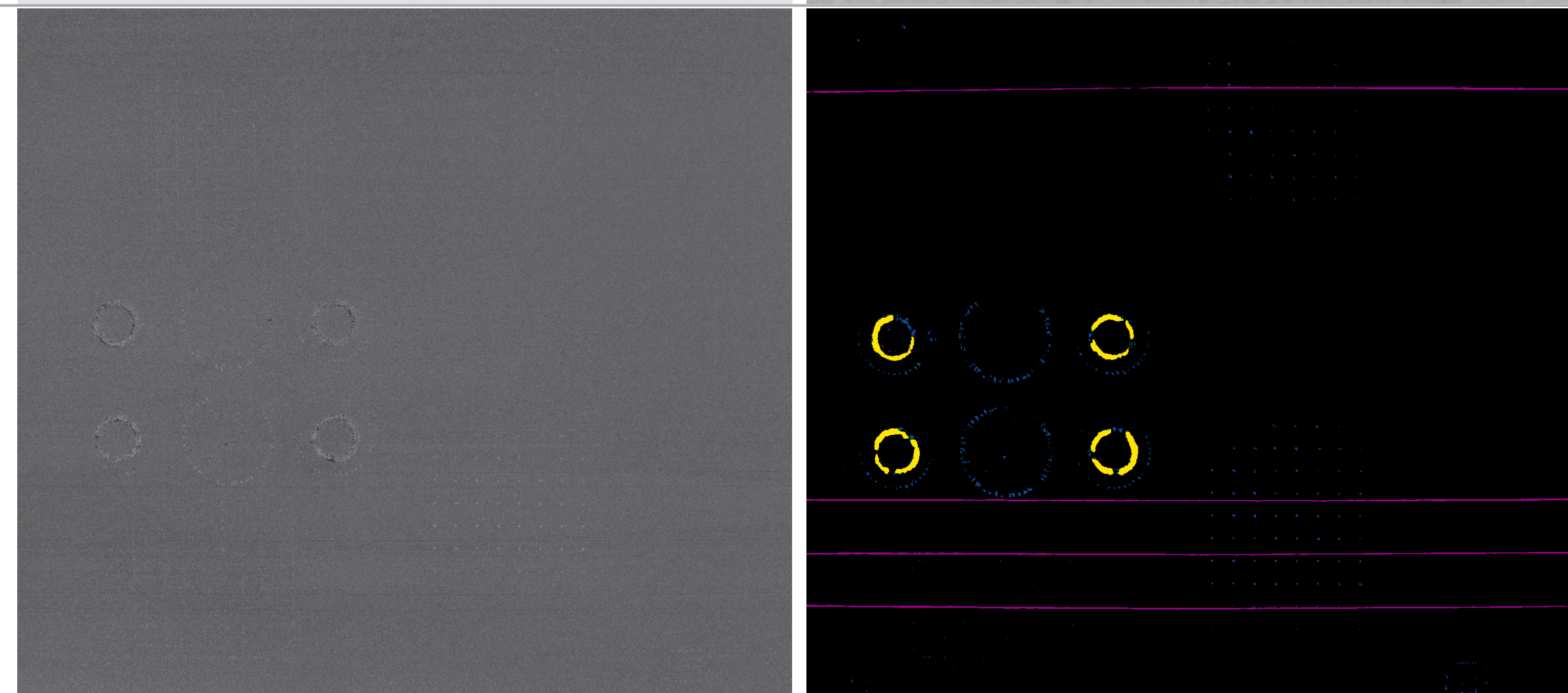
*In cooperation with Pankl

Powder Bed Inspection

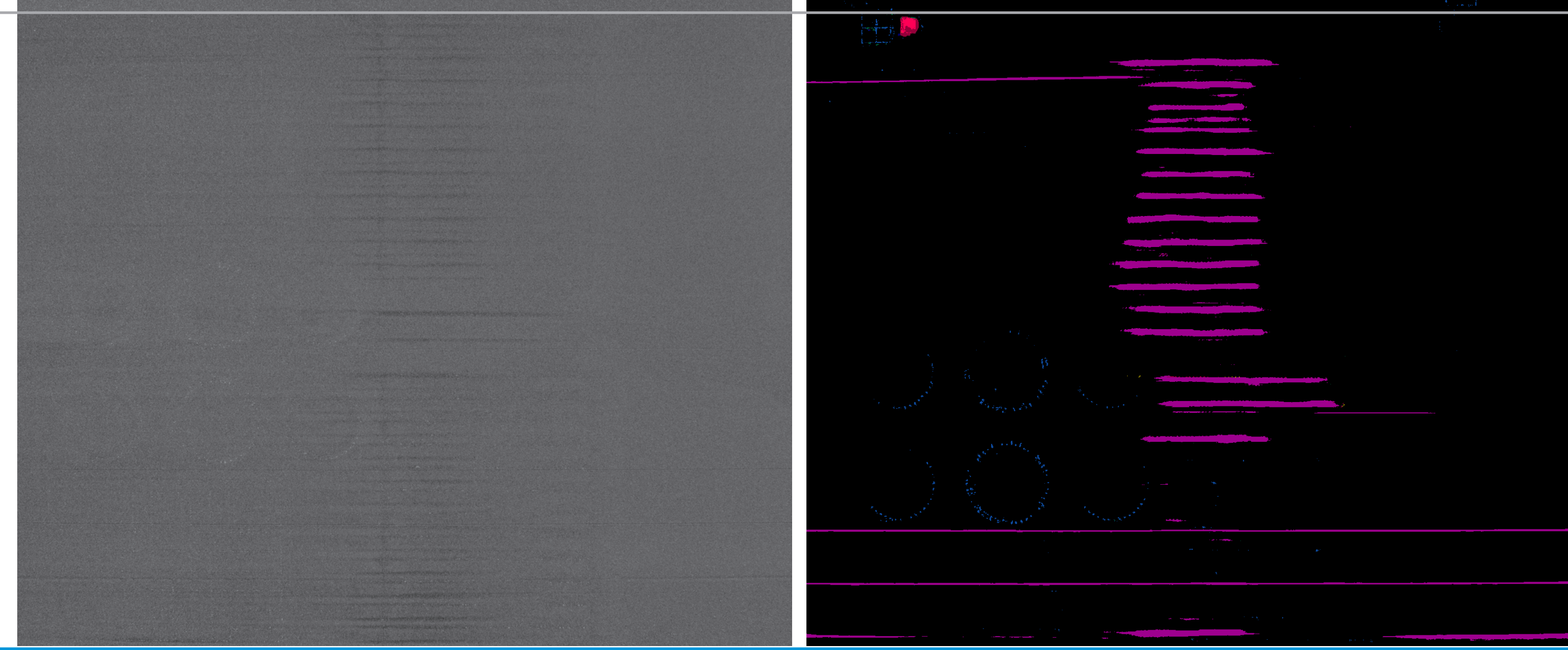
Using a patented technology from ZEISS, all features of the powder bed are captured for a thorough, reliable analysis. Defects are automatically detected and classified. This approach guarantees a robust inspection result across different materials and geometries.

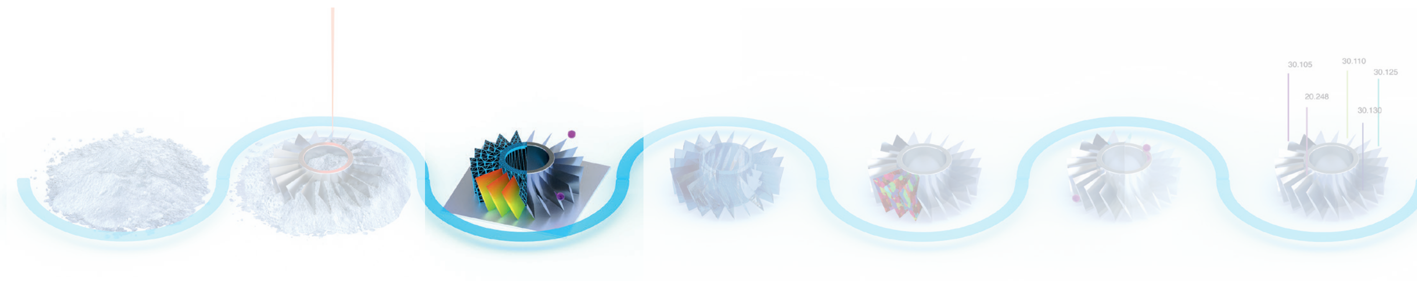


Defect classification is carried out in real time during the build to allow for both manual and automatic intervention in case issues with the powder bed arise. The results can also be used for post print quality assurance as well as quality documentation.



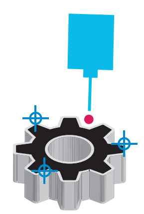
When communication interfaces between the ZEISS AM in-process powder bed monitoring and the AM machine are established, an automatic reaction of the AM machine tailored to the detected defect category can be triggered to correct issues in the powder bed before they can impact part quality.



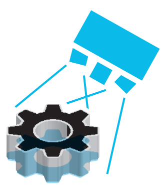


Post-Print Heat Treatment and Part Removal

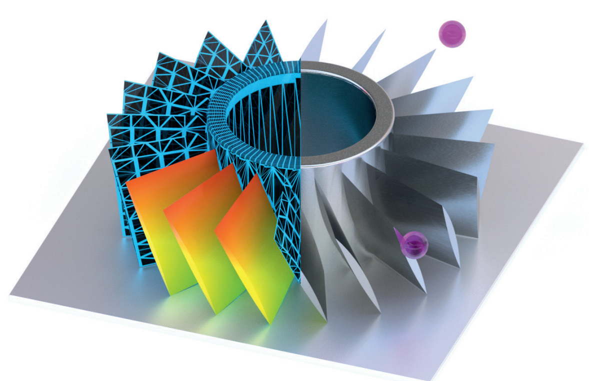
Successful build requires various post-processing treatments to ensure dimensional accuracy and optimal material properties. After printing, the part is still attached to the build plate. It is then heat-treated for stress relieving and removed from the build plate with a band saw or wire EDM. Some parts are then heat treated again for microstructure changes. To better understand the influence of those processes on final accuracy, a CMM or optical 3D scanner can be used.

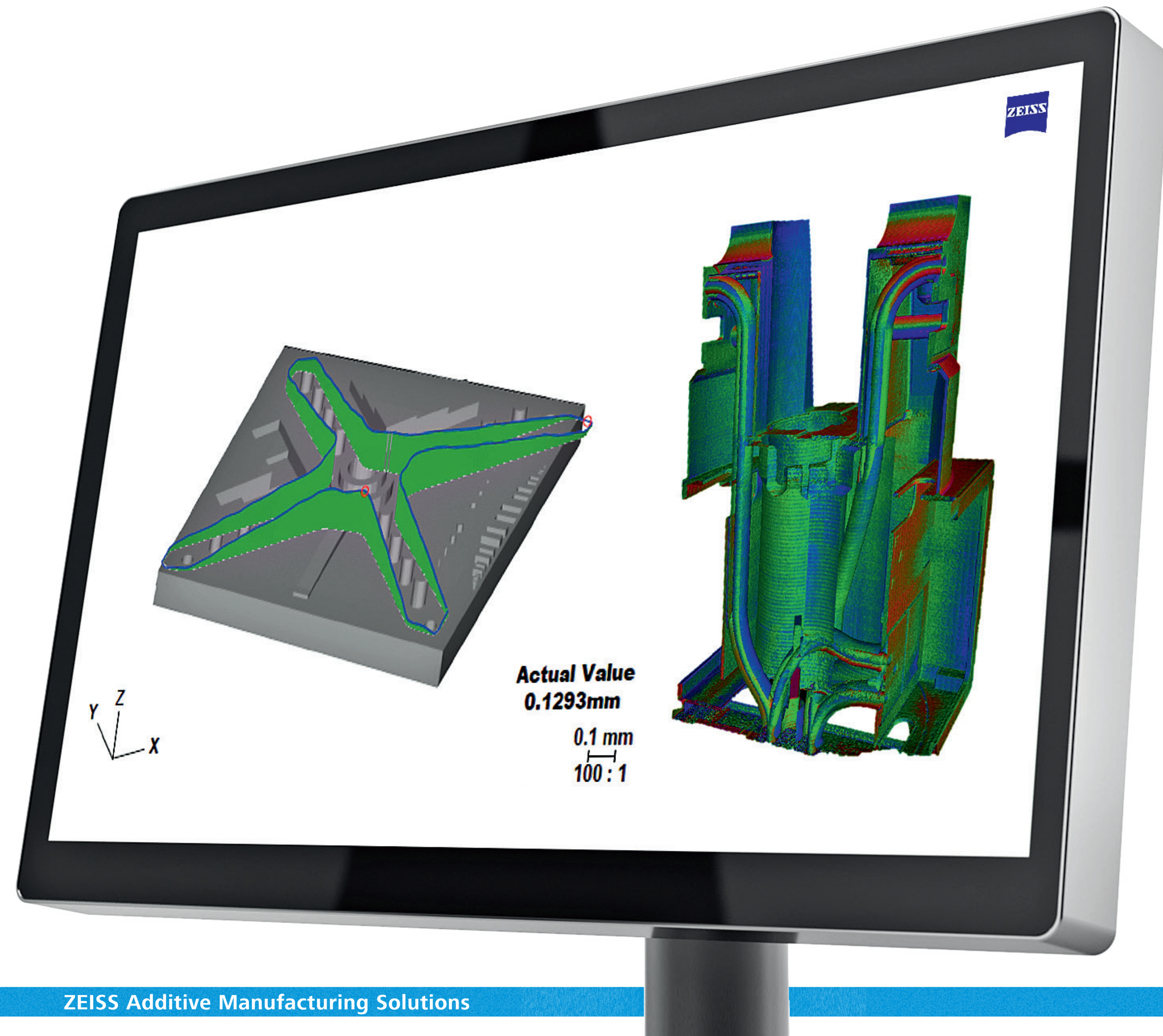


Coordinate Measuring Machine (CMM)



3D Scanning

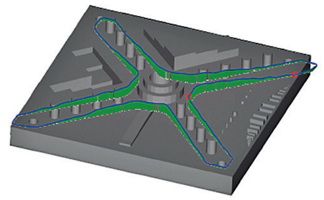




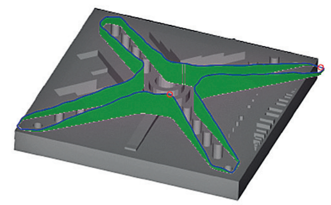
Post-Print Heat Treatment and Part Removal

Coordinate Measuring Machine (CMM)

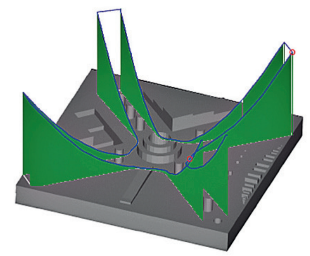
Shop floor CMMs can be used as a quick check of the part's dimensional condition across all three post-process steps: as built, heat-treated, removed and cleaned. Tactile measuring machines allow consistent measurement across many surface finish conditions and metrology of deeper holes and cavities, providing valuable information regardless of part density.



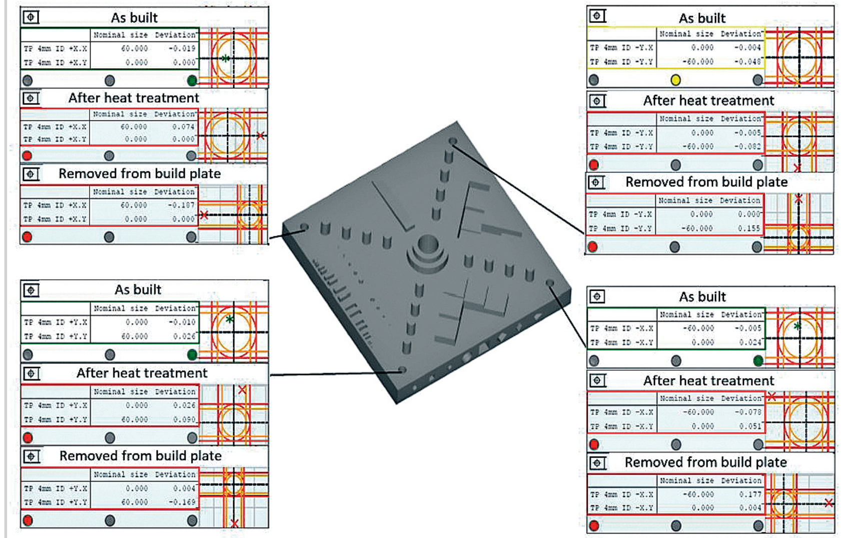
As built



After heat treatment

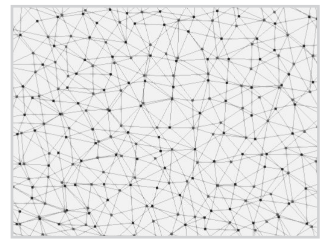


Removed from build plate and cleaned

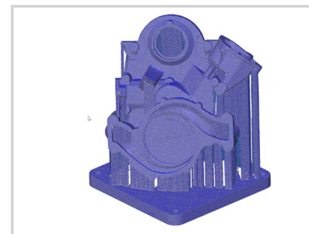


3D Scanning

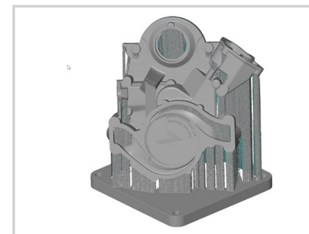
Non-contact 3D scanners provide precise scans with detailed resolution at high speed. From this, the software generates a digital twin of the component, which serves as the basis for inspection and analysis.



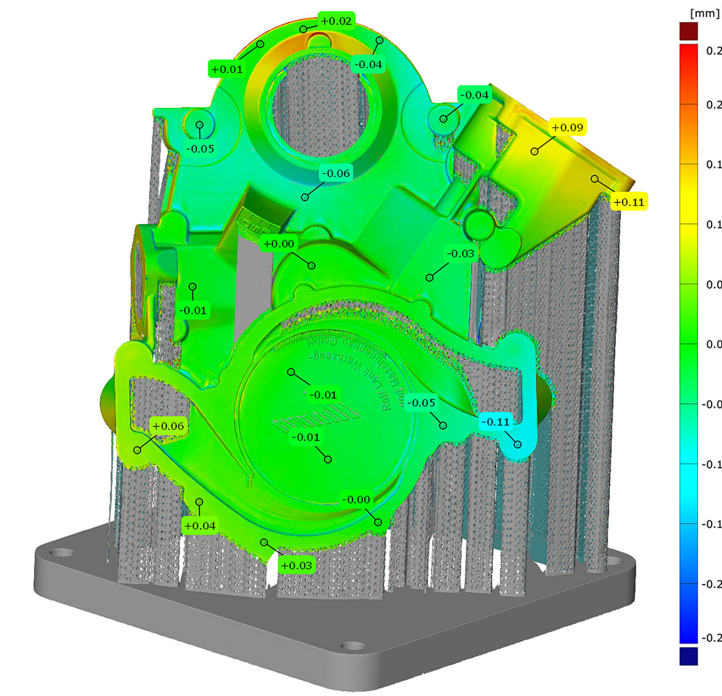
Single point cloud generated with 3D scanner



Combined point cloud of all captured data

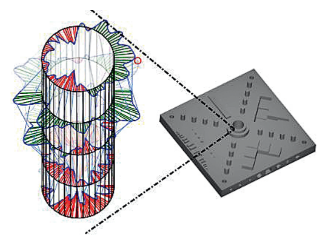


Triangle mesh (STL) calculated on the basis of the captured point cloud



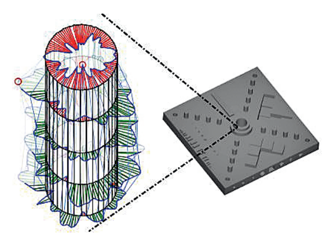
Heat Treatment Effects

The form, size, and position of holes and features can be drastically affected by thermal stresses. The part could be within tolerance in as-built state. However, following heat treatment and part removal, significant distortions may occur.



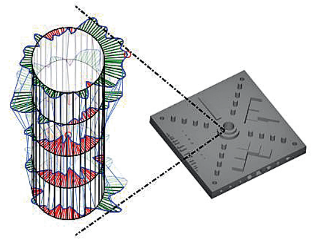
Actual value 0.0531 mm

As built



Actual value 0.0457 mm

After heat treatment



Actual value 0.0387 mm

Removed from build plate and cleaned

As built

	Nominal size	Deviation
TP 4mm ID +X.X	60.000	-0.019
TP 4mm ID +X.Y	0.000	0.000

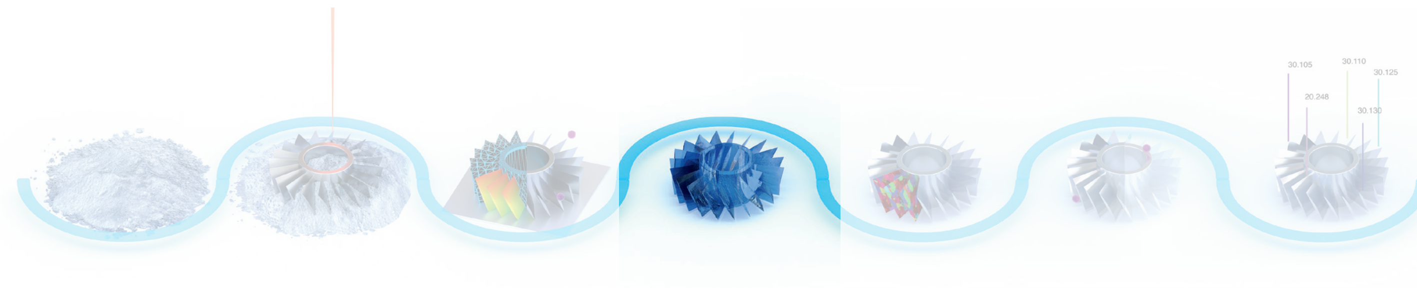
After heat treatment

	Nominal size	Deviation
TP 4mm ID +X.X	60.000	0.074
TP 4mm ID +X.Y	0.000	0.000

Removed from build plate

	Nominal size	Deviation
TP 4mm ID +X.X	60.000	-0.187
TP 4mm ID +X.Y	0.000	0.000

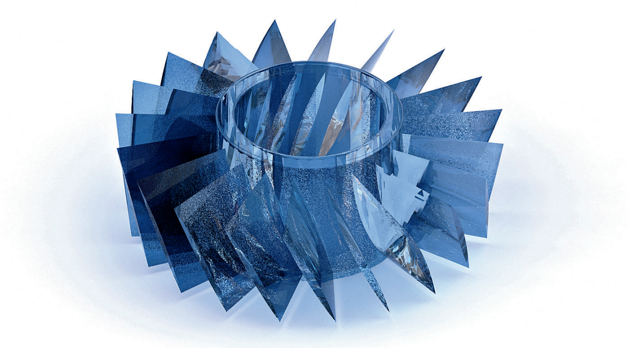
Internal Defect and Structural Inspection

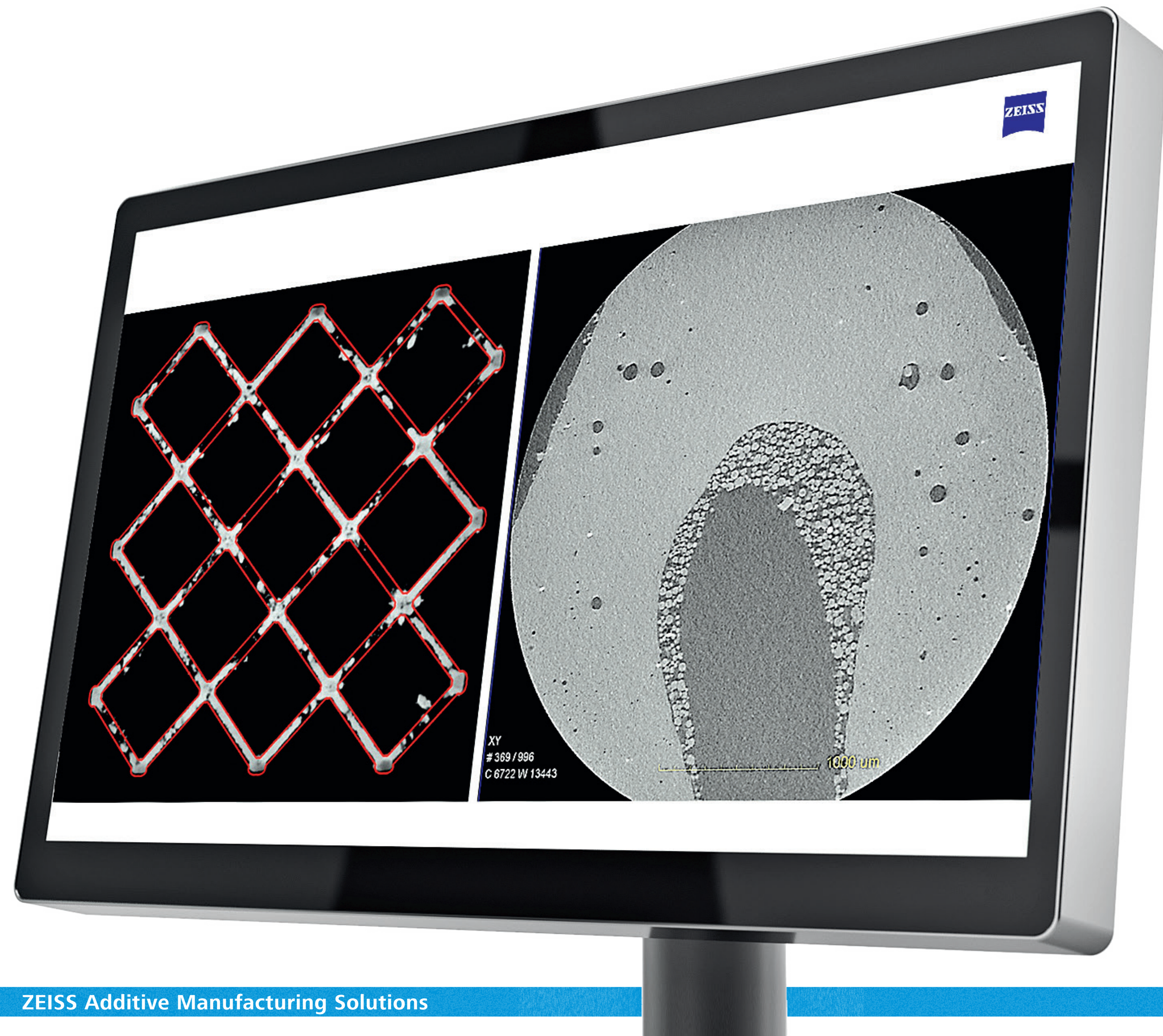


Improper powder quality, powder rheology as well as the process parameters might cause voids to form in the structure. Inspecting the quality of the build with LM or internal structures with high-resolution X-ray CT helps to determine powder characteristics and process parameters influence and faster define a possible path to achieve optimal settings.

Light Microscope (LM)

X-ray Computed Tomography (X-ray CT)

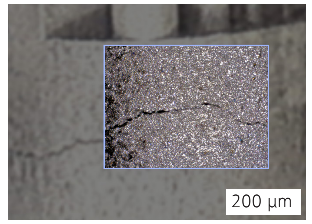


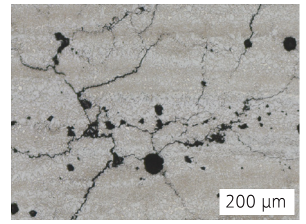


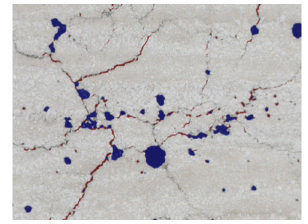
Internal Defect and Structural Inspection

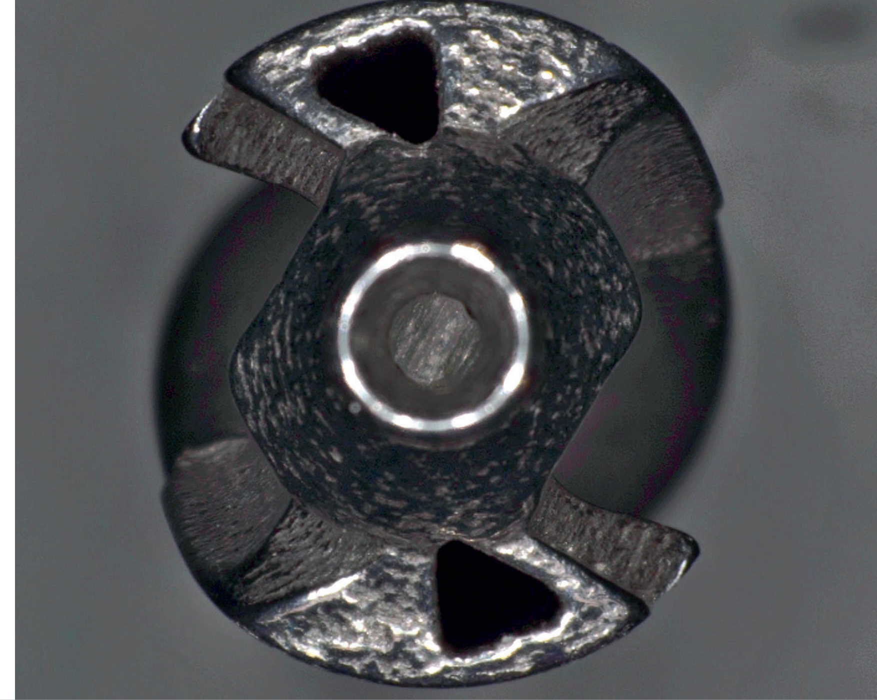
Light Microscope (LM)

An optical microscope can be used to inspect build surfaces and features at high resolution providing valuable insight into part quality. Defects, such as pores, micro cracks and delamination can be inspected and correlated to processing parameters.



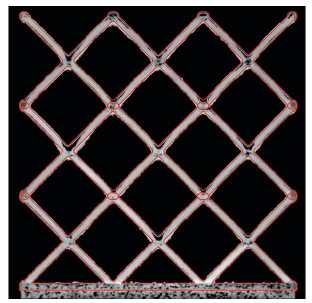


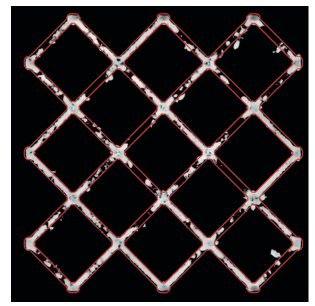


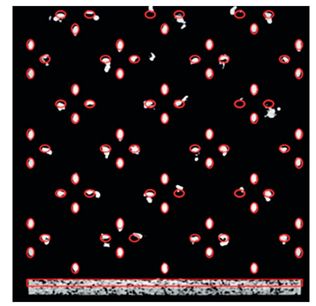


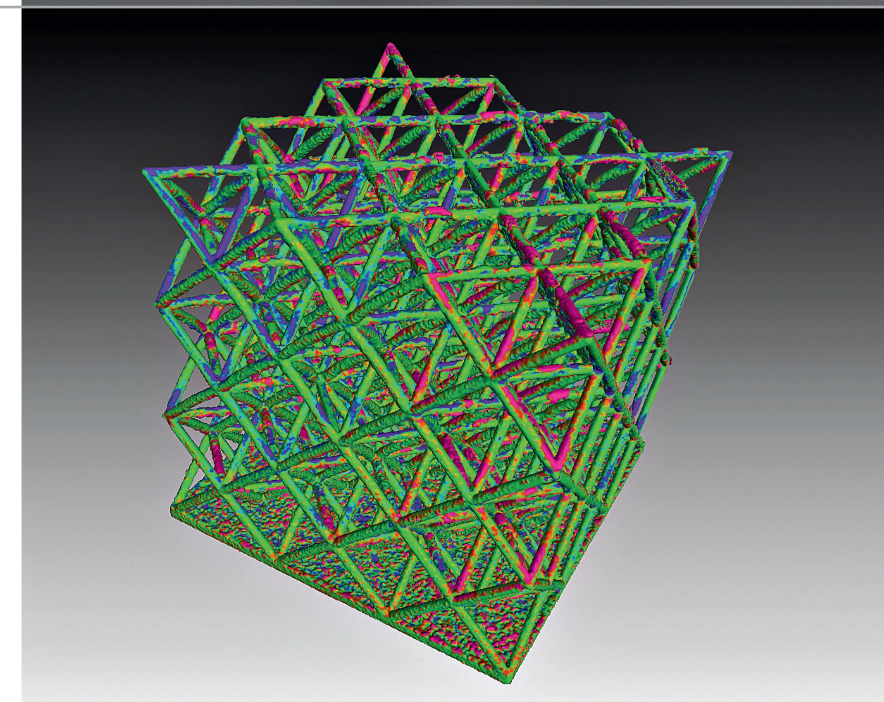
X-ray Computed Tomography (X-ray CT)

Additive manufacturing opens the door for unprecedented design freedom and allows complex inner structures. High resolution X-ray CT enables unique views of those structures and analysis of potential build defects.



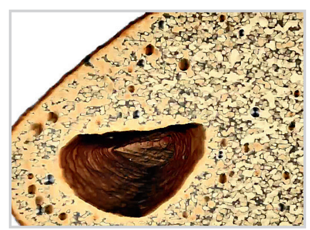


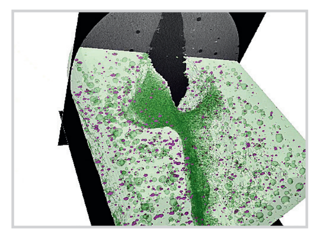


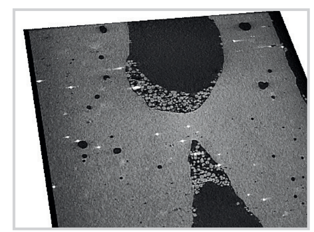


Inner Defects

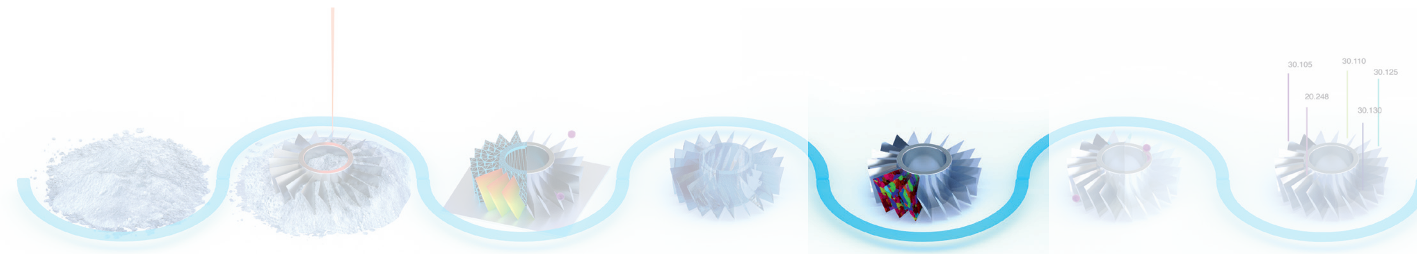
X-ray CT inspection and metrology can provide a unique view of integrity of the build and significantly aid the optimization of the 3D printing process. Scanned images of the part can be cross-sectioned in any direction and compared to the nominal CAD representation.







Post-Print Material Quality Inspection



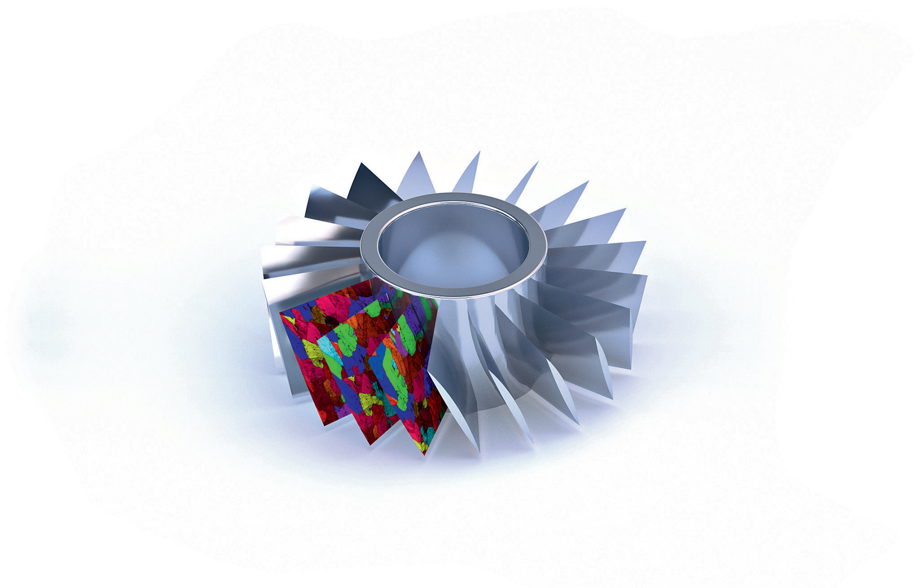
Light Microscope (LM)

Scanning Electron Microscope (SEM)

3D Testing

X-ray Computed Tomography (X-ray CT)

The additive manufacturing process, unlike traditional manufacturing methods, requires powders to be melted layer by layer during the build. Melt temperatures and process parameters greatly affect the crystallography and, as a consequence, part properties.



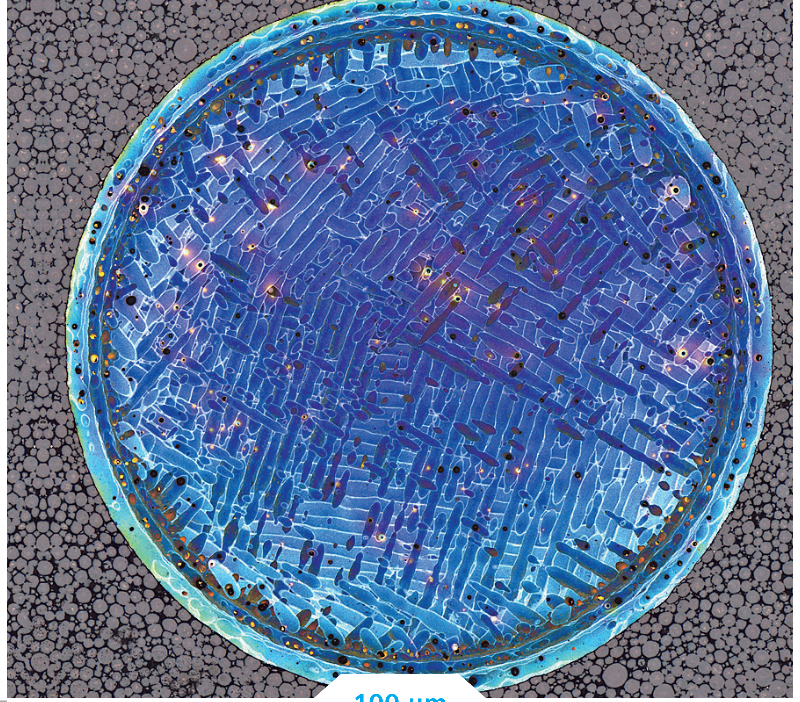
Post-Print Material Quality Inspection

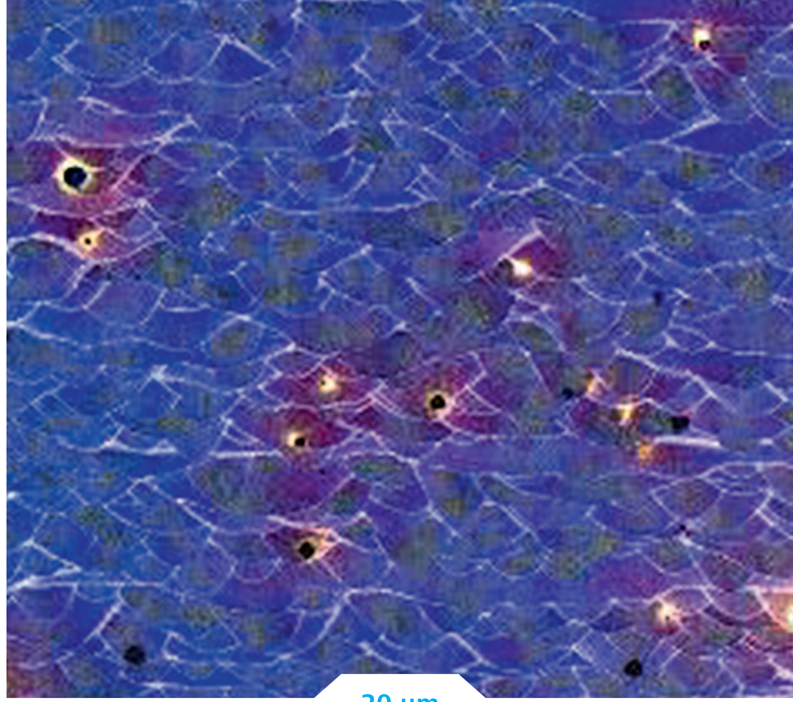
Light Microscope (LM)

Due to the high energy density, additively manufactured parts are typically created with high thermal gradients and solidification rates. Scanning strategies and weld pools are among characteristic patterns which can be analyzed with optical microscopes and have a direct impact on mechanical properties.

>
Light microscopy
image of metal powder

AlSi10Mg cross section transverse and along the build direction



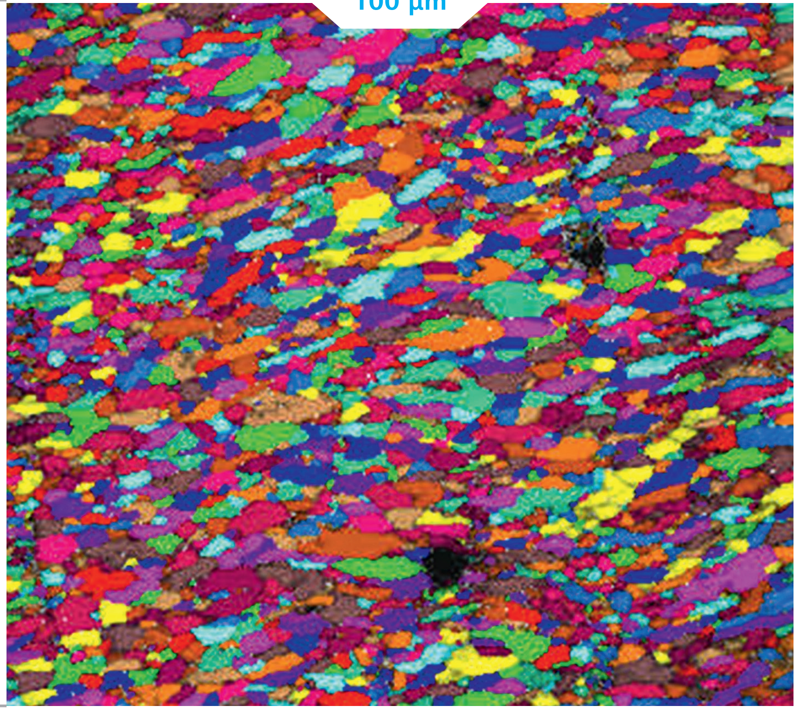


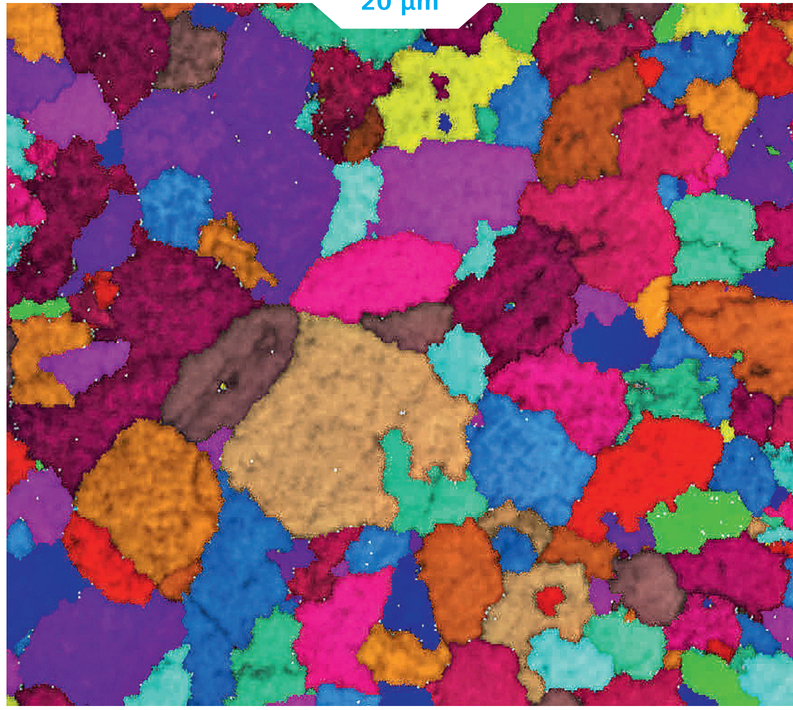
Scanning Electron Microscope (SEM)

SEM equipped with Electron Backscatter Diffraction (EBSD) enables microstructural crystallographic characterization and the study of single crystal and polycrystalline materials.

>
Same area
SEM, EBSD

EBSD-mapping, individual grains colored, laser structure not visible



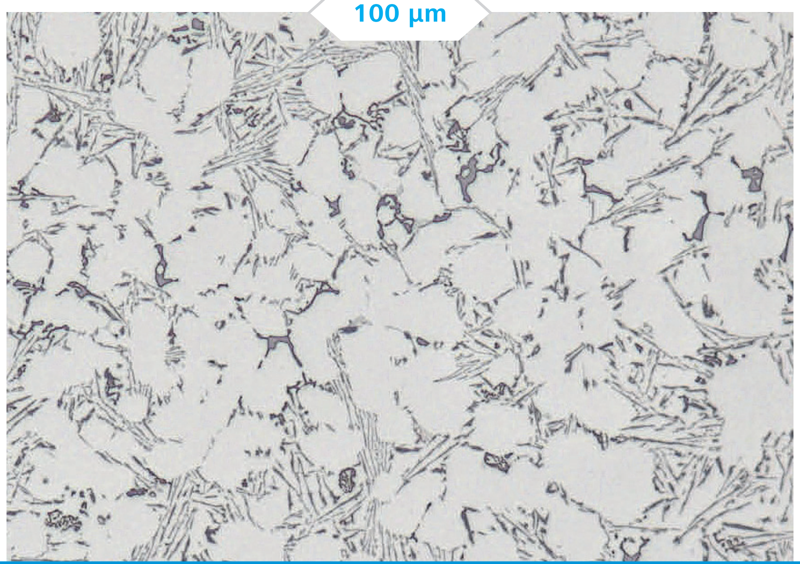


Analysis of Grain Structure

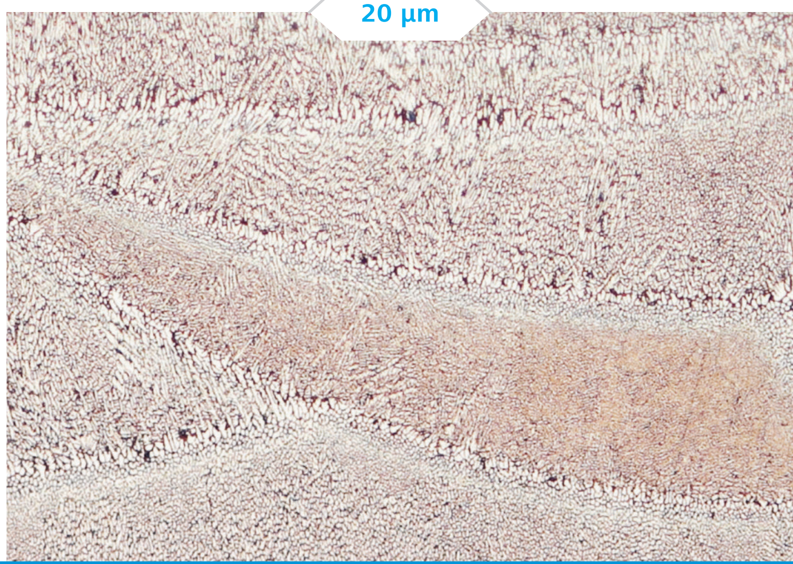
The grain structure produced by conventional means is very different from that of 3D Printed part of the same material. This difference will drastically influence the mechanical properties of the finished part.

>
Comparison
of conventional and additively made AlSi10Mg

CONVENTIONAL



3D PRINTED



Mechanical Properties

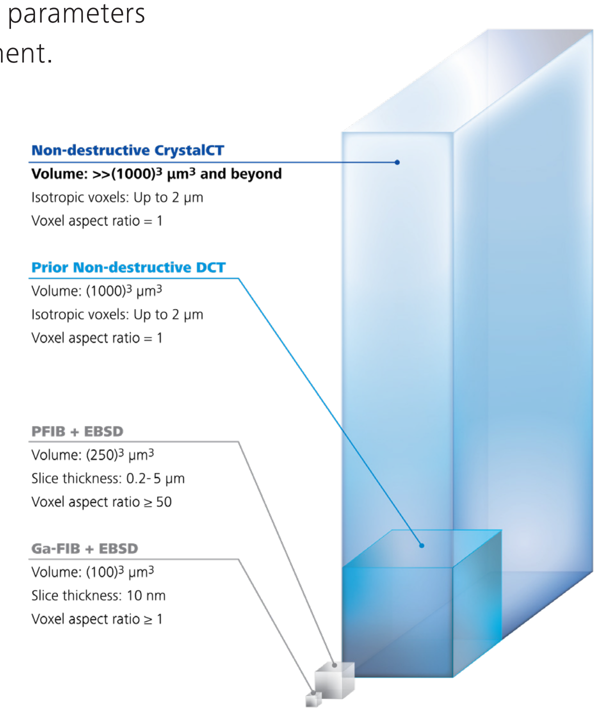
3D Testing

Provides information on material characteristics like 3D displacements and 3D surface strains, and the behavior of components under load. These results form the basis for product durability, geometrical layout, reliable numerical simulations and their validation.

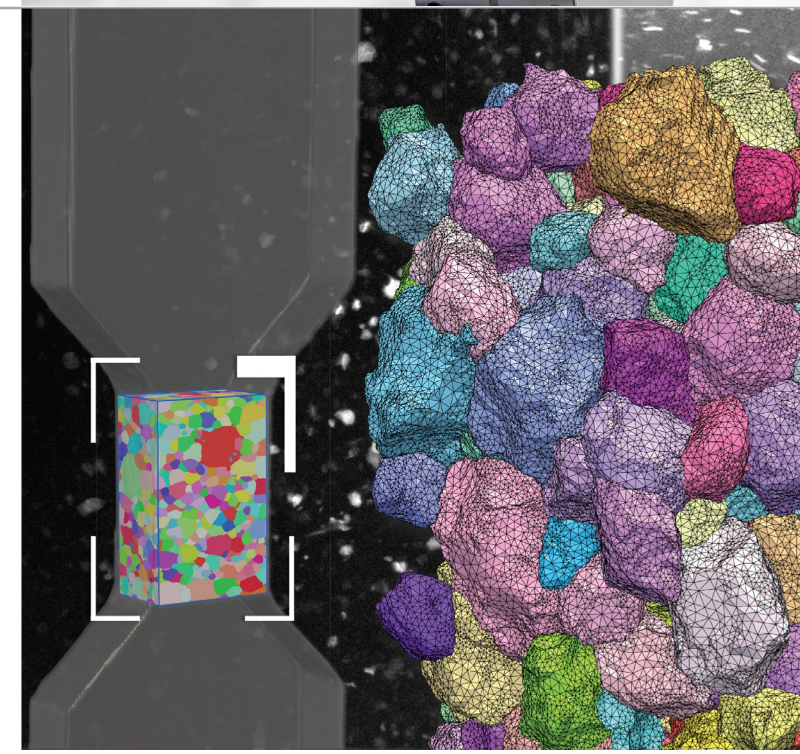
Post-Print Material Quality Inspection

X-ray Computed Tomography (X-ray CT) LabDCT and CrystalCT

Additive manufacturing enables an unprecedented control over material micro structures. LabDCT and CrystalCT are tools which enable 3D grain structure and crystallography analysis making it possible to link it to the AM process parameters and heat treatment.



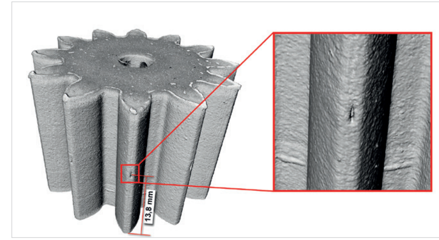
Grain boundary normal | Grain boundary curvature | Grain boundary misorientation



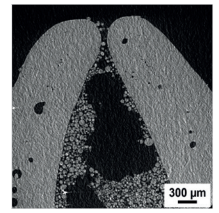
Cross Correlations

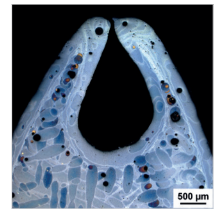
Often, time analysis of metallographic structures, irregularities or defects needs to take place at different length scales and hence with different tools such as light microscopes, scanning electron microscopes and CT. Within the ZEISS solution, regions of interest can easily be marked and navigated to using different tools to narrow down defect root causes.

Entire sample (low resolution XRM)



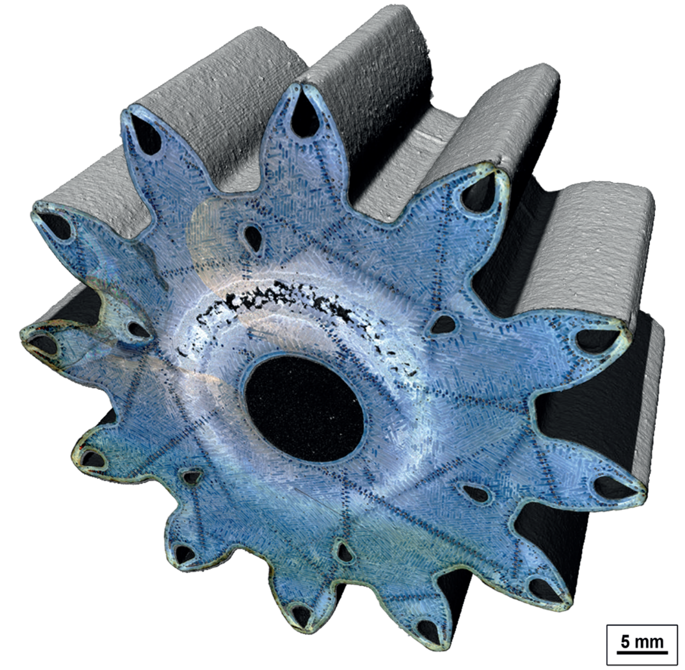
Definition of region of interest (ROI)





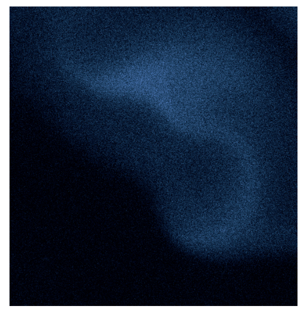
Left: High resolution XRM scan and light microscopy scan of ROI

Right: Correlated data of XRM and LM

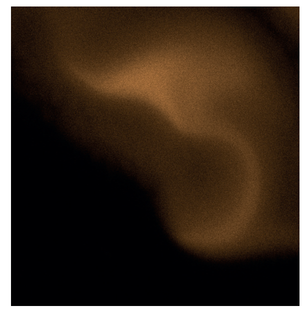


Chemical Composition Analysis

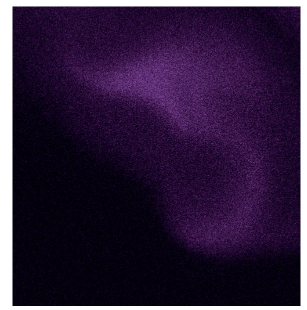
In additive manufacturing, chemical composition of materials can be essential. EDX, an optional feature of SEMs, enables mapping of the chemical composition which allows for characterization of metallurgic phases and detection of impurities in the material.



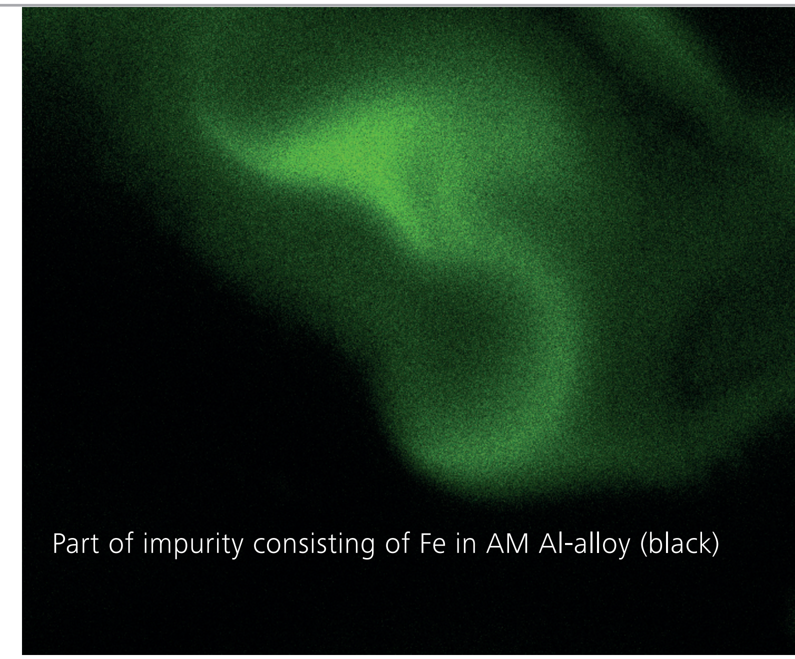
Part of impurity consisting of Co in AM Al-alloy (black)



Part of impurity consisting of Cr in AM Al-alloy (black)



Part of impurity consisting of Mn in AM Al-alloy (black)



Part of impurity consisting of Fe in AM Al-alloy (black)

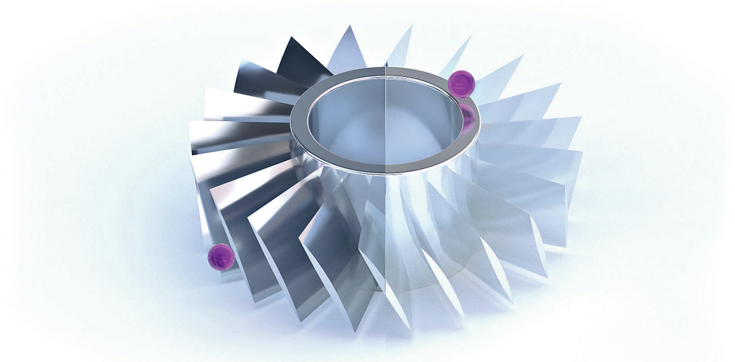
Dimensional and Surface Quality Inspection

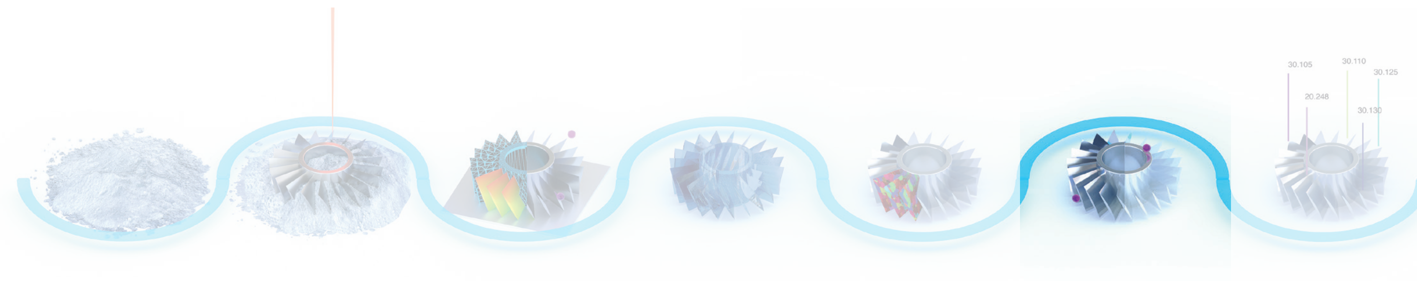
X-ray Computed Tomography (X-ray CT)

3D Scanning

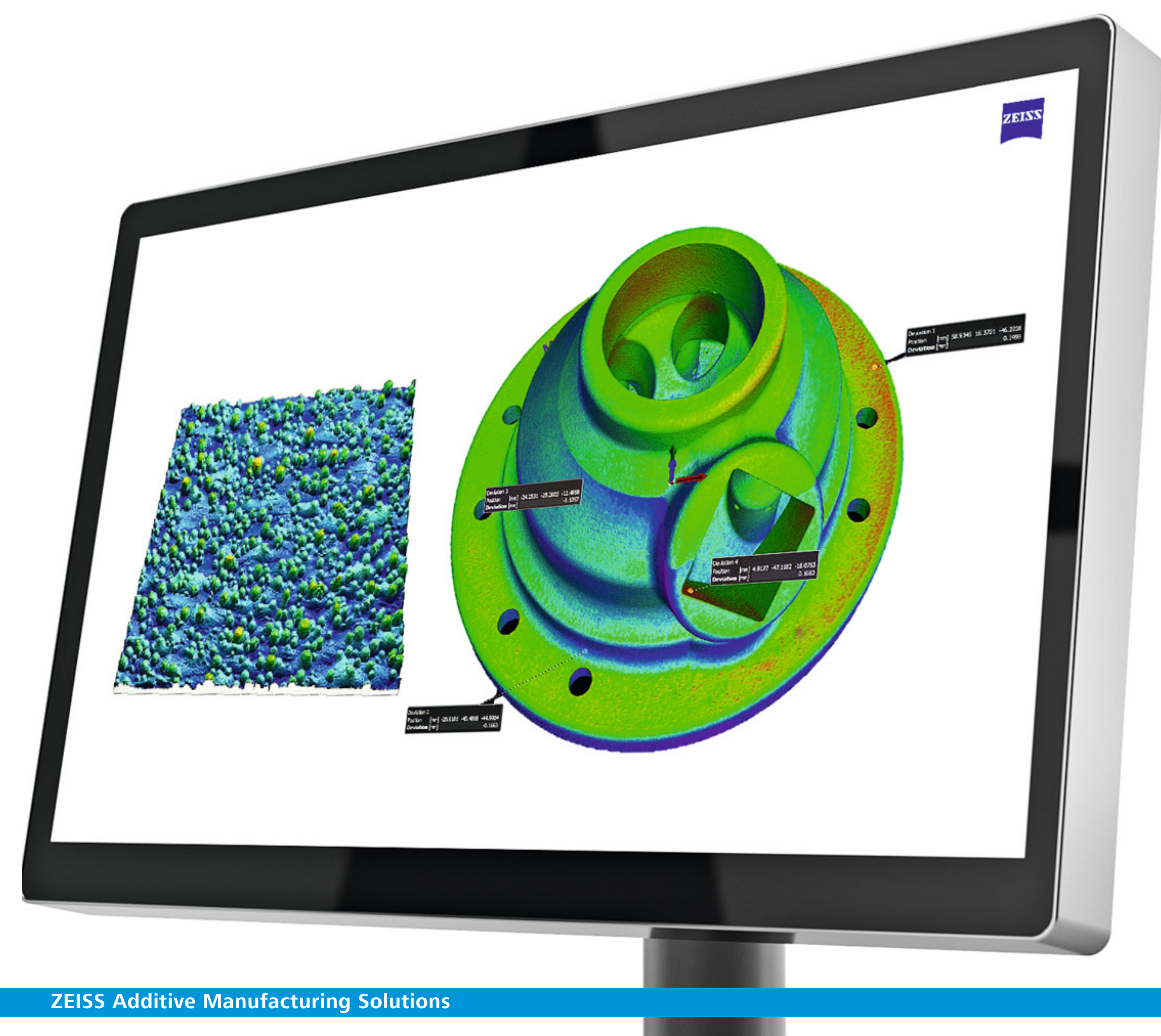
Light Microscope (LM)

Coordinate Measuring Machine (CMM)





Dimensional accuracy and surface finish are critical to ensure proper assembly and consistent matching across multiple parts. The surface finish can be analyzed with optical methods, and the internal surface is examined with X-ray CT. Dimensional accuracy of the final part can be validated either with CMM, optical 3D Scanning or with X-ray CT.

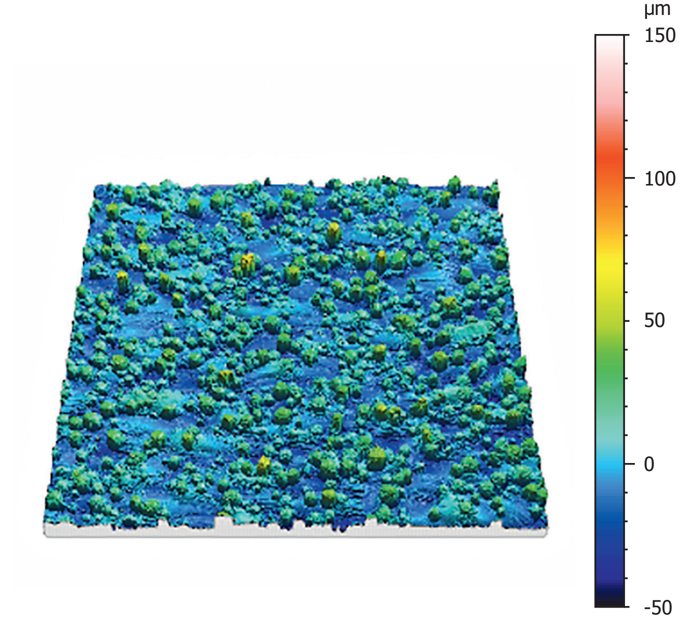


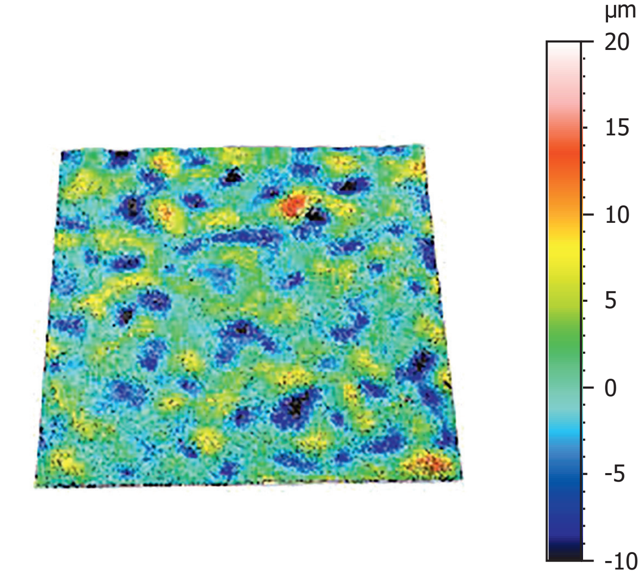
Surface Quality Inspection

Light Microscope

Surface quality defines functional and visual quality of the part. Optical profilometers offer high density of data in relatively short time, allowing detailed topographic maps of a surface of interest.

>
Analysis of as built part with LM before and after sand blasting





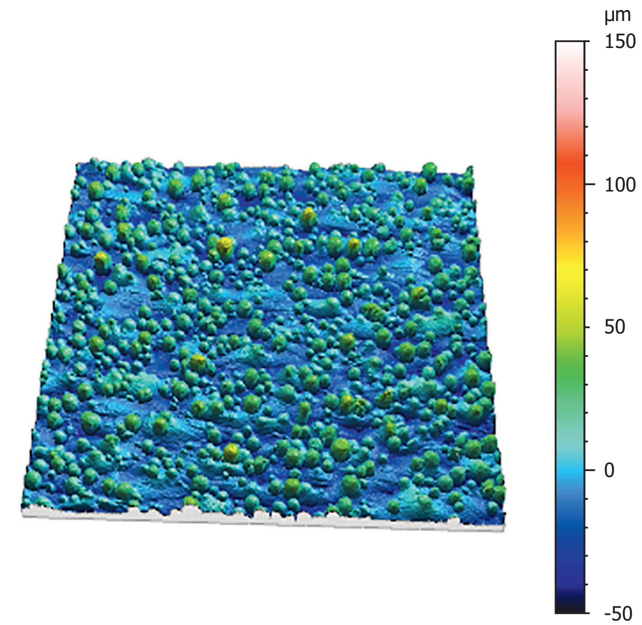
As built

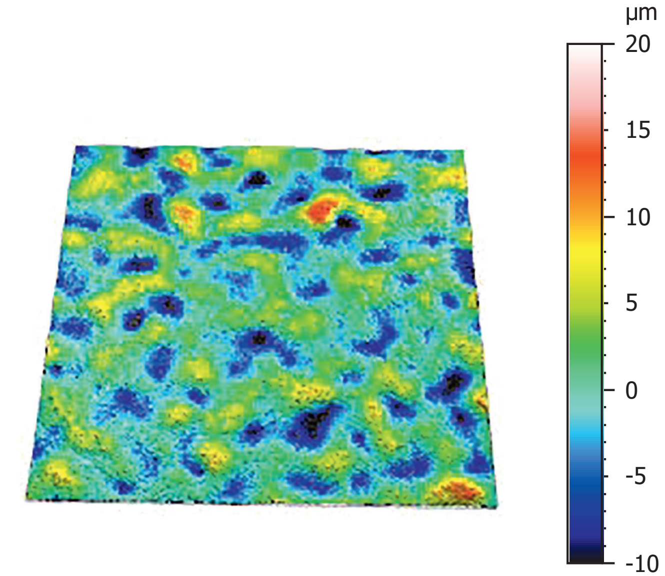
After sand blasting

X-ray Computed Tomography (X-ray CT)

Additive manufacturing allows creation of very complex internal surfaces which often might serve as channels, allowing gas or liquid flows. Internal surface finish can not be accessed with an optical profiler. Therefore, high resolution X-ray CT is the only way to obtain internal surface analysis.

>
Analysis of as built part with high-resolution X-ray CT before and after sand blasting





Surface Quality

Surface roughness is critical with respect to mechanical properties and visual qualities of the part. Additively manufactured parts can be very complex with hidden inner structures which are not accessible. The ability to use a well-correlated optical profiler and high-resolution X-ray CT enables detailed surface analysis regardless of its location (inner or external).

>
Comparison of surface analysis results obtained with LM and X-ray CT

ISO 25178
Height Parameters

	ZEISS Xradia Versa	ZEISS Smartproof 5	
Sq	15.1	14.8	µm
Ssk	0.700	0.776	
Sku	3.11	3.29	µm
Sp	66.9	71.3	µm
Sv	40.7	86.9	µm
Sz	108	158	µm
Sa	12.2	12.0	µm

ISO 25178
Height Parameters

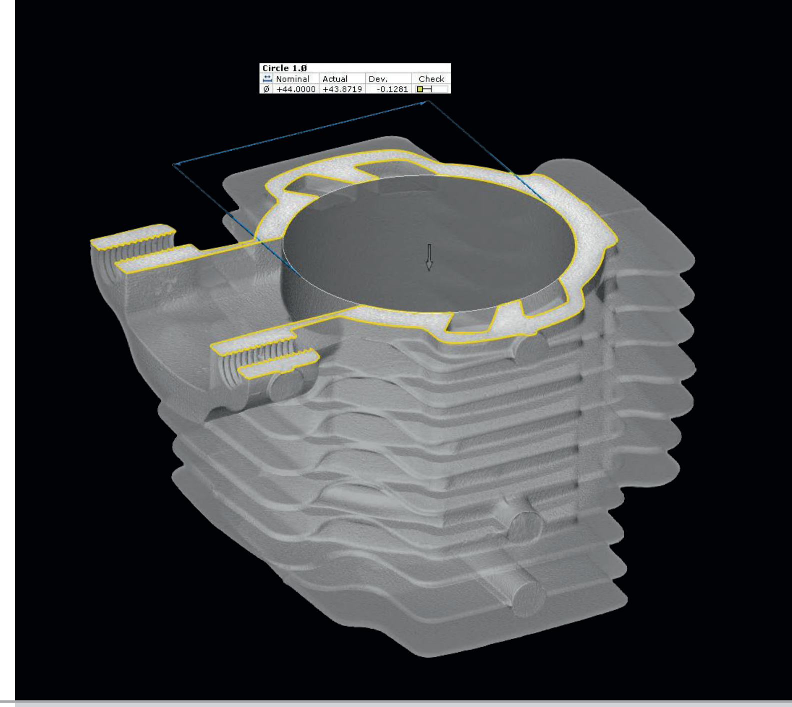
	ZEISS Xradia Versa	ZEISS Smartproof 5	
Sq	3.9	3.75	µm
Ssk	-0.174	-0.111	
Sku	3.52	3.57	µm
Sp	14.8	14.8	µm
Sv	26.4	23.8	µm
Sz	41.2	38.6	µm
Sa	3.06	2.93	µm

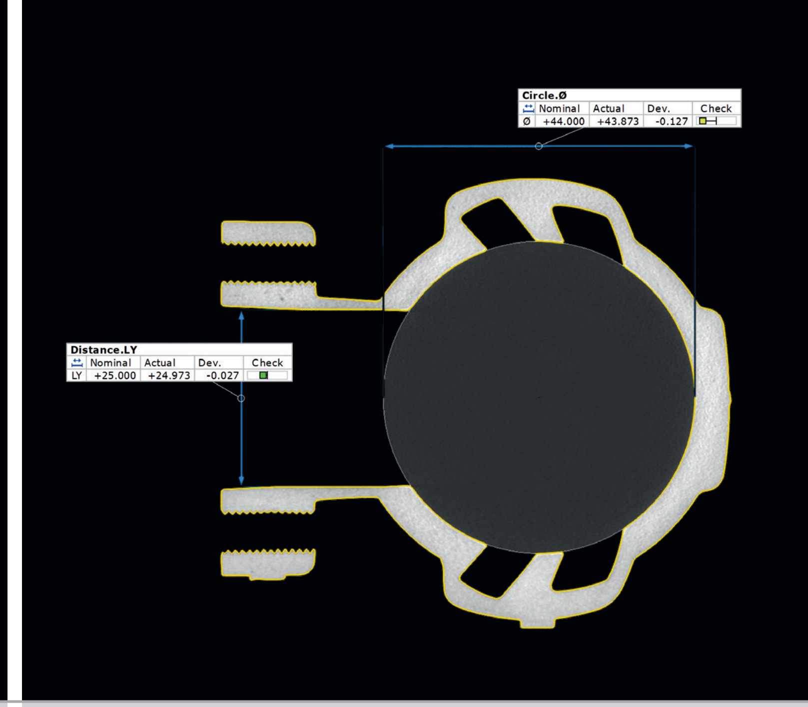
Dimensional Quality Inspection

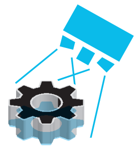
X-ray Computed Tomography (X-ray CT)

Dimensional accuracy of additively manufactured parts is critical, as it will affect the actual system performance. Given the extreme complexity of those parts, X-ray CT is the only option for non-destructive and accurate metrology of complex internal and external features.

> Sample measurements of internal features using X-ray CT



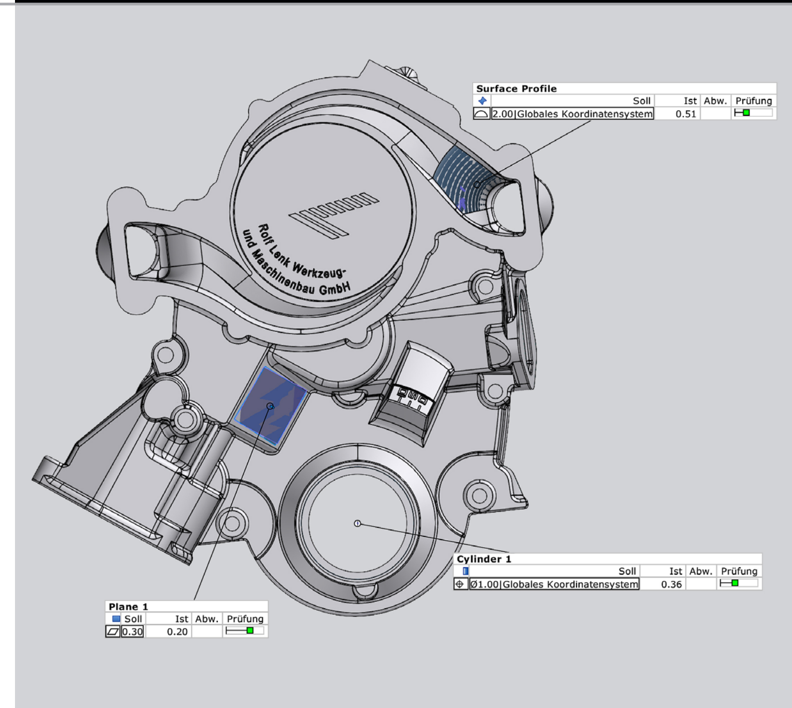


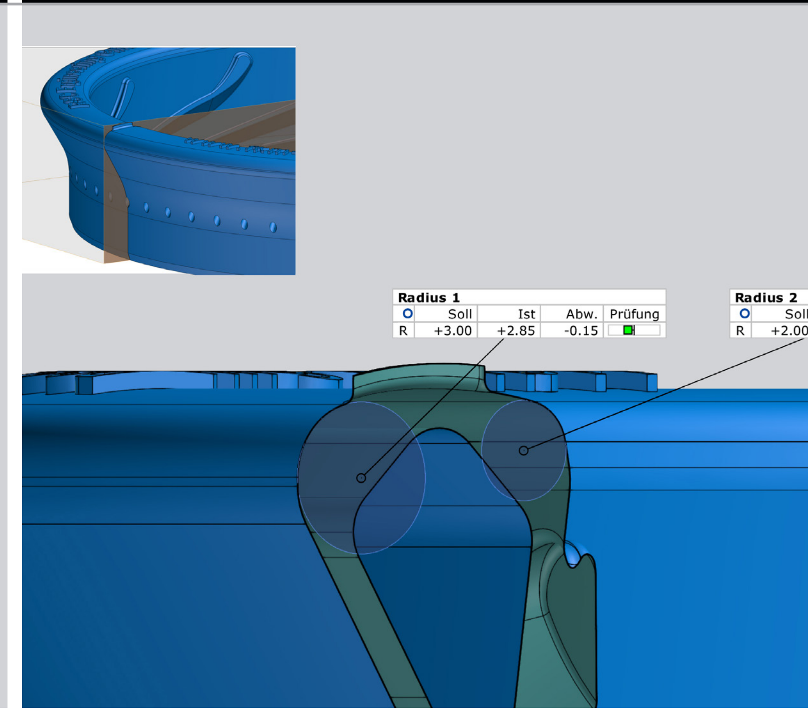


3D Scanning

3D scanning offers an alternative to X-ray CT for parts that have no complex internal features and whose external shape, form, and size are of interest.

> Dimensional analysis of parts using 3D scanning



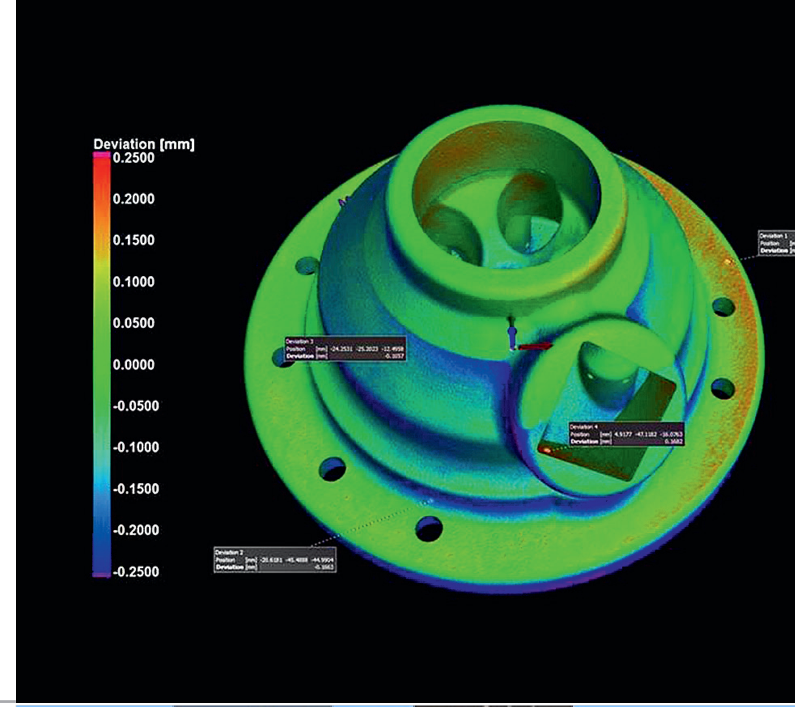


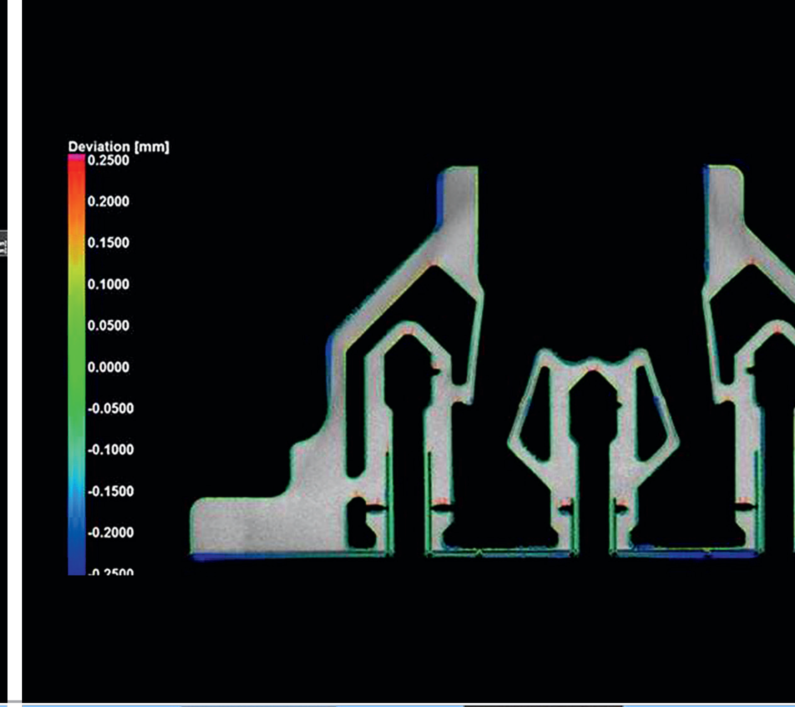
Dimensional Quality Inspection

Dimensional Metrology

Printed parts are often assembled into larger systems. Therefore, dimensional accuracy is just as critical as it is for subtractively produced parts. The ability to verify critical dimensions is necessary to validate the quality of the build.

> Dimensional analysis of internal features using X-ray CT

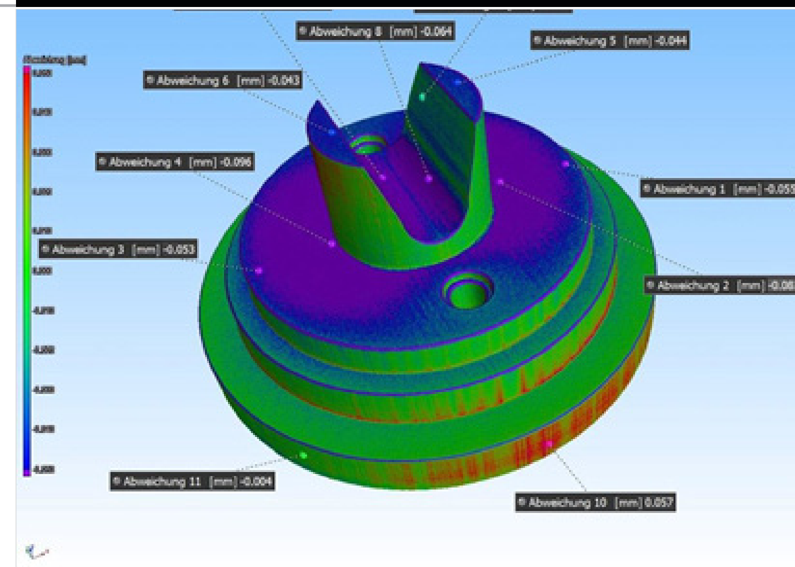




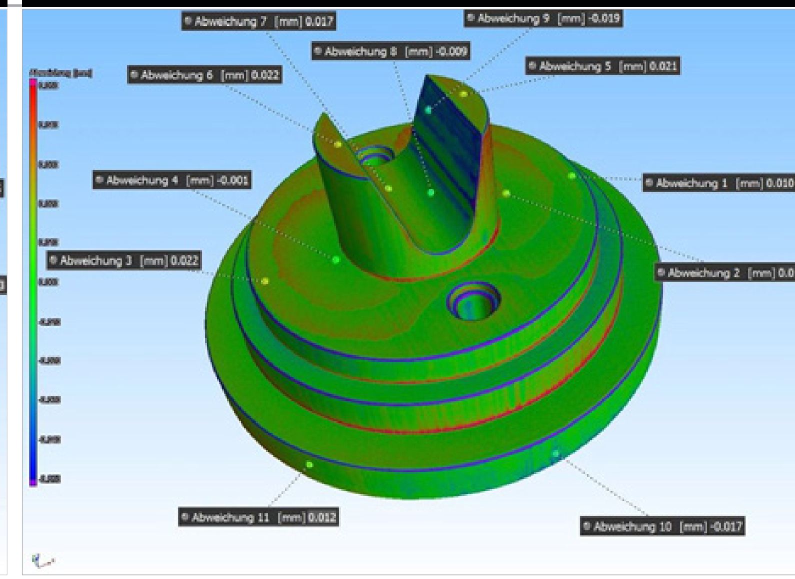
Correction of Print Input Data

After the alignment of the nominal and actual data, the areas which must be corrected are automatically determined. After this correction loop, a watertight CAD / STL model can be provided to the 3D printer.

> Correction of print input data using ZEISS REVERSE ENGINEERING

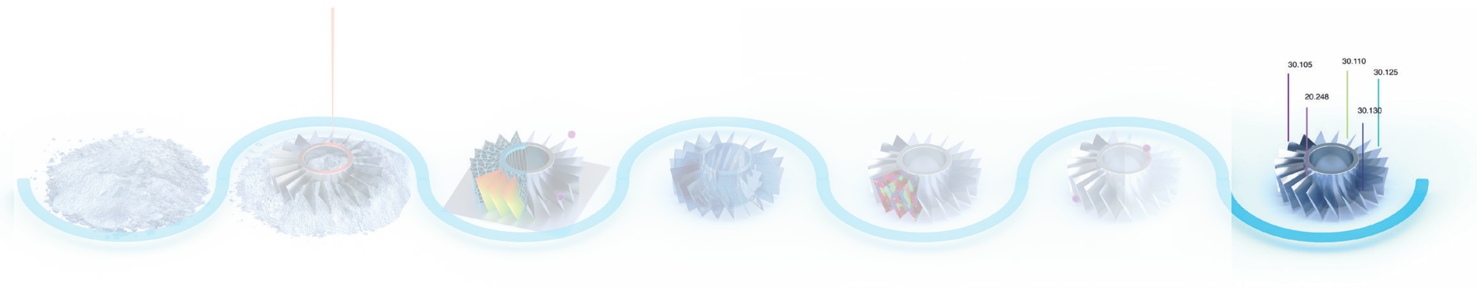


False color comparison (nominal/actual data) after first print

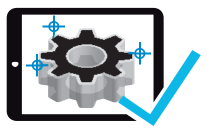


False color comparison (nominal/actual data) after first correction loop using ZRE

Correlative and Advanced Data Analysis/Statistics

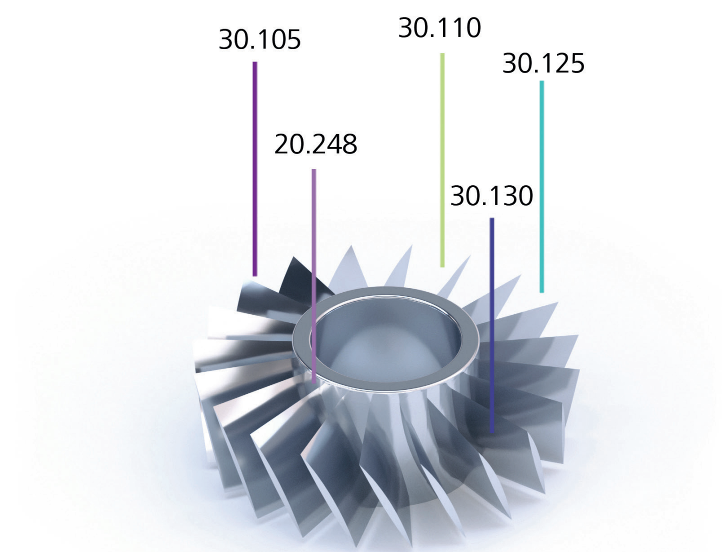


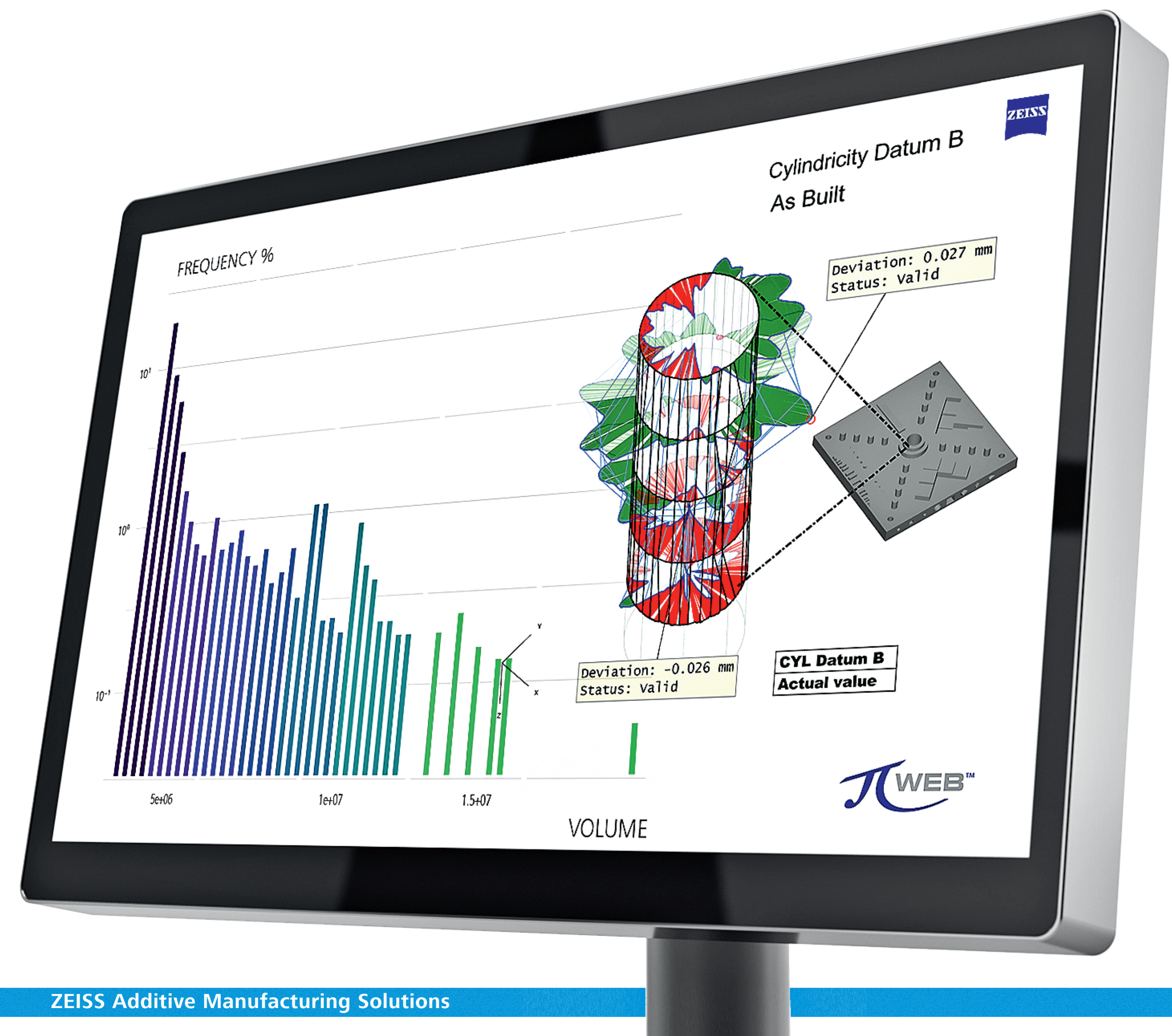
Collection and analysis of data across the entire process chain provides a deep understanding of how process changes might correlate with different dimensional and material properties. Clear visual representation and correlation of results across all process steps helps to quickly and more efficiently develop printing strategies while increasing yield.



ZEISS PiWeb

ZEISS AM Parameter





Correlative and Advanced Data Analysis/Statistics

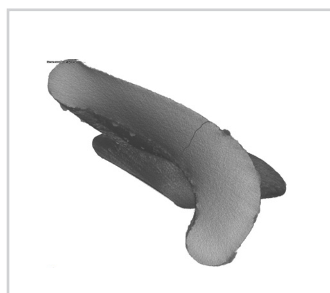
Correlation Analysis

Through correlating data obtained along the process chain previously hidden connections can be re-vealed. E.g. combining microscopy and CT data through a correlation software, the impact of powder properties on part defect density can be assessed.

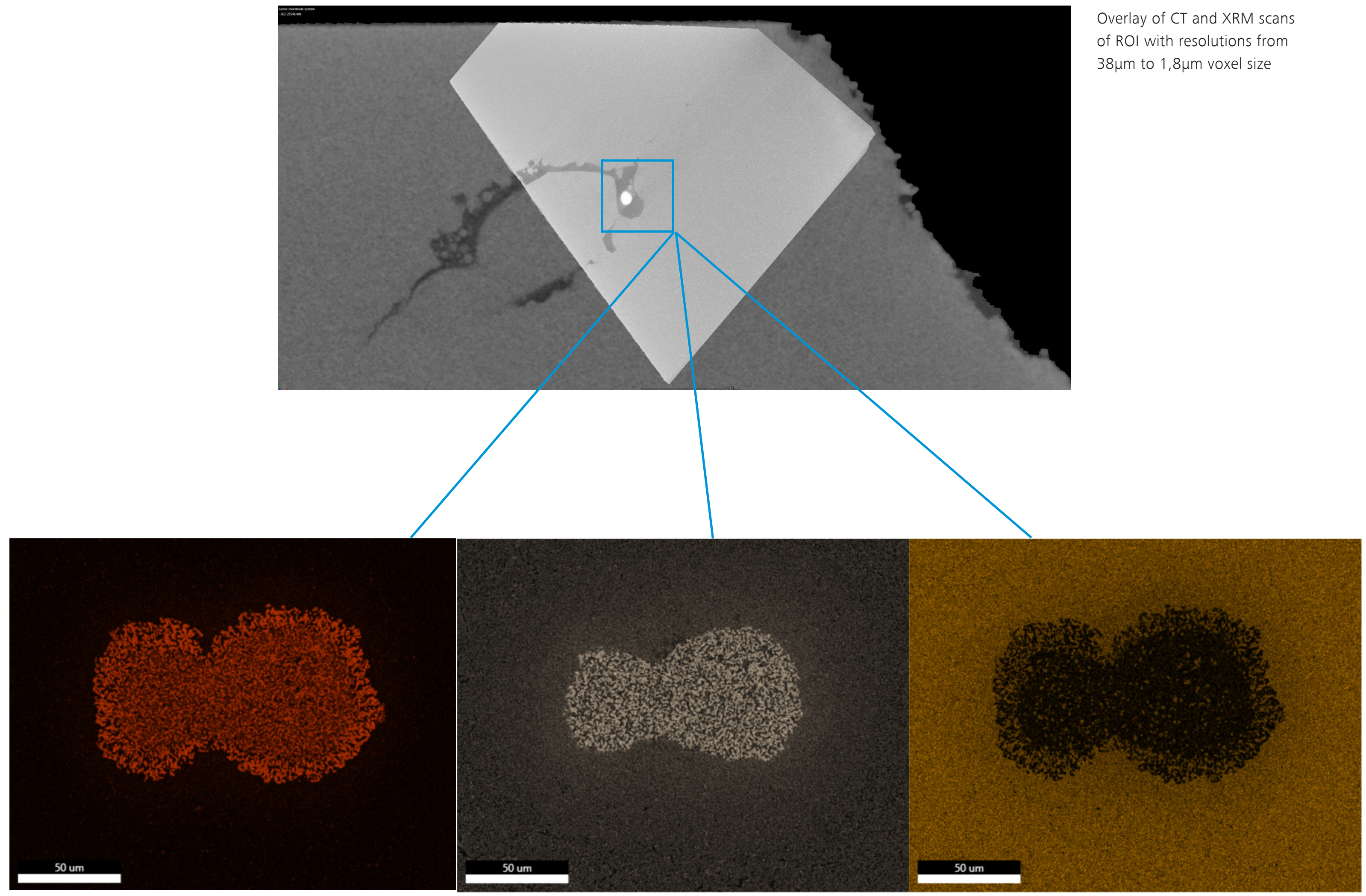
Multi Modal Analysis

Cause and effect in AM can span over different modalities and process steps. Therefore, ZEISS offers ways for easy transition of samples between different tools for full assessment and retrieve ROI across all modalities.

Entire sample
(low resolution CT scan)



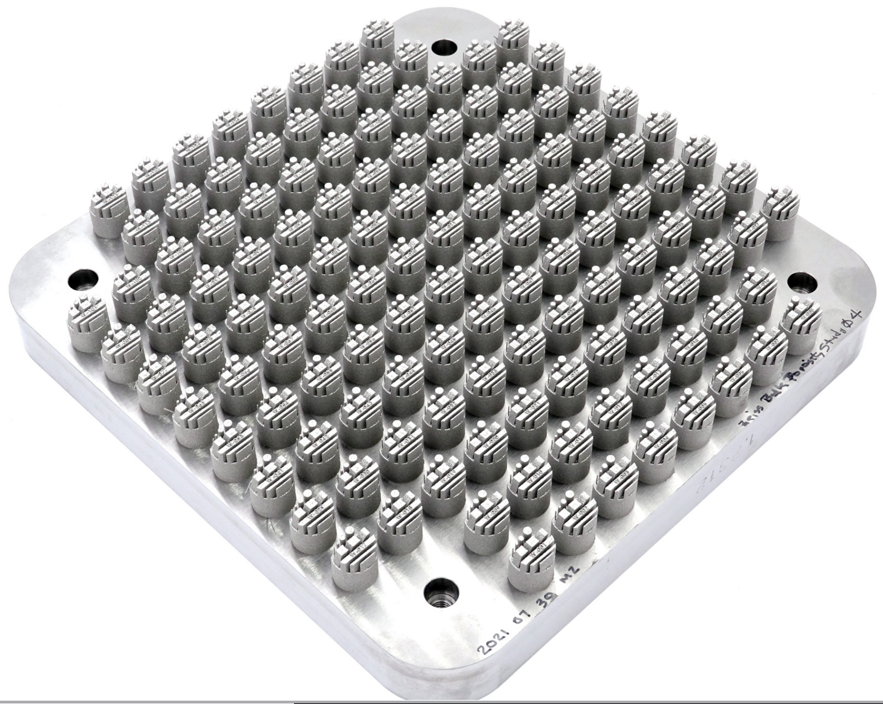
Definition of region of interest (ROI):
crack in blade

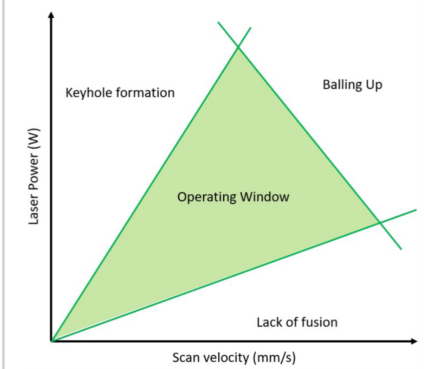


Overlay of CT and XRM scans of ROI with resolutions from 38µm to 1,8µm voxel size

Chemical analysis of inclusion found in crack reveals con-tamination with tungsten in Inconel alloy using Electron Microscope

Parameter Development





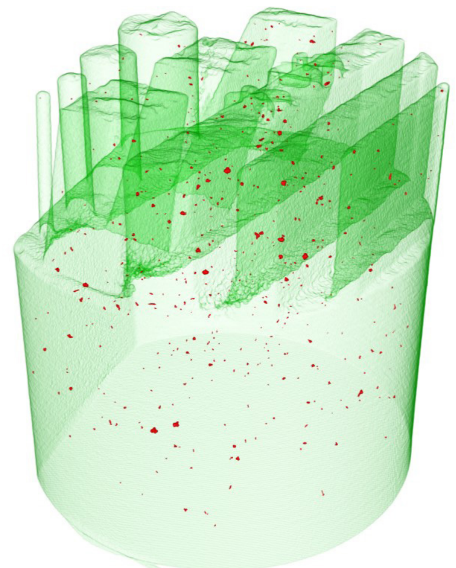
Parameter Development

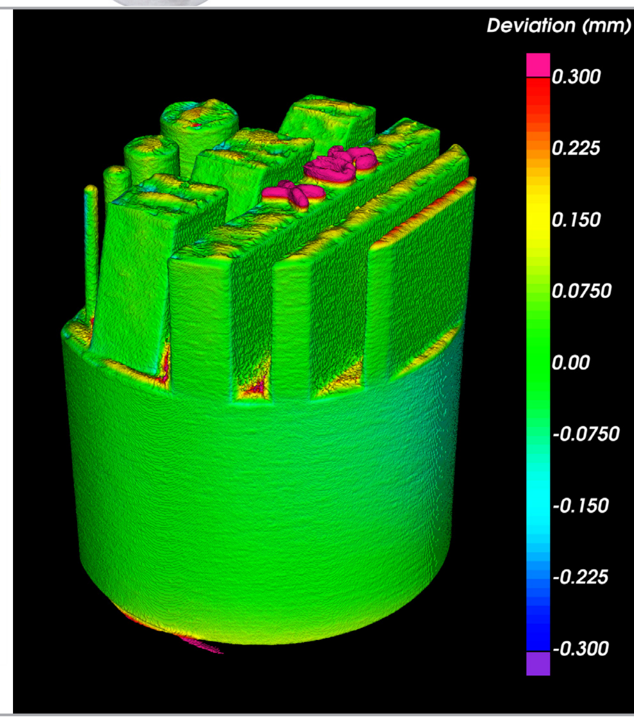
Parameter development for metal AM typically requires printing multiple coupons, each printed with a combination of print parameters to evaluate the best set of parameters to print in order to minimize defects (porosity, cracks), deformation and smoother surface finish.

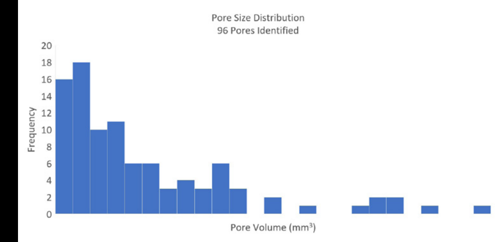
Currently, evaluating a single build plate consisting of approximately 36 coupons can take up to 6-8 weeks, because it involves multiple techniques applied in series. ZEISS AM parameter provides a fully automated, fast and reproducible evaluation of the entire build plate of coupons in 12-24 hours through leveraging the full capabilities of ZEISS computer tomography systems.

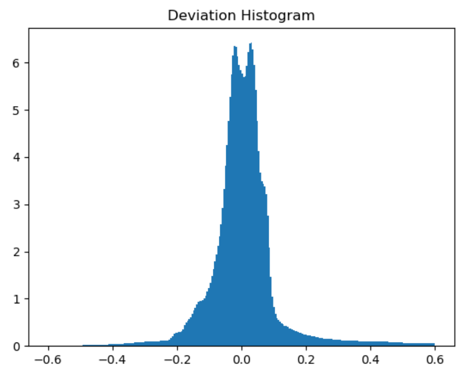
> Left
porosity detected in 3D volume

> Right
geometrical devitations of part to CAD file

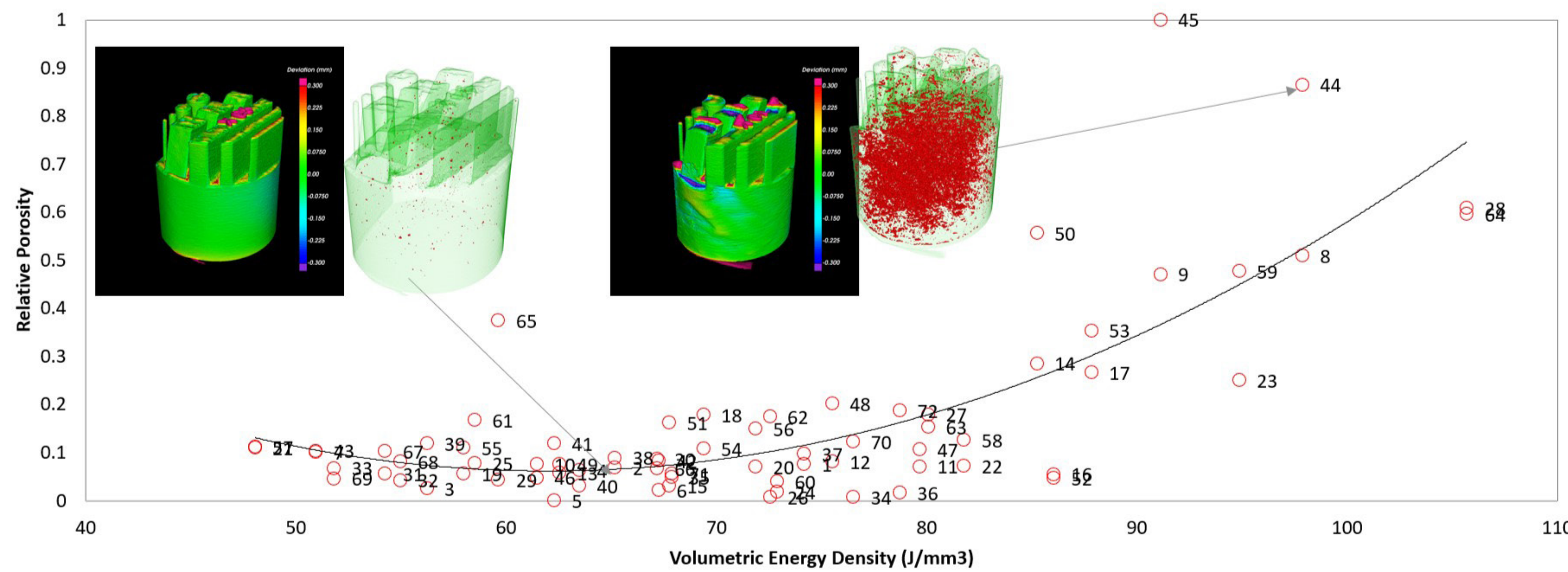


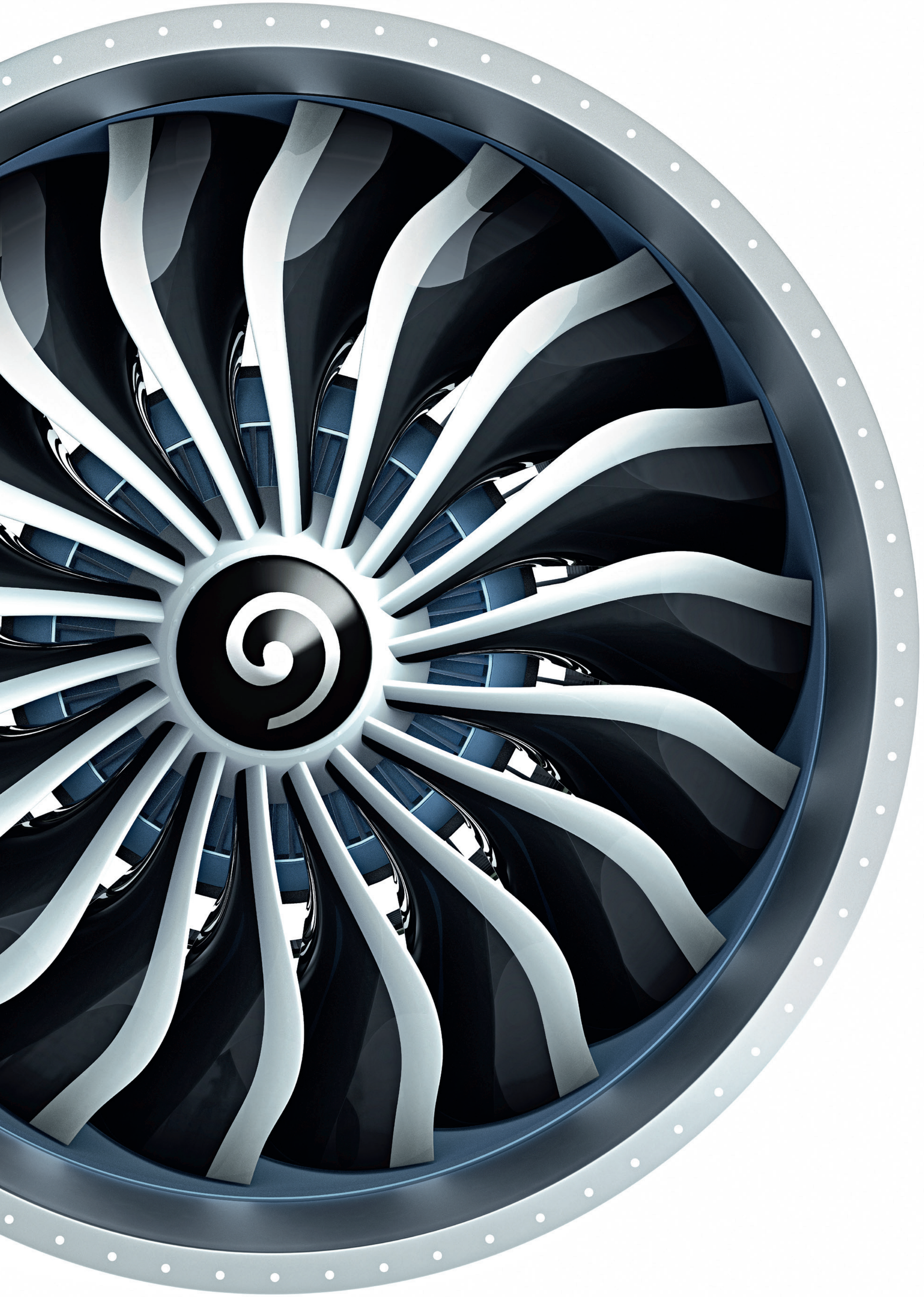






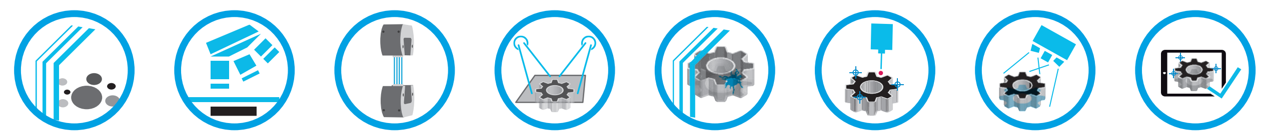
ZEISS AM parameter enables the users to rapidly qualify parameters in order to print faster with increased layer thickness, quickly refine parameters for various powder grades and degree of recycling, novel alloy development, build area qualification or laser performance mapping for multi-laser systems



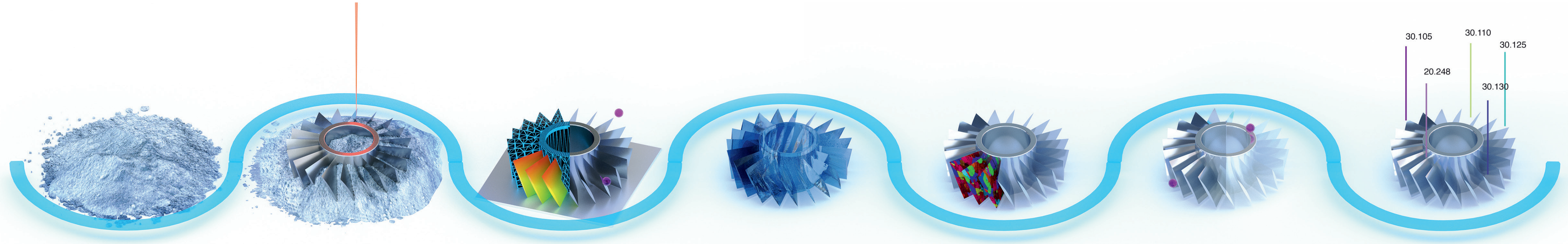


ZEISS AM Solutions

Increasing productivity with
the holistic solution from ZEISS.



ZEISS Additive Manufacturing Solutions



SEM, LM, X-ray CT | Powder Bed Inspection | CMM, 3D Scanning | X-ray CT, LM | SEM, LM, X-ray CT, 3D Testing | CMM, X-ray CT, 3D Scanning, LM | PiWeb, Analytics and Correlation Tools

Scanning Electron Microscope (SEM)

ZEISS Crossbeam
Research-grade FIB-SEM enabling nanoscale material removal and 3D tomography for EDS and EBSD investigations.

ZEISS GeminiSEM
High-performance FE-SEM with EBSD and EDS, enabling microstructural crystallographic characterization and powder analysis.

ZEISS EVO
Professional-grade SEM with EBSD and EDS, enabling efficient characterization of microstructures and elemental composition.

Light Microscope (LM)

ZEISS Smartproof 5
High-resolution and high-speed optical profilometer for detailed surface analysis.

ZEISS Smartzoom
With the digital microscope it is possible to view the sample from multiple directions while maintaining focus for speed and simplicity of use.

ZEISS Axio Imager
Microscope System for Automated Material Analysis – Introduce ease of operation into your microscopy workflow.

In-Process Powder Bed Inspection

ZEISS AM in-process
In-process monitoring for automatic analysis of powder bed defects and classification for quality assurance.

X-ray Computed Tomography (X-ray CT)

ZEISS Xradia Versa
High-resolution X-ray CT to support detail analysis of powders, surfaces, and structures with voxel size down to 500 nm (160 kV).

ZEISS METROTOM
High-accuracy X-ray CT to support dimensional verification and defect analysis of parts with complex internal and external structures (225 kV).

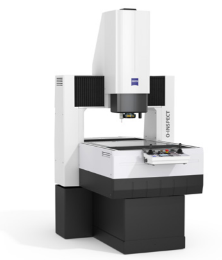
ZEISS VoluMax
High-speed X-ray CT to support automated dimensional verification and defect detection of mass production quantities (225 kV).

BOSELLO SRE MAX
High-power 2D X-ray inspection system able to penetrate large parts made from dense materials (450 kV).

ZEISS Xradia CrystalCT
Ground-breaking microCT for unlocking the crystallographic and microstructural secrets of your samples.

Coordinate Measuring Machine (CMM)

ZEISS DuraMax HTG
The compact shop floor CMM allows investigation of post-build processes, showing any influences on dimensional accuracy of finished parts.



ZEISS O-INSPECT
Multisensor measuring machine enables to optimally measure each characteristic in compliance with ISO-10360 – optically or by contact.

3D Testing

GOM ARAMIS
High-resolution 3D camera system for dynamic acquisition of 3D coordinates, 3D displacements and 3D surface strains.

3D Scanning

GOM ATOS Q
Full-surface measurements for precise and detailed 3D meshes for 3D printing, reverse engineering or component inspection.

ZEISS T-SCAN hawk
Portable, hand-held 3D laser scanner for confined spaces and hard-to-reach areas.

ZEISS Additive Manufacturing Solutions

Software

ZEISS ZEN core
Most comprehensive suite of imaging, segmentation, analysis, and data connectivity tools for multi-modal microscopy in connected material laboratories.

ZEISS CALYPSO
Universal metrology software with several options for special requirements. Measure standard geometries easily, quickly and reliably.

GOM Volume Inspect
All-in-one software for CT data. Visualize and inspect CT data with GOM Volume Inspect and gain highly precise information on the quality of your measurement objects.

GOM Inspect
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