2025

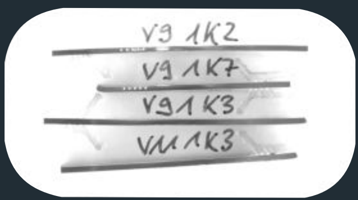
Applications

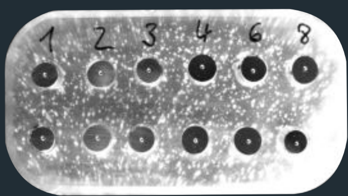
MATERIAL TESTING SOLUTIONS

Small Samples

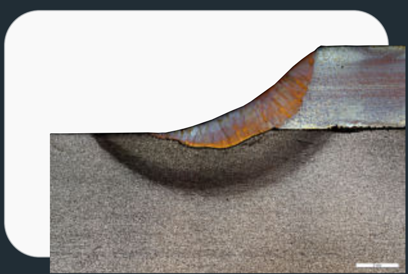
Ti-6Al-4Vi
Yield Strength 930 MPA
Tensile Strength 1180 MPA

Multisample Screening

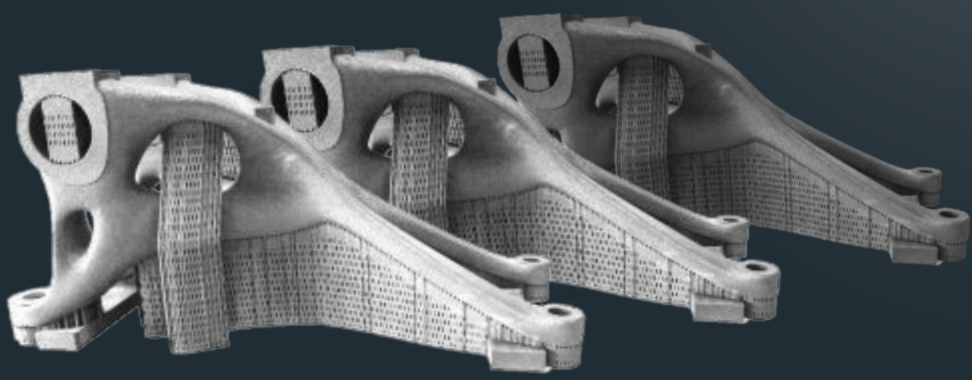


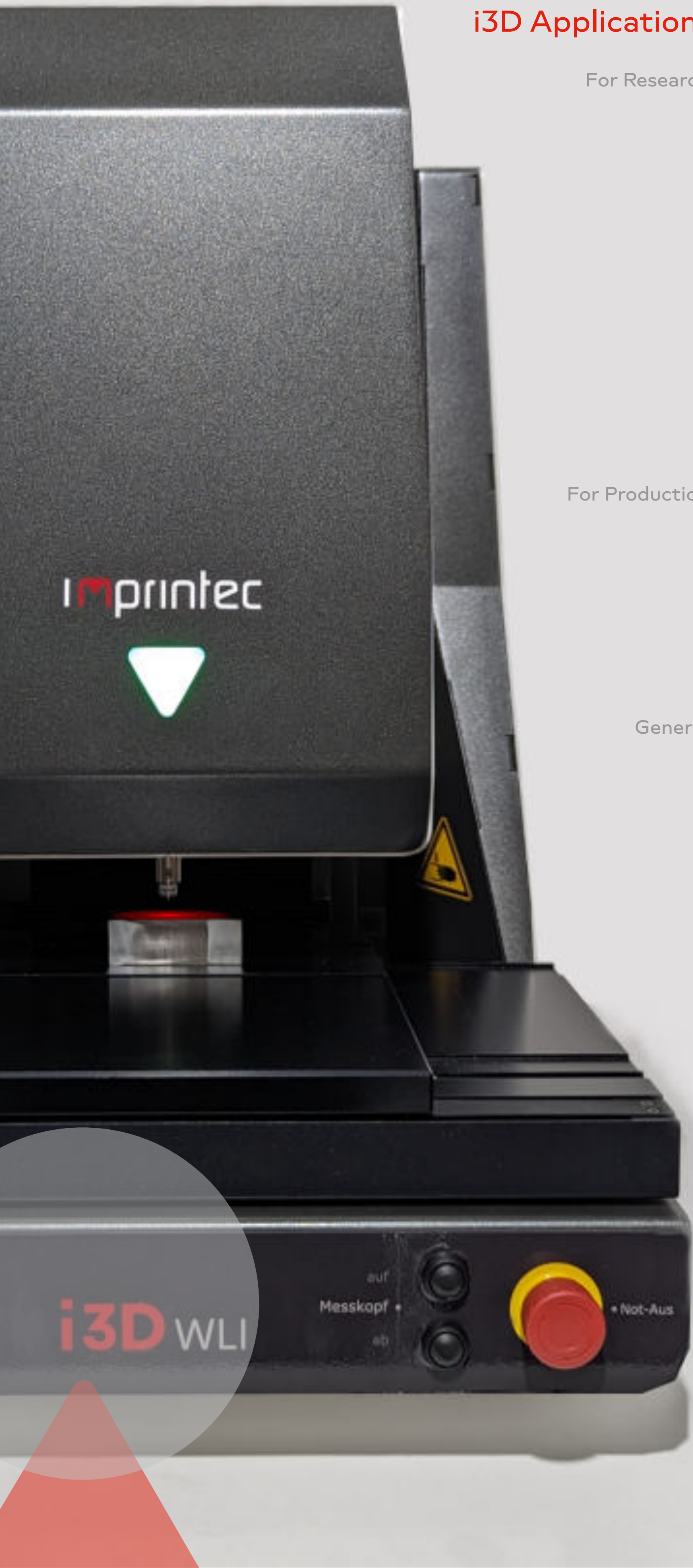


Welds



Testing on Parts





i3D Applications

For Research
- Multisample Screening
- Welds
- Screws
- High Temperature
- Data for FE Simulation
- Small Parts & Samples (Coming Soon)
- Coldforming (Coming Soon)
- Additive Manufacturing (Coming Soon)

For Production
- Inline Testing
- High-Throughput-Testing
- Comparison Tensile Test and i3D
- Testing on Parts (Coming Soon)

General
- Costs on Tensile Test vs. i3D

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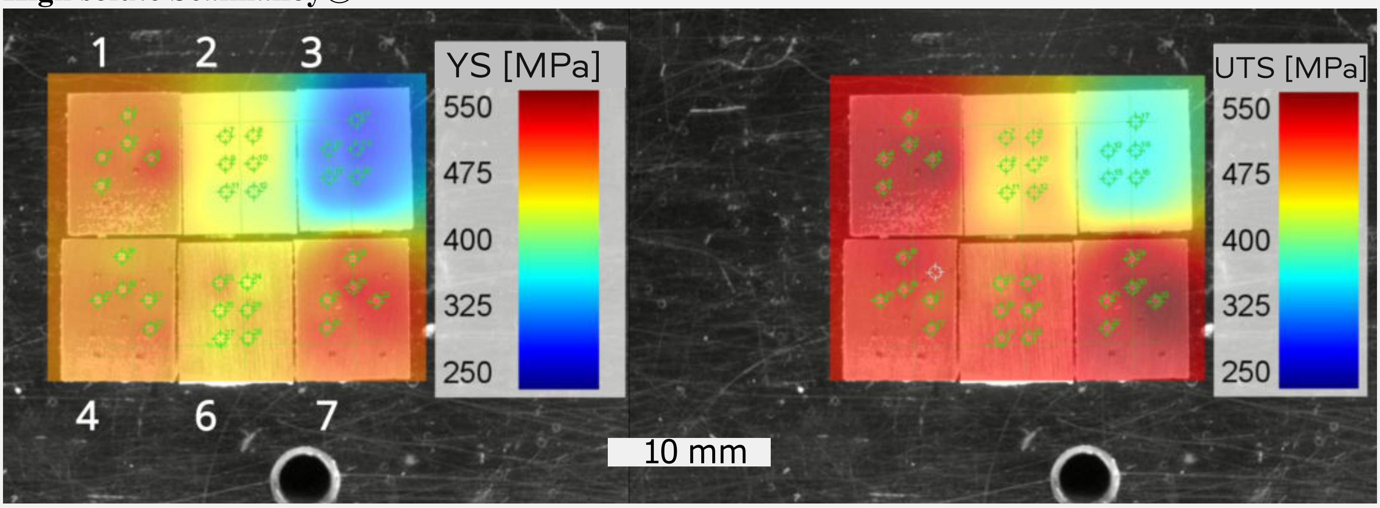
Multisample Screening with i3D on LPBF Samples (Scalmalloy®) - Comparison of Tensile Testing and Imprint Testing for Alloy Development

Abstract: Multisample screening or high-throughput testing with Imprint Test supports the development of alloys by quick determination of material data, especially in the field of additive manufacturing. In this study, 12 samples with a total number of 62 plastic stress-strain curves were automatically characterized within one hour. The samples (2 Scalmalloy® [AlMgScZrMn] variants) were printed as cubes and the measuring surface has been grinded with 800 grit. Furthermore, for the same print job the determined material properties from the Imprint Test were compared with corresponding tensile tests. The Imprint Test achieves a cost reduction of 70 to 90% compared to tensile testing for these measurements.

"Hence, the Imprint Test offers many new opportunities for fast (high-throughput) development as well as other quality assurance applications. The demonstrated approach for additively (LPBF) manufactured parts and materials is only one of those possibilities where it can be deployed successfully."

Frank Palm
Central Research & Technology
AIRBUS

High solute Scalmalloy®



Low solute Scalmalloy®

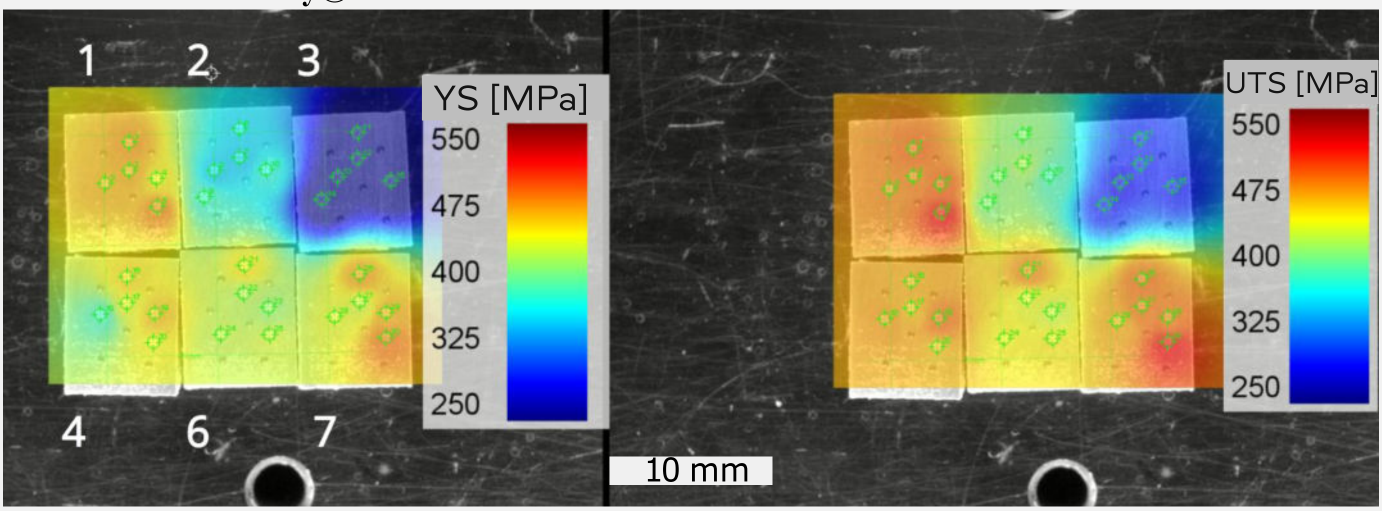


Fig.1: *Heat map of mechanical properties (yield strength and tensile strength) from the Imprint Test on 12 samples (Scalmalloy®)*

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Additive manufacturing processes like laser powderbed fusion (LPBF) are of growing interest for lightweight part production. This is primarily driven by an increasing need for sustainable and environmentally conscious product development. The LBPF manufacturing process involves layer-wise material addition, melting, and rapid solidification. This process implicitly allows for new material concepts especially for Aluminum alloys to be manufactured. Sc-modified AlMg-alloys ("Scalmalloy®") are a really good example of a material produced using this new direct manufacturing process.

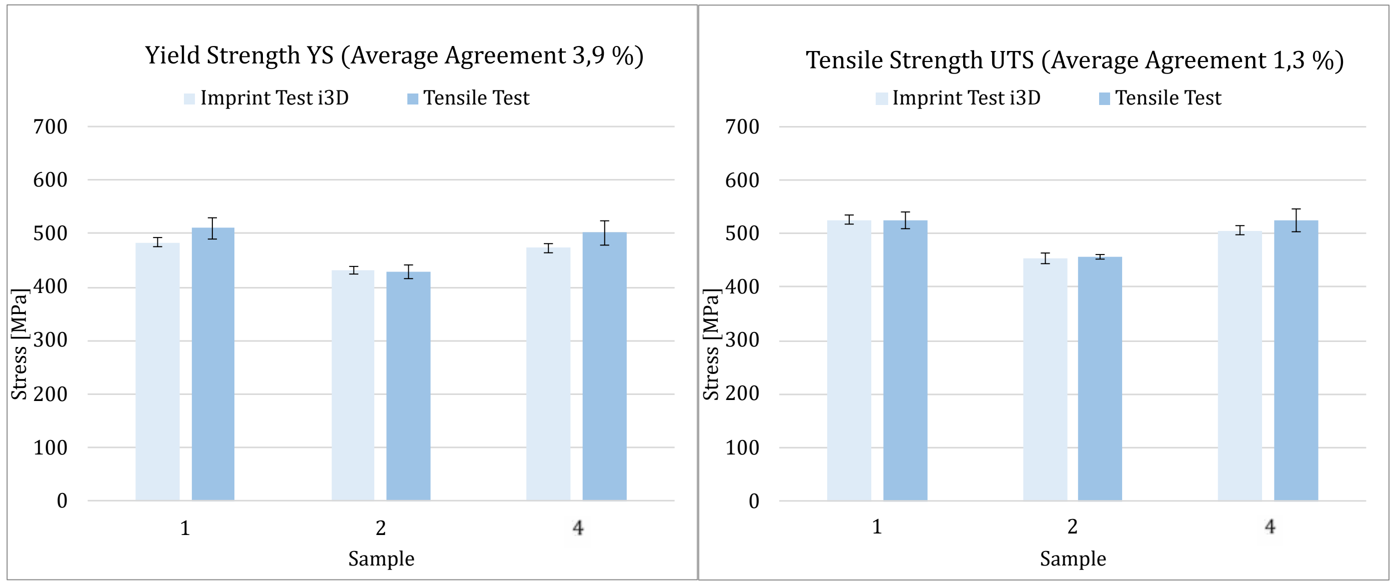
However, some inherent challenges for "3D printed" materials come from the complex interaction of the solidification microstructure with the final mechanical properties. These properties are determined by a selected post-manufacturing (LPBF) heat treatment. Unfortunately, such a material microstructure tailoring (to minimize residual stresses [due to solidification], optimize strength and ductility [precipitation hardening]) is challenging due to the LPBF process dynamics causing irregularities, imperfections (originating from the highly dynamic melting peculiarities, solidification rates, and boundary conditions). Aluminium alloys are susceptible to 3D-printing build defects such as solidification porosities (gas and shrinkage), fusion defects (bonding) due to oxide contamination and other microstructural inhomogeneities.

LPBF is a complex multi-parameter process that has to be accompanied by fast and reliable high throughput testing methods so as to find the "sweet spot" for manufacturing high-performance parts as well as assure the part integrity (absence of major defects in the 3D printed part). Standardized material evaluation with respect to strength and ductility and also in general from a quality assurance perspective is time-consuming and expensive. Traditional hardness tests like Brinell or Vickers have proven to be versatile with respect to global material strength, however, they lack providing reliable answers regarding the material's plasticity. It is also known from many tensile tests that elongation at fracture and necking are very sensitive to undesired LPBF build defects (material density < 99.5%) and correct or incorrect post LPBF heat treatments. Here, a technical extension of an established indentation test like Brinell with a force-controlled procedure, 3D image analysis combined with a hybrid-AI based algorithm (Imprint Test) can disclose new options to asses material properties (strength and ductility) quickly and accurately.

A study was conducted with 2 LPBF-generated Scalmalloy® (AlMgSZrMn) variants which was tested in different post-LPBF temper conditions. The high Sc content of the alloy remains almost completely in solid solution after 3D printing so that a precipitation hardening heat treatment taking the specific metallurgy of Al-Sc into account is possible. Depending on the temper conditions a diffusion-driven Sc decomposing is affecting a remarkable strength increase originating from Sc-enriched nano-sized cluster (1 - 2 nm) which culminates in an ordered ~ 4 - 6 nm sized, fully coherent intermetallic L12 - phase (Al3Sc(Zr)). At this peak-aged temper, the yield strength of the Scalmalloy® material is more than double compared to the "as printed" (soft) alloy while retaining good ductility. The mechanical properties evaluated using standardized tensile testing vs Imprint Test were compared and found to be successful (see Fig 1). Slight discrepancies were observed in the measured values for elongation at fracture from the tensile and predicted values from the

Imprint Test. On further evaluation, it was found that the tensile tests also showed a wide scatter in measured elongation at fracture. These scatter or deviations in the results can be mainly attributed to imperfections in the build material due to unstable LPBF process parameters. Such differences are instantly visible as fluctuations in the elongation at fracture on evaluated plastic stress-strain curves from the Imprint Test, thereby accurately reproducing the scatter. Furthermore, the determined stress-strain curves evaluated from the Imprint Test trials on separate heat-treated test cubes fit quite well (within sufficient material sensitivity) to the real tensile test results (see Fig.2).

High solute Scalmalloy®



Low solute Scalmalloy®

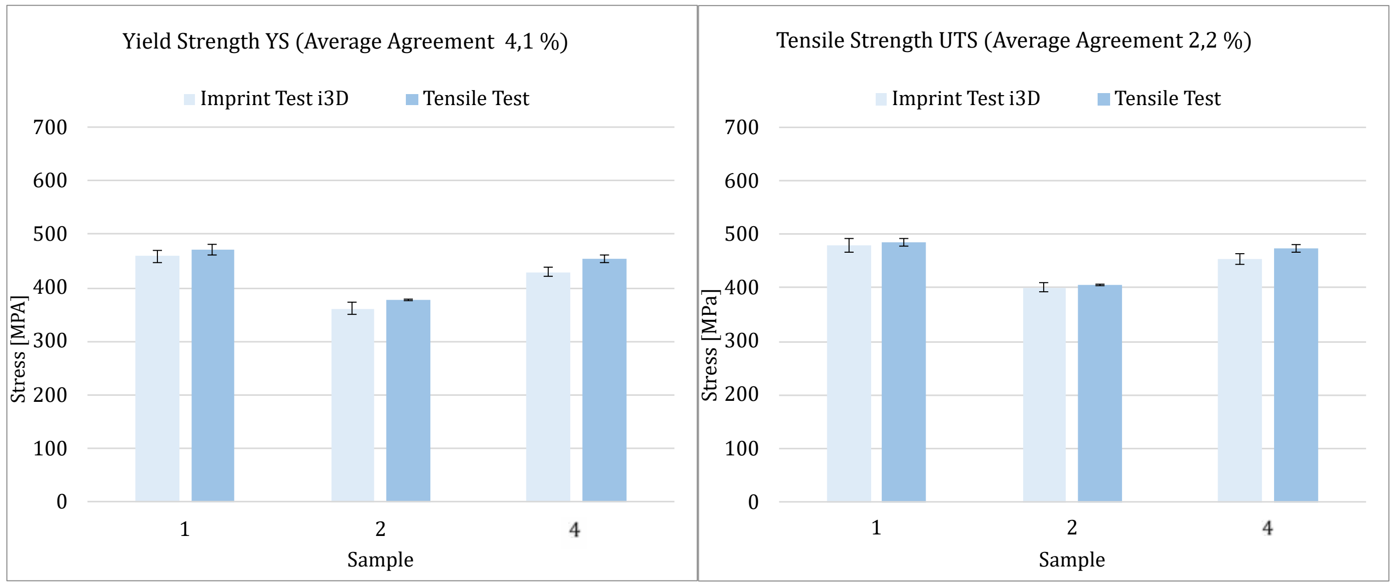


Fig.2:*Comparison between Imprint Test and tensile testing results on yield strength and tensile strength on samples 1,2 & 4 from 2 Scalmalloy® variants.*

29.12.2023

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Mechanical Testing on Welds with i3D

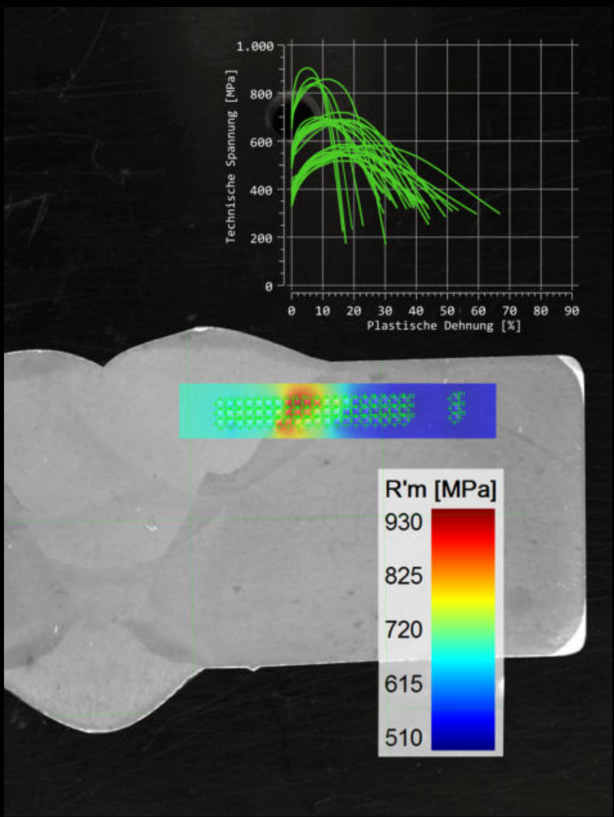

Fig.: Contour Plot of Ultimate Tensile Strength on Weld

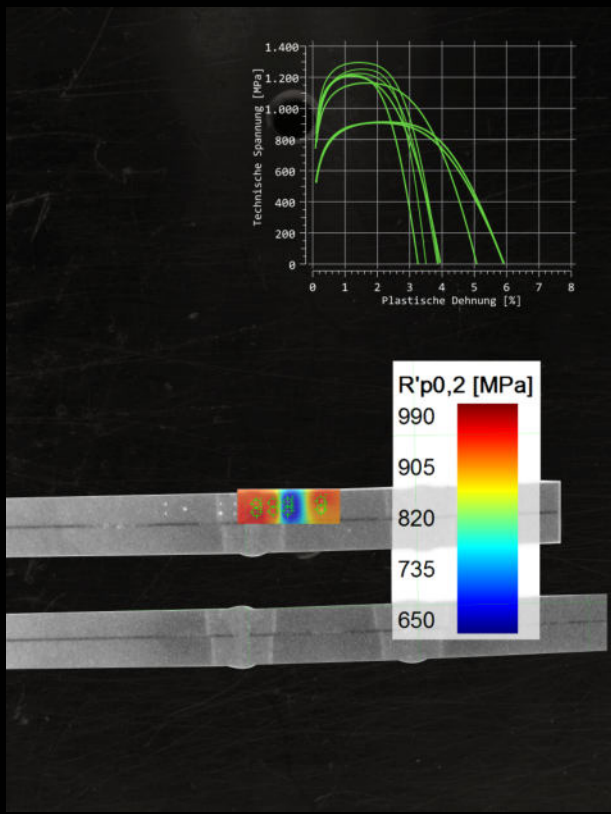

Fig.: Contour Plot of Yield Strength on Weld

The imprint testing method, as defined in DIN SPEC 4864, provides a unique, non-destructive approach to characterizing mechanical properties directly within the real component. Unlike conventional tensile testing, which requires standardized samples, this method allows for localized strength analysis at previously inaccessible or critical points on the actual part.

By generating a small, controlled indentation (typically only a few microns deep), the procedure extracts a full stress-strain curve, enabling precise determination of key parameters such as the yield strength (YS), ultimate tensile strength (UTS), strain hardening behavior, and ductility.

Compared to hardness testing, which often relies on empirical correlations, imprint testing delivers higher reliability and resolution with respect to mechanical behavior – especially in complex or non-homogeneous materials. It is particularly advantageous in applications where traditional destructive testing is not feasible or would compromise part integrity.

Moreover, the spatial resolution of the method enables mapping of property gradients – for example, across welds, heat-affected zones, or near-surface treatments – offering engineers powerful insights for quality control, material development, and failure analysis.

This makes imprint testing a cost-efficient, insightful, and highly versatile alternative to conventional mechanical testing methods.

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More Examples on mechanical Testing on Welds with i3D

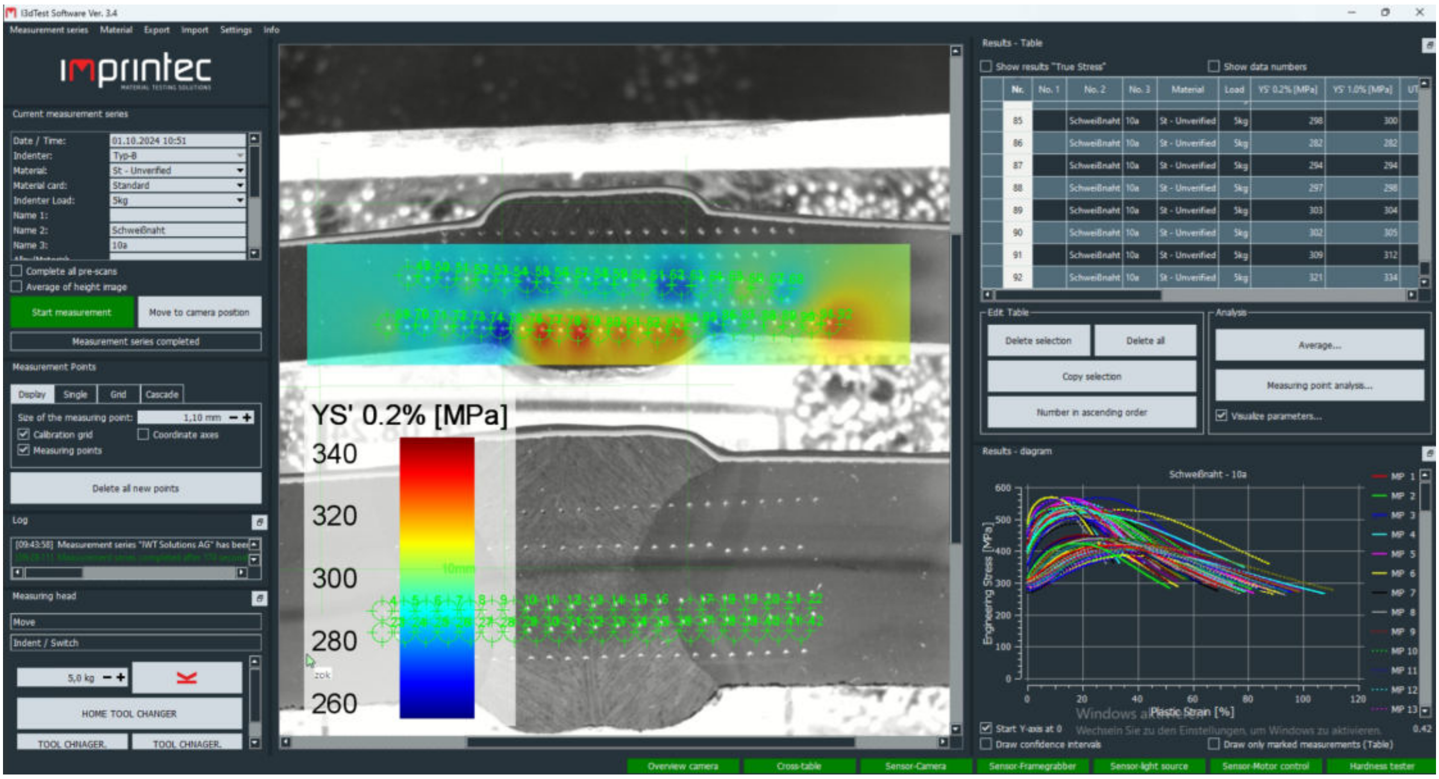


Fig.: Contour Plot of Yield Strength on Weld from i3D User Interface

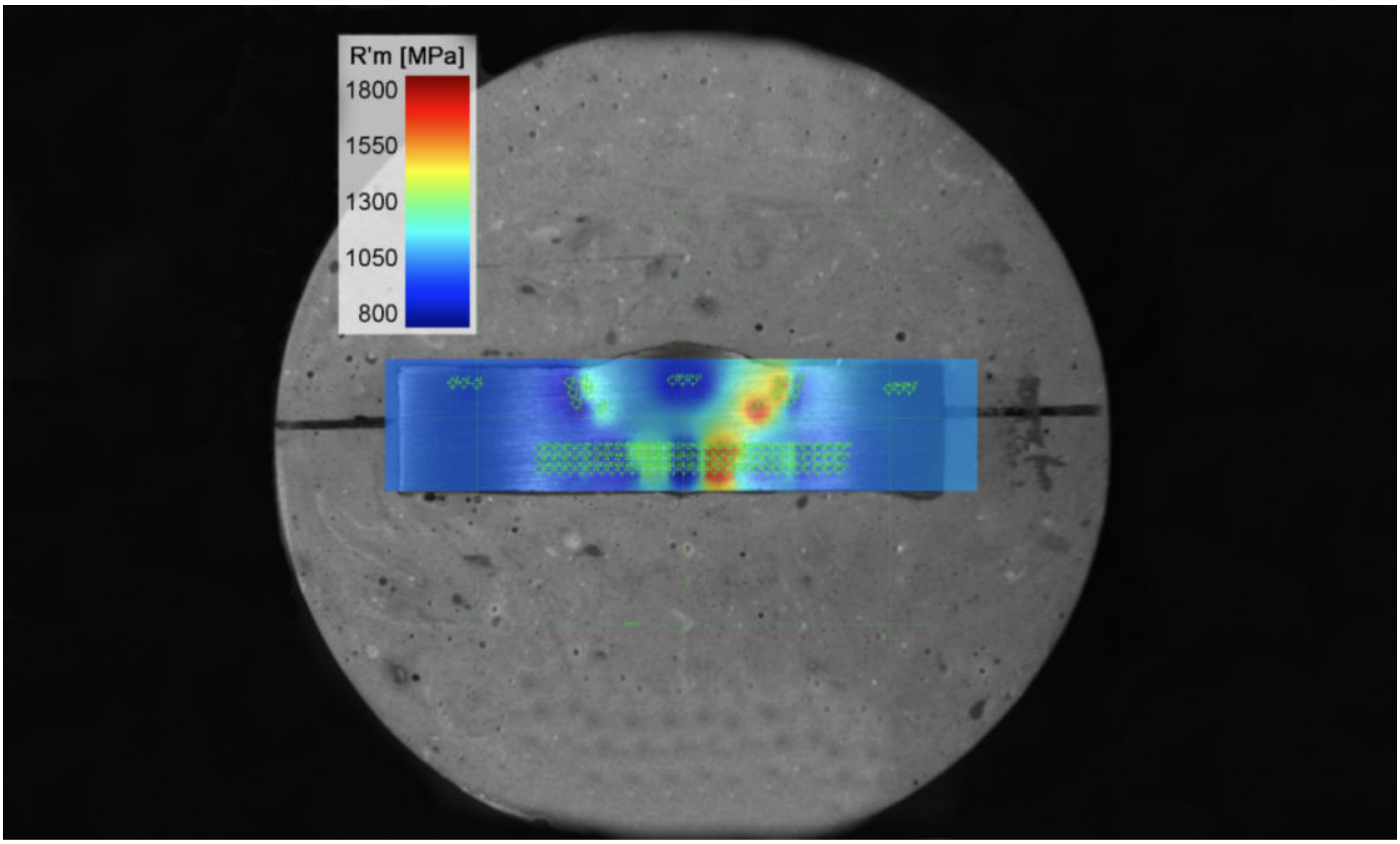
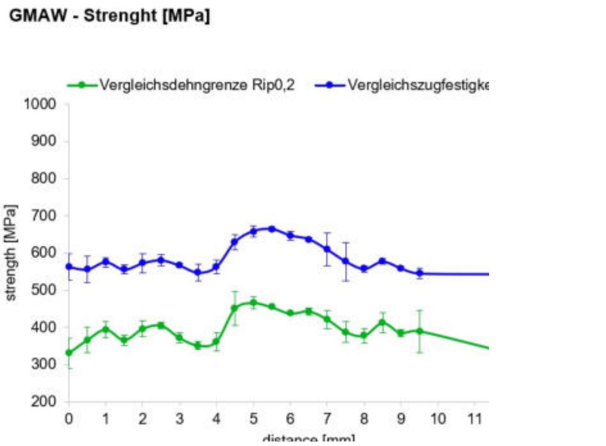
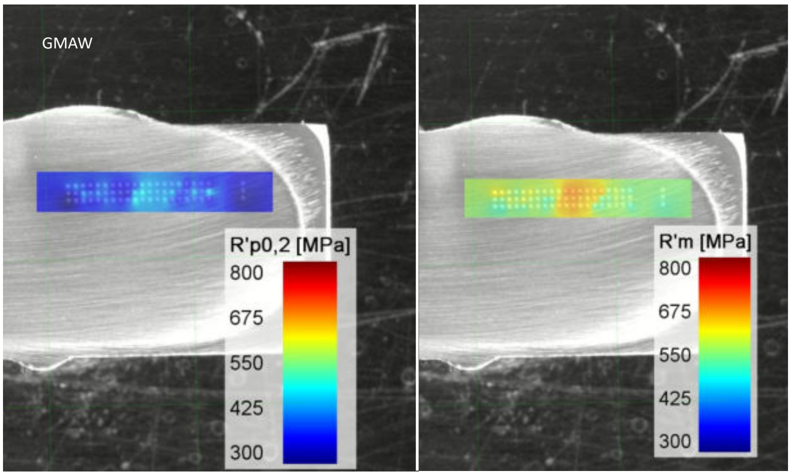
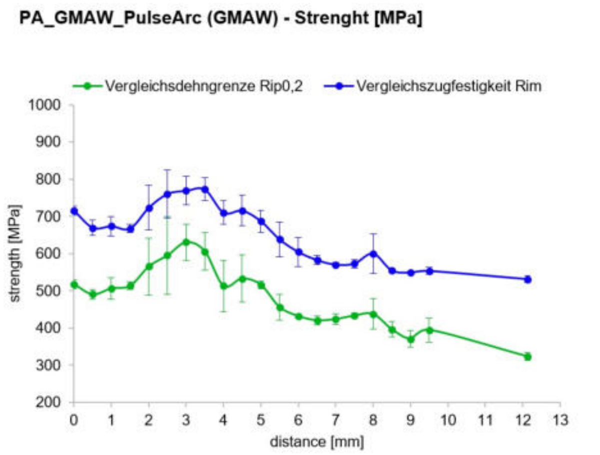


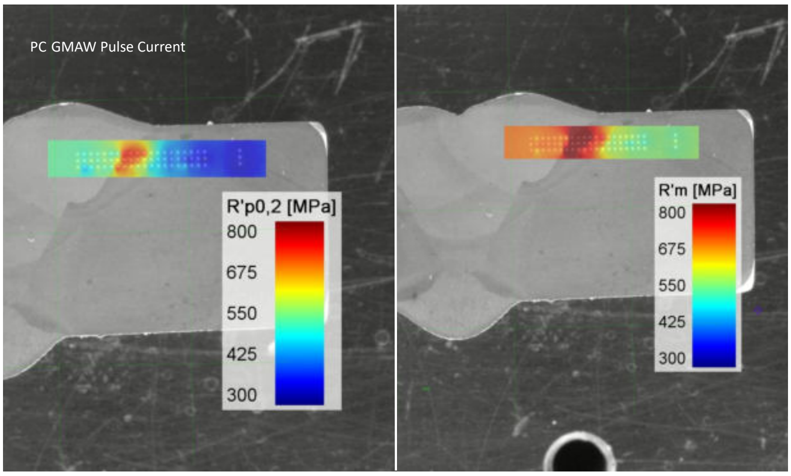
Fig.: Contour Plot of Ultimate Tensile Strength on Weld from Overview Camera from i3D WLI

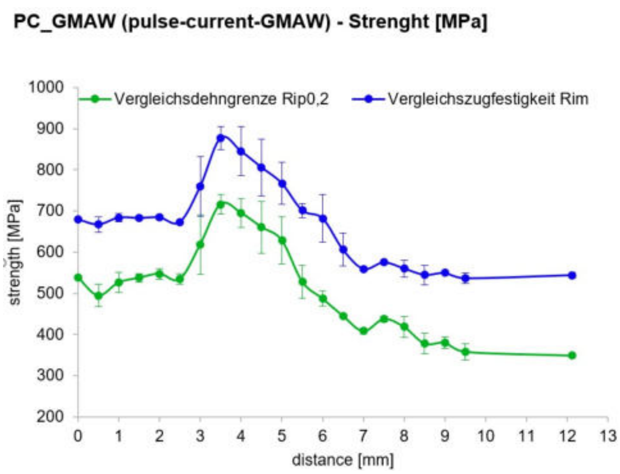
More Examples on mechanical Testing on Welds with i3D

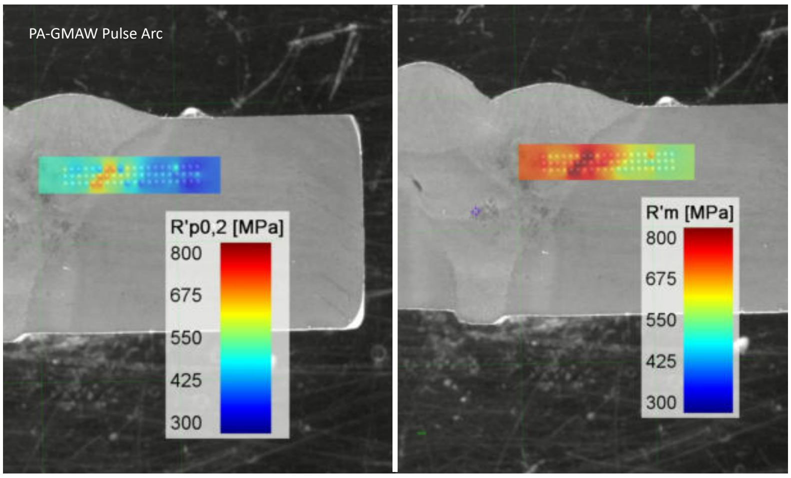


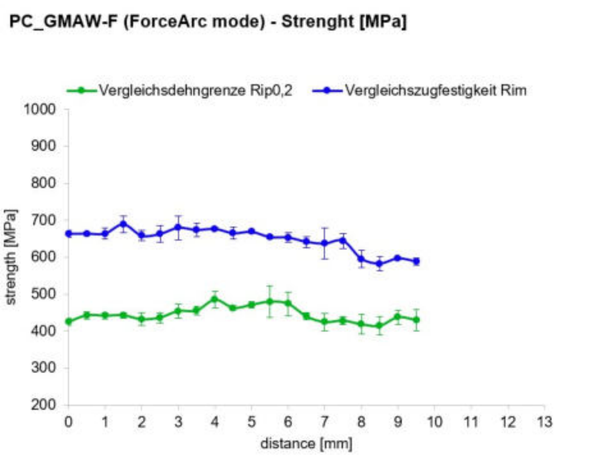












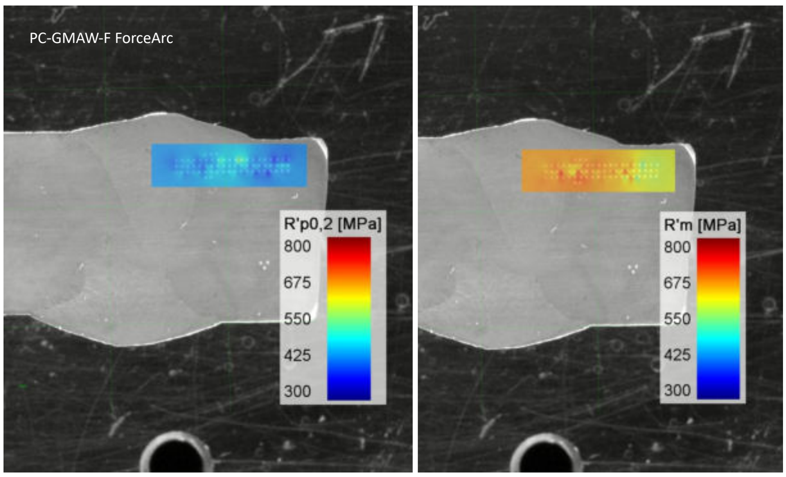


Fig.: Contour Plot and Diagramms of Yield Strength ($R'_{p0,2}$ - German Declaration) and Tensile Strength (R_m - German Declaration)

A. Zavdoveev, P. Zok, V. Pozniakov, M. Rogante, T. Baudin, M. Heaton, A. Gaivoronskiy, S. Zhdanov, P. Acquier, T. Solomijchuk, V. Kostin, M. Skoryk, I. Klochkov & S. Motrunich

Mechanical Testing of Screws with the Imprint Method

The imprint method offers a non-destructive way to evaluate the mechanical properties of screws and similar components directly on the finished part — without cutting, machining, or preparing standard specimens.

This innovative technique provides localized stress-strain curves, enabling precise determination of:

- Yield strength from indentation ($R^I_{p0.2}$ - Vergleichsdehngrenze zum Zugversuch in German Declaration)
- Ultimate tensile strength from indentation (R^I_m - Vergleichszugfestigkeit zum Zugversuch in German Declaration)
- Ductility
- Strain hardening characteristics

Unlike traditional hardness testing, the imprint method delivers quantitative and reliable mechanical data, even for materials like austenitic steels, where standard hardness-to-strength conversions often fail. Compared to tensile testing, it enables cost-efficient and spatially resolved analysis, ideal for critical zones such as thread roots, weld seams, or surface-treated areas.

This makes the method particularly valuable for quality assurance, failure investigation, and material development, where preserving the component is essential. It opens new possibilities in validating mechanical performance — even in areas previously inaccessible to conventional testing methods.

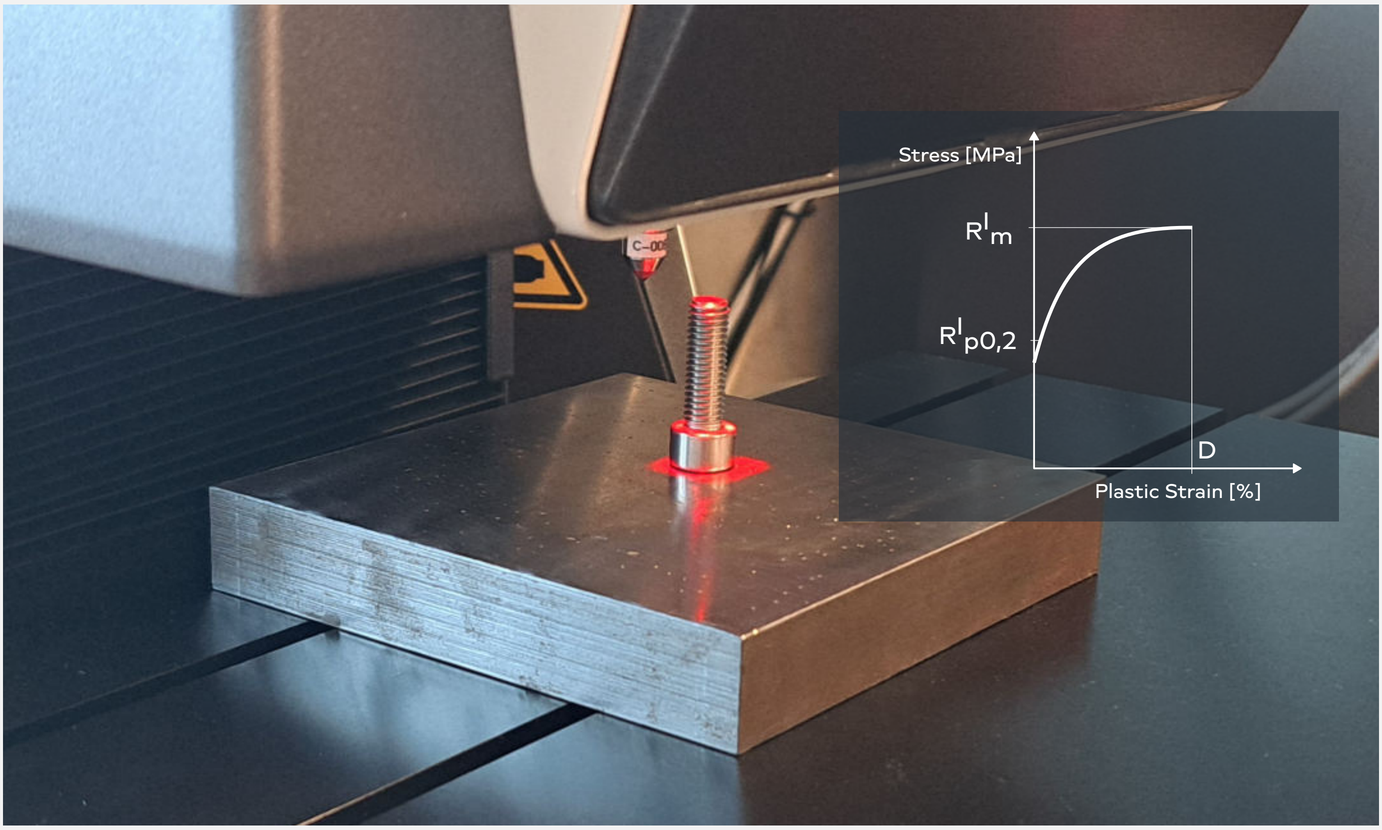


Fig.: Mechanical Screw Testing on i3D WLI

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Practical Insight into Mechanical Testing of Screws

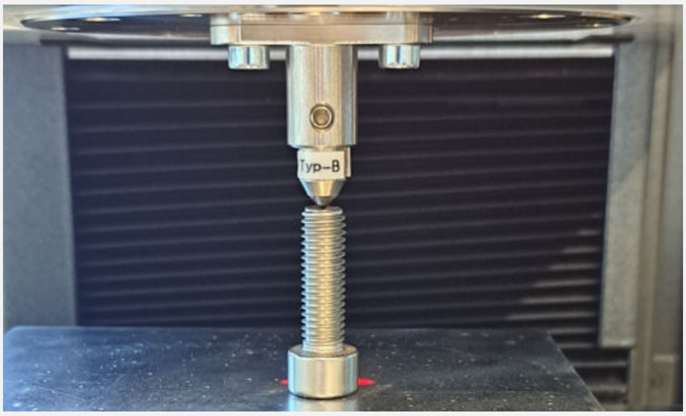

Fig.: Indentation into Screw with i3D WLI

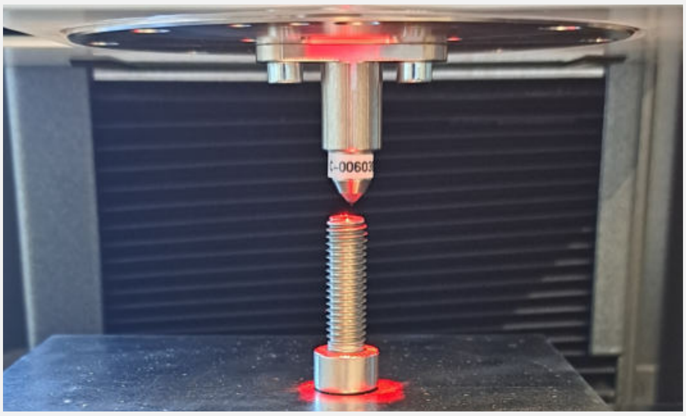

Fig.: Optical 3D Measurement with i3D WLI

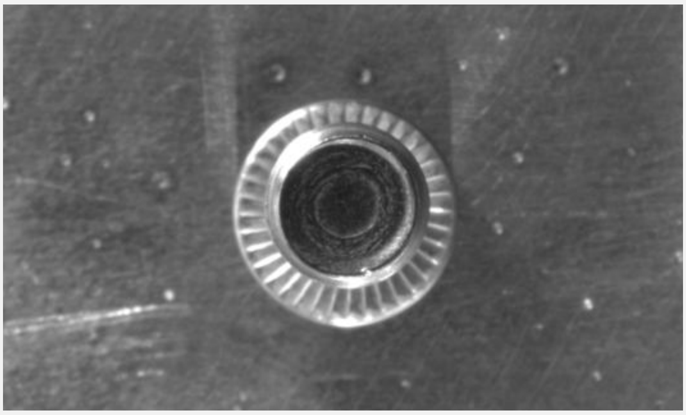

Fig.: Screw before Testing

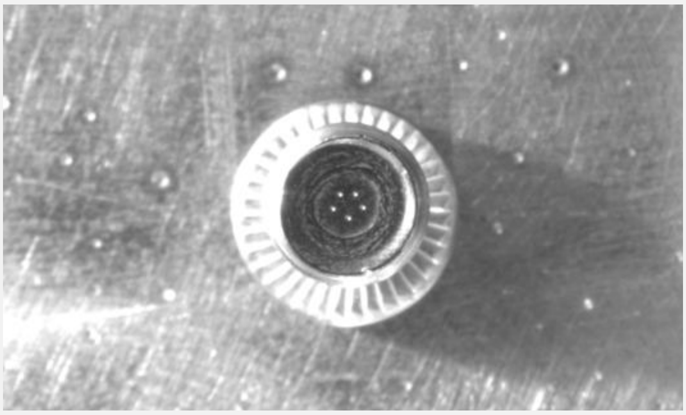

Fig.: Screw after Testing

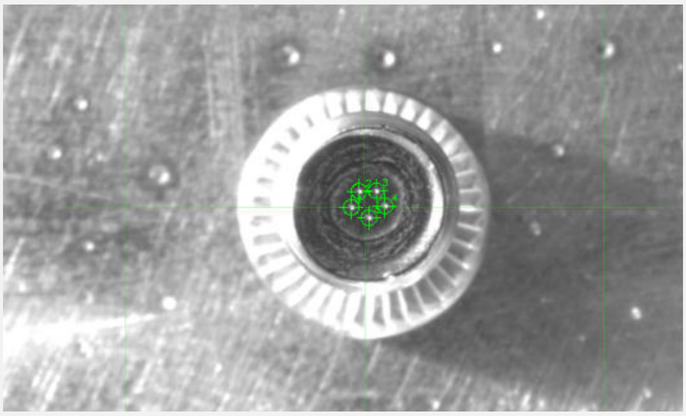

Fig.: Screw after Testing with marked Indents

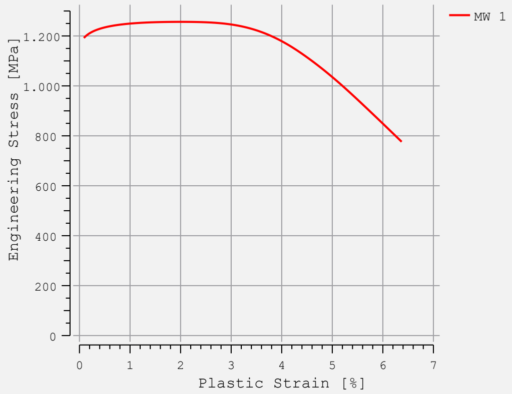

Fig.: Averaged Stress Strain Curve from 5 Indents

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Insight High-Temperature Stress-Strain Analysis with the i3D Module

The i3D module now enables stress-strain curve measurements at elevated temperatures, opening up new possibilities for material characterization under realistic thermal conditions. Ongoing developments have successfully extended the method to temperatures of 400 °C and beyond, with recent tests demonstrating excellent correlation with conventional tensile test data.

These measurements allow for localized, non-destructive mechanical analysis even at high operating temperatures - a key advantage in sectors such as aerospace, energy, and high-performance engineering. The method captures changes in yield strength, strain hardening, and ductility under thermal load, helping engineers better understand creep behavior, temperature-dependent material limits, and design safety margins.

Further developments are currently underway to extend the usable temperature range to above 1000 °C, offering insight into the mechanical performance of metals and alloys at extreme service conditions. These advancements mark a significant step in combining precision testing with real-world thermal environments.

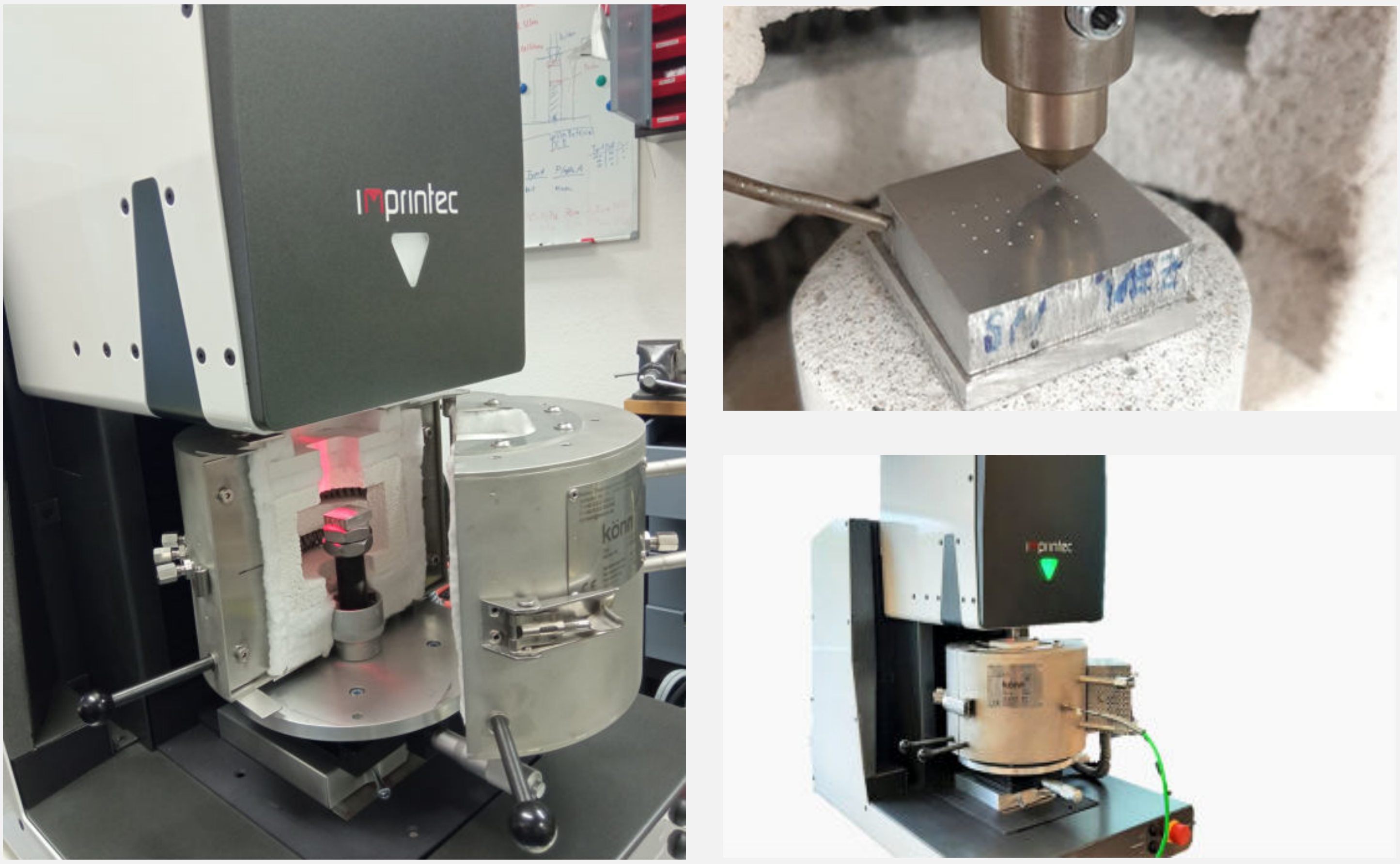

Fig.: High Temperature Module for i3D

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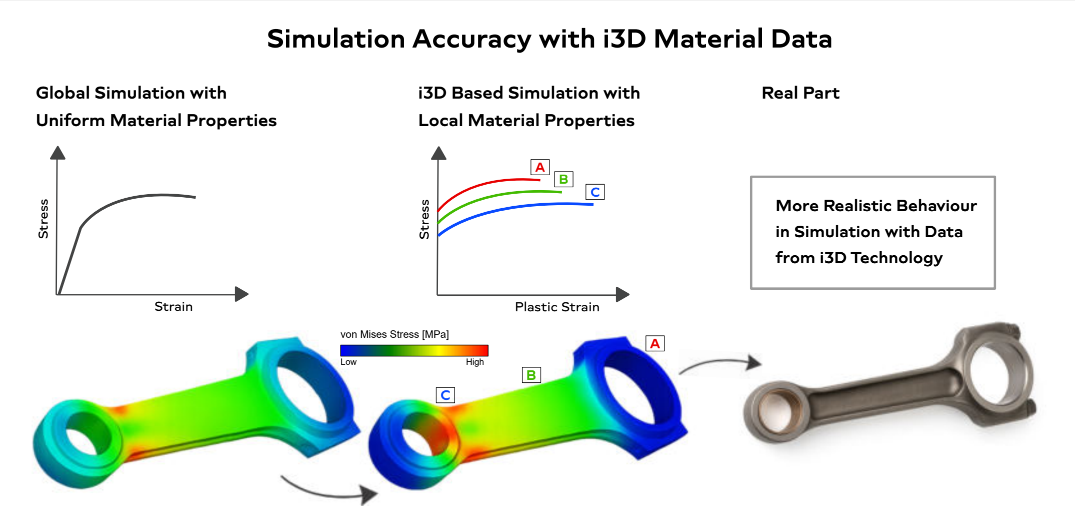
Enhanced Material Simulation with i3D Technology



Application Example: Rod Simulation

In the example shown, a connecting rod is simulated using two different material models:

- Global Simulation (left) – using a single, uniform stress-strain curve
- i3D-Based Simulation (center) – using locally resolved curves based on measured material variation.

While the global model assumes identical mechanical behavior across the rod, the i3D-based model captures spatial variation—e.g., lower yield strength near the pin bore (label C), medium performance in the shaft (B), and higher strength near the bolt region (A).

This results in a simulation that better predicts real part behavior. Combined with the actual component geometry and loading conditions, it enables improved design decisions, virtual optimization, and reduces the need for physical testing.

In conventional simulation workflows, material behavior is typically described using uniform mechanical properties derived from classical tensile tests. These global stress-strain curves are then applied to entire components—assuming homogeneity throughout the material. While this method offers simplicity, it fails to reflect the true local variations caused by factors such as:

- wall thickness gradients,
- core-shell structure differences,
- or manufacturing effects (e.g., heat treatment, forming).

This limitation leads to inaccuracies in the prediction of stress distribution, deformation, and failure.

How i3D Technology Improves This

The i3D-Imprint Test enables precise, location-specific mechanical characterization using a miniature indentation method. Instead of deriving only global curves, it generates local plastic stress-strain curves at multiple points across the part. These curves are then used as direct input for FEA simulations, enabling:

- highly localized material modeling,
- realistic stress and strain distribution predictions,
- more reliable virtual validation of parts under load

Customer Benefit

“i3D empowers engineers to simulate what actually happens inside a part—not just what they assume.”

With i3D, your simulation reflects reality.

Efficient High-Throughput Testing with i3D Technology

Traditional tensile testing is often time-consuming and expensive, especially when analyzing a high number of samples during process development or quality assurance.

The i3D method offers a powerful alternative — enabling fast, non-destructive, and process-near mechanical testing directly on the component. This allows for:
- Accelerated material characterization
- Effective quality assurance
- Significant reduction in scrap rates
- Time and cost savings, especially when evaluating different heat treatment conditions
- Rapid iteration of process parameters

As shown in the example, the i3D method can reduce the overall testing time from 72 to just 4 hours, and cut costs per measurement by over 90%. At the same time, testing throughput increases nearly fourfold, allowing for faster decision-making and process optimization. This makes the method ideal for industrial environments requiring fast and reliable feedback, such as in automotive sheet metal production or component heat treatment validation.

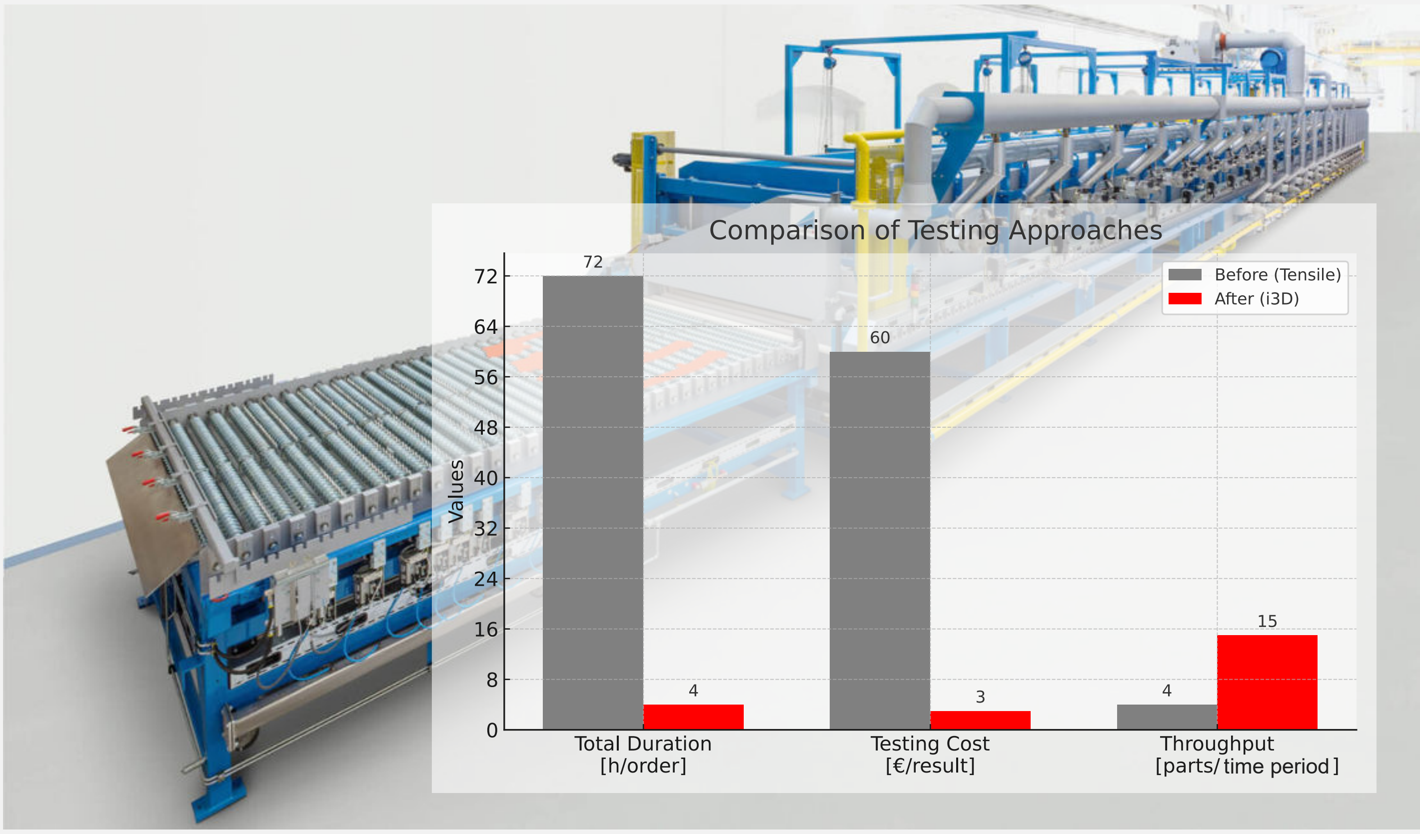
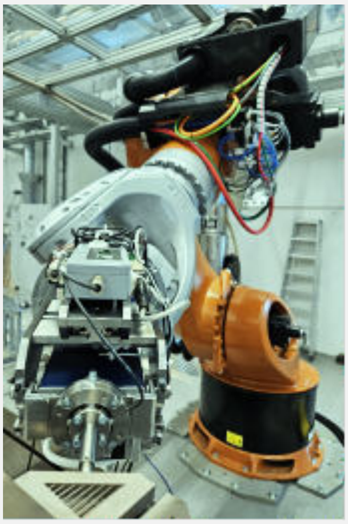


Fig.: Comparison between Tensile Testing and Imprint Test with i3D

Innovative Quality Assurance for Complex Metal Components



This advanced, minimal-destructive quality assurance approach enables the mechanical characterization of metal components directly on the part - regardless of the manufacturing process. Originally developed as part of the Enabl3D project, the methodology is highly adaptable and ideal for production environments requiring detailed insight into material performance without compromising the integrity of the part.

Core Elements of the Approach:

- Imprint Testing (DIN SPEC 4864): Delivers local, stress-strain curves directly on the part, allowing for precise evaluation of yield strength, tensile strength, strain hardening, and ductility. Particularly useful for components with complex geometries or in cases where traditional destructive testing is not feasible.

Benefits for Industrial Production:

- Suitable for a wide range of materials and manufacturing methods — from casting to forming and more.
- Reduces scrap and rework through early defect identification.
- Enhances process transparency and product reliability.
- Enables rapid iteration of process parameters and faster quality loops.

This method offers manufacturers a powerful, cost-efficient tool for ensuring structural integrity and optimizing process efficiency — right from the shop floor.

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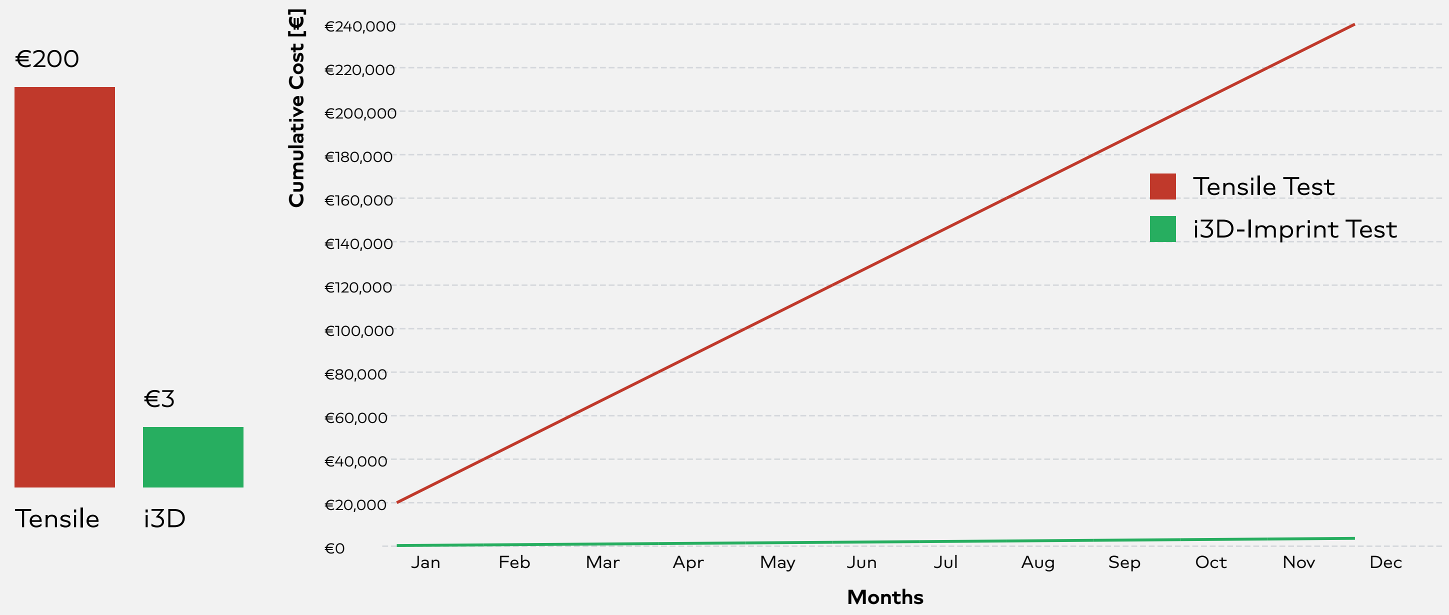
Efficiency Comparison – Tensile Test vs. i3D-Imprint Test (DIN SPEC 4864)

Cost per Stress-Strain Curve & and Yearly Progress with 100 Stress-Strain Curves per Month



Traditional tensile testing remains the most common method for mechanical material characterization. However, it comes with considerable limitations in terms of cost, speed, and local resolution:

Criterion	Tensile Test	i3D-Imprint Test (DIN SPEC)
Typical cost per test	€40–250	€0,5-3
Sample preparation	Machined tensile bar (laborious)	None or minimal
Location resolution	Global (1 per test)	Local (multiple points per part)
Throughput	0,5–4 tests/hour	1 stress-strain curve/min
Machine investment	Tensile tester + extensometer	i3D testing device
Suitability for complex parts	Low (needs standard geometry)	High (works on real geometry)

Cost-Efficient Material Characterization

With i3D, generating **a full plastic stress-strain curve at a cost of around €0,5-3** per location becomes feasible—even for smaller budgets or high-volume testing strategies. Because the method requires only a small indentation and surface measurement, sample prep and logistics are minimal.

In contrast, tensile testing involves:

- Cutting out specimens, - Machining them to standard dimensions, - Mounting in large equipment, - Often destroying valuable parts. This means each tensile test comes with both high direct cost and long turnaround times.

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