Gefördert durch:

Bundesministerium
für Forschung, Technologie
und Raumfahrt

imprintec
MATERIAL TESTING SOLUTIONS

WHITE PAPER | ADDITIVE MANUFACTURING | MATERIAL QUALIFICATION | INDENTATION PLASTOMETRY

i3D® Indentation-Based Evaluation of Laser Powder-Bed Fusion (L-PBF) Print Parameters of AlMg-Alloy

A faster, minimally invasive route to mechanical property mapping
Worked example: **AlMgTy®70**

AlMgTy®70 (Al–Mg powder): Mg 7–9 wt.%; Si, Fe <0.1 wt.%; Cu, Mn, Zn <0.05 wt.%; Ti 0.011–0.5 wt.%; balance Al

Adithya Kalliath*, Dr.-Ing. Karl-Heinz Lindner, Dr.-Ing. Benjamin Schmaling, Saskia Siegert

Imprintec GmbH, Konrad-Zuse-Straße 18, 44801 Bochum, Germany | *Corresponding author: kalliath@imprintec.de

Executive summary. In laser powder-bed fusion (L-PBF), mechanical properties depend strongly on the chosen print parameters — principally laser power and scan speed. Qualifying a parameter window conventionally requires extensive tensile testing campaigns that are slow, costly, destructive and material-intensive. Imprintec's i3D® indentation technology determines yield strength ($R_{p0,2}$) and tensile strength (R_m) from simple, minimally prepared cube specimens — in conformance with DIN SPEC 4864 and ASTM E3499 — enabling the full laser-power × scan-speed space to be mapped from a fraction of the specimens. Using AlMgTy®70 as a worked example, this paper shows how i3D® turns print-parameter evaluation into a high-throughput screening step, cutting cost, CO_2 and lead time by factors of roughly 20x, 25x and 5x respectively versus conventional tensile testing.

1. Why print-parameter evaluation is the bottleneck for AM Production?

The advantages of additive manufacturing (AM) — design freedom, efficient material use and lower CO_2 than casting are well established. Yet qualifying an AM part still hinges on the print parameters. The L-PBF process melts and re-solidifies each layer under a moving melt pool, and if laser power, scan speed, hatch spacing or layer thickness are not properly balanced the result is porosity, lack-of-fusion defects and build-direction anisotropy. These directly govern $R_{p0,2}$ and R_m.

Establishing the parameter set that reliably delivers the required properties therefore demands a broad experimental matrix. Done conventionally, each point in that matrix consumes a machined tensile specimen and a destructive test — multiplied across power levels, scan speeds and build orientations. The campaign is expensive, time-consuming and discards the very material it characterises. This is the bottleneck that limits how thoroughly a process window can be explored before production.

2. The i3D® indentation method

The i3D® method is a minimally invasive, indentation-based alternative to the tensile test. A diamond spheroconical indenter tip is pressed into a minimally prepared specimen under a defined, force-controlled load, and the three-dimensional residual impression left behind is measured by optical profilometry (white-light interferometry).

From imprint to properties — inverse analysis by optimization. The mechanical properties are recovered by an inverse finite-element (FE) analysis driven by optimization [1]. A finite-element model simulates the indentation for a trial set of elastic–plastic material parameters and predicts the residual-imprint profile those parameters would produce. An optimization algorithm compares this simulated profile against the measured one, quantifies their deviation as an error metric, and then iteratively adjusts the material parameters. When the simulated imprint matches the measured imprint to within tolerance, the parameters of that best-fit simulation are accepted as representative

of the tested material, and the engineering properties — yield strength ($R_{p0,2}$), tensile strength (R_m) and uniform elongation (A_g) — are derived from them. The method conforms to **DIN SPEC 4864** [2] and **ASTM E3499** [3].

Because it needs only small, cube-shaped coupons rather than machined tensile bars, and because each measurement is fast and non-destructive, the method can sample many points — across parameter sets, build directions and even within a single specimen. For parameter evaluation the consequence is direct: instead of one destructive test per parameter point, a single cube can be probed at several locations and in several directions, so the mechanical property response across the parameter space can be mapped and the favourable window identified without an exhaustive tensile matrix.

3. Worked example: evaluating print parameters for AlMgTy®70

AlMgTy®70 is a high-strength aluminium–magnesium alloy (nominal 7–9 wt.% Mg, balance predominantly Al). The manufacturer's as-built reference values frame the target window (Table 1). For the evaluation, cubes were printed across a representative process window — laser power from 125 to 300 W and scan speed from 400 to 800 mm/s, with hatch spacing and layer thickness held constant. Within this window, nine parameter sets spanning 150–275 W and 400–800 mm/s were evaluated, and each cube was probed with i3D® in three orientations: the build direction (BD) and two perpendicular directions (PBD1, PBD2), as illustrated in Figure 1.

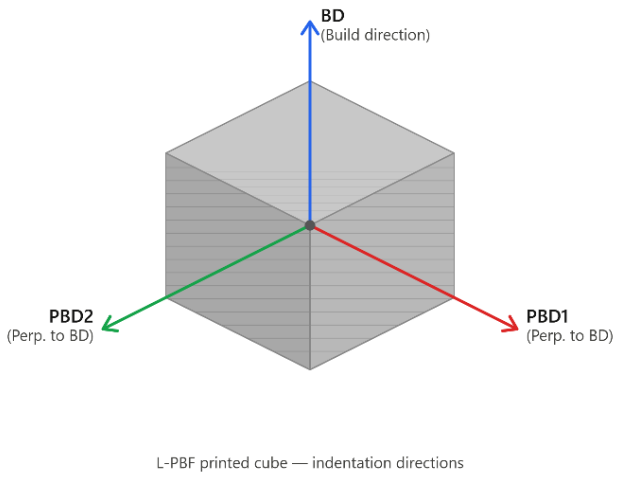


Figure 1. The three i3D® indentation orientations on an L-PBF cube: the build direction (BD) and two directions perpendicular to it (PBD1, PBD2).

Table 1. AlMgTy®70 reference frame (manufacturer as-built data).

Property	Basis	Reference	Note
Composition (Mg)	nominal	7–9 wt.%	balance predom. Al
$R_{p0,2}$ (yield)	as-built	≤ 180 MPa	datasheet upper bound
R_m (tensile)	as-built	≥ 300 MPa	datasheet lower bound
Build orientations	indentation	BD, PBD1, PBD2	3 directions per cube

Mapping the indentation-derived properties over the laser-power $\times$ scan-speed grid produces a response surface for each property and direction (Figure 2). Such maps give an at-a-glance view of how $R_{p0,2}$ and R_m respond across the window and reveal the parameter combinations that deliver favourable property pairs — the kind of insight that would otherwise require testing every combination individually.

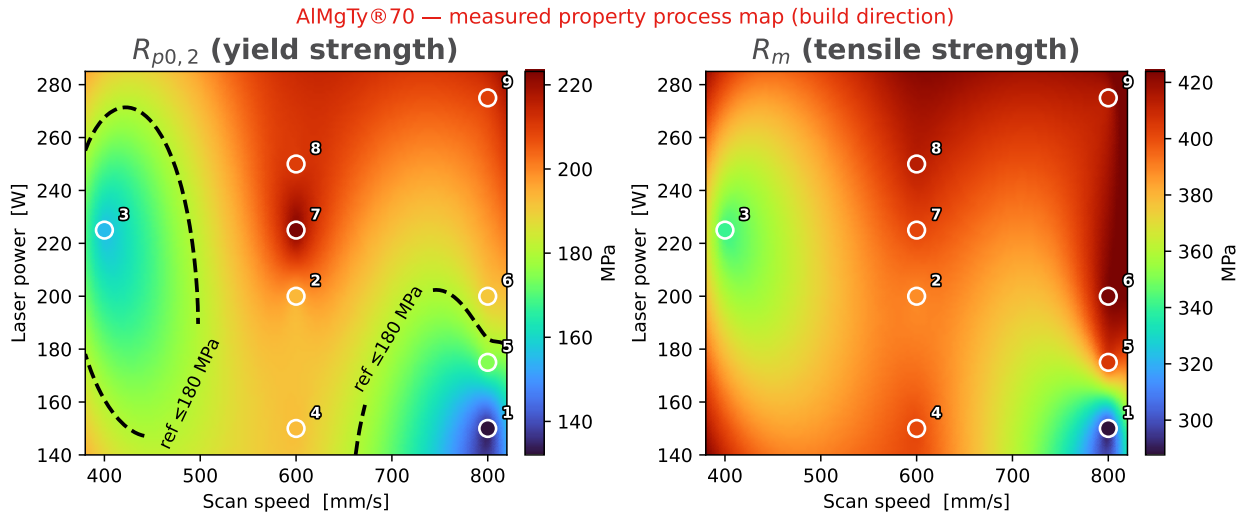


Figure 2. AlMgTy®70 process map (build direction): measured $R_{p0,2}$ and R_m across the laser-power / scan-speed window. The surface is interpolated so that it honours each of the nine measured parameter sets; numbered markers (1–9) are the tested combinations, coloured by their measured value. The dashed line marks the manufacturer reference ($R_{p0,2} \leq 180$ MPa; $R_m \geq 300$ MPa). Warmer colours indicate higher strength.

What the evaluation reveals. For AlMgTy®70, the indentation-derived build-direction R_m exceeds the 300 MPa lower bound across almost the entire window (roughly 340–424 MPa). The single exception is set 1 (150 W / 800 mm/s) — the lowest line energy (∼0.19 J/mm) — which drops to ∼288 MPa, a clear signature of lack-of-fusion at insufficient energy input. Yield strength ($R_{p0,2}$) rises from ∼132 MPa at that low-energy corner to ∼210–223 MPa for the higher-power sets. The map thus locates the favourable window directly from data: moderate-to-high laser power away from the low-energy/high-speed corner. Because the indentation probes local material behaviour, it is comparatively insensitive to the macro-scale porosity and defects that reduce the load-bearing cross-section of a tensile bar; the same effect is consistent with the project-wide observation that indentation R_m tracked the manufacturer reference closely (roughly $+14\%$ to $+31\%$ above the lower bound across the AlMgTy® alloys) while in-house tensile specimens fell 17–38% below it.

Resolving the result by indentation direction (Figure 3) shows that the directional differences between BD, PBD1 and PBD2 are generally modest and specimen-dependent rather than a uniform build-direction anisotropy, and that the point-to-point scatter (whiskers) is itself a useful indicator of build consistency. In practice this lets unsuitable parameter windows be screened out early and the promising window confirmed — with directional behaviour captured — from a handful of cubes rather than a full tensile matrix.

Key result — locating the favourable window. Combining both targets pinpoints the usable process window directly. Of the nine parameter sets, six meet the $R_m \geq 300$ MPa target alone, one meets only the $R_{p0,2} \leq 180$ MPa target, and **two (sets 3 and 5) satisfy both** (Figure 4). These two — 225 W / 400 mm/s and 175 W / 800 mm/s — are the candidate windows an engineer would carry forward, identified from a handful of cubes rather than a full tensile matrix.

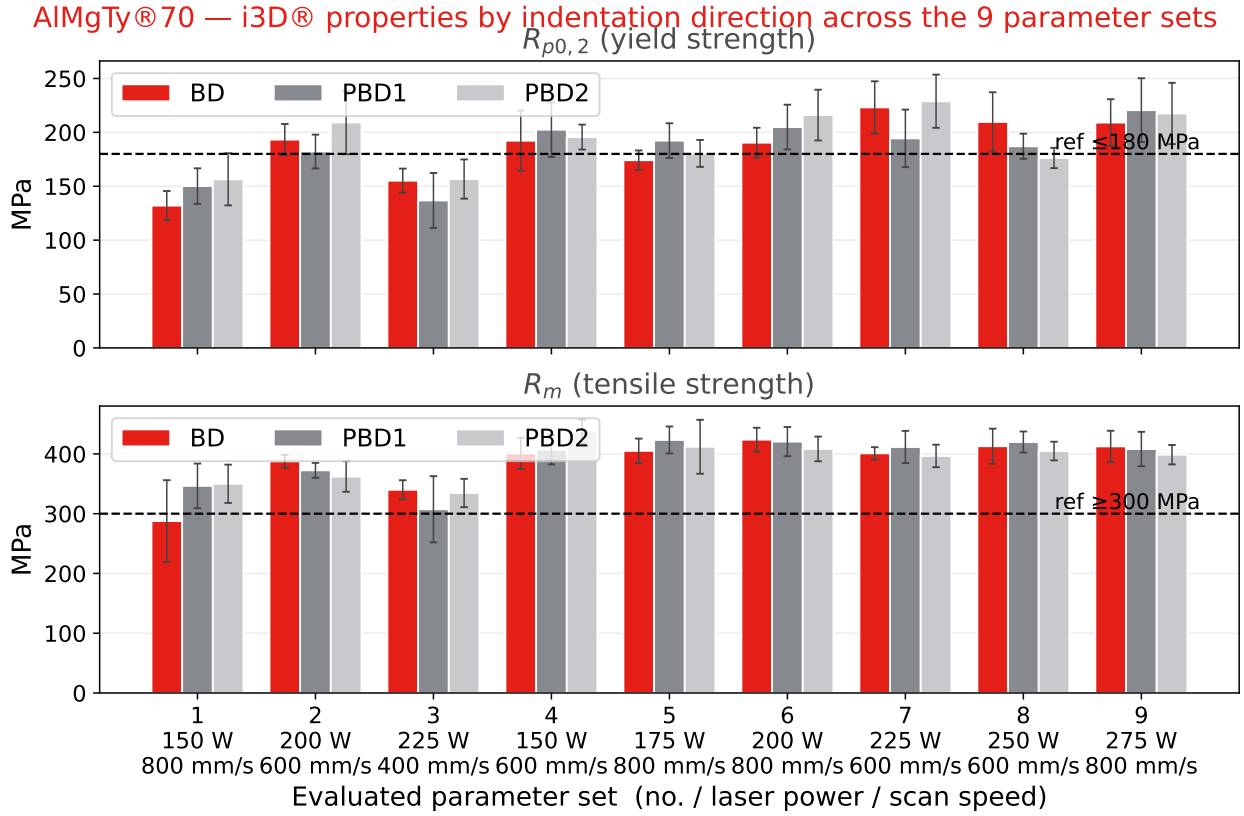


Figure 3. AlMgTy®70 mechanical properties measured by i3D® in three indentation directions (BD, PBD1, PBD2) across the nine evaluated parameter sets. Bars are means over measurement points; whiskers are ±1 standard deviation. Dashed lines mark the manufacturer as-built reference ($R_{p0,2} \leq 180$ MPa, $R_m \geq 300$ MPa).

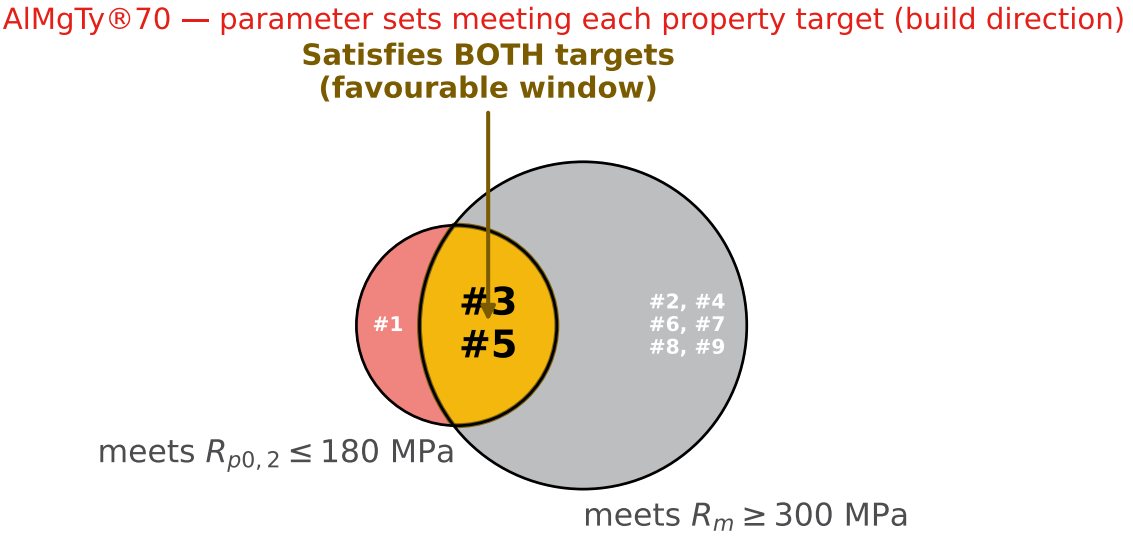


Figure 4. AlMgTy®70 parameter sets classified by which mechanical property target they meet (build direction). The intersection contains the sets satisfying both targets simultaneously — the favourable processing window. Numbers are parameter-set IDs.

4. Efficiency and sustainability gains

The benefits of replacing destructive tensile screening with indentation are quantitative. For AlMgTy®70 specifically, characterising the nine parameter sets took 271 i3D® indents (across the three directions) versus 36 conventional tensile tests — and the two routes differ by large factors in energy, CO_2, cost and time (Figure 5, Table 2). The decisive contributors are the elimination of energy-intensive CNC specimen machining (∼20 min per tensile bar) and the much smaller number of specimens required.

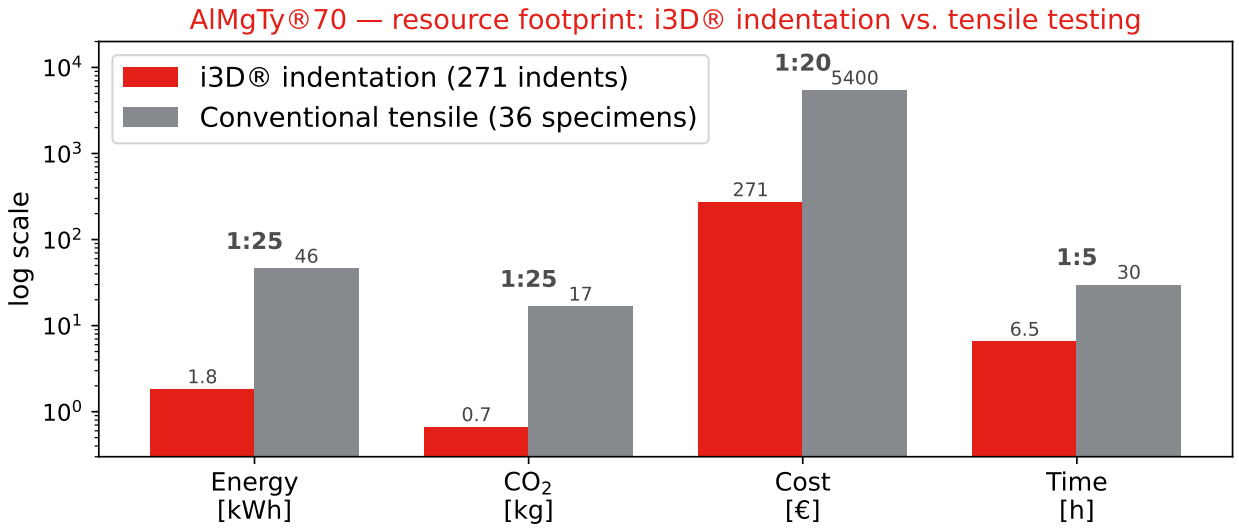


Figure 5. AlMgTy®70 resource footprint: i3D® indentation (271 indents) versus conventional tensile testing (36 specimens), log scale. Bold labels give the approximate ratio.

Table 2. Indentation versus tensile testing — AlMgTy®70 only.

Metric	i3D® (271 indents)	Tensile (36 specimens)	Ratio
Energy [kWh]	∼1.8	∼46	∼1 : 25
CO_2 [kg]	∼0.7	∼16.6	∼1 : 25
Cost [€]	∼270	∼5,400	∼1 : 20
Time [h]	∼6.5	∼30	∼1 : 5
Specimen prep	grinding, ∼2 min/face	CNC, ∼20 min/specimen	—
Specimen impact	non-destructive	destructive (36 bars)	—

Energy, CO_2 and time are scaled from the project's per-unit campaign figures; cost assumes ∼150 € per accredited tensile test and ∼1 € per indent; CO_2 uses the German grid factor of 363 g CO_2/kWh (**Umweltbundesamt** [4]).

Importantly, these advantages *scale with the breadth of the print-parameter evaluation*. Every additional parameter set, build orientation or replicate adds a destructive, machined specimen to a tensile campaign, but only a handful of fast, non-destructive indents to the i3D® workflow. The wider the process window screened, the larger the cost, resource and CO_2 advantage becomes — so the gains shown here for nine AlMgTy®70 parameter sets grow further in a full industrial qualification spanning many more parameters.

5. Takeaways

- **Parameter screening, not parameter guessing.** i3D® maps the laser-power × scan-speed window to $R_{p0,2}$ and R_m, hence favourable process windows are identified from data rather than trial and error.

- **Fewer specimens, multiple directions.** A single cube yields readings at several points and in three orientations, capturing build-direction effects without a dedicated tensile matrix.
- **Lower cost and footprint.** For the AlMgTy®70 evaluation (271 indents vs. 36 tensile tests), the indentation route reduces cost, CO_2 and lead time by roughly $20\times$, $25\times$ and $5\times$ versus conventional tensile testing — while leaving the part intact.

Acknowledgements. This work was carried out within the **GeniAl** project (Funding Reference Number: 01LY2301C), funded by the German Federal Ministry of Research, Technology and Space (BMFTR). The L-PBF print parameters and cube specimens were produced at Fraunhofer IAPT, and the aluminium powder was provided by Fehrmann Alloys GmbH & Co. KG. Their support is gratefully acknowledged.

6. References

1. B. Schmaling and A. Hartmaier, "Determination of plastic material properties by analysis of residual imprint geometry of indentation," *Journal of Materials Research*, vol. 27, no. 16, pp. 2167–2177, 2012. doi:10.1557/jmr.2012.212.
2. DIN SPEC 4864, *Prüfverfahren zur Ermittlung von Fließkurven und Vergleichskennwerten zum Zugversuch mittels zerstörungsarmem Prüfeindruck, 3D-Vermessung und Finite-Elemente-Werkstoffmodell.* Beuth, Berlin, 2019.
3. ASTM E3499-25, *Standard Test Method for Indentation Plastometry of Metallic Materials.* ASTM International, West Conshohocken, PA, 2025.
4. Umweltbundesamt, *CO_2-Emissionen pro Kilowattstunde Strom 2024 — 363 g CO_2/kWh*, 2025. `https://www.umweltbundesamt.de/themen/co2-emissionen-pro-kilowattstunde-strom-2024`

How to cite this white paper. DOI: 10.5281/zenodo.21157637. Use the BibTeX entry below:

```
@techreport{kalliath2026i3d,
  author = {Kalliath, A. and Lindner, K.-H. and Schmaling, B. and Siegert, S.},
  title = {{i3D Indentation-Based Evaluation of L-PBF Print
                Parameters of AlMg-Alloy}},
  institution = {Imprintec GmbH},
  type = {White Paper},
  year = {2026},
  doi = {10.5281/zenodo.21157637},
  url = {https://doi.org/10.5281/zenodo.21157637}
}
```

The AlMgTy®70 process-map surface (Figure 2) is interpolated between the nine measured parameter sets. AlMgTy® is a registered trademark, and the AlMgTy® powders are supplied by Fehrmann Alloys GmbH & Co. KG. i3D® is a registered trademark of Imprintec GmbH.

About Imprintec. Imprintec GmbH develops patented i3D® Indentation Plastometry systems and laboratory services for fast, minimally invasive determination of local mechanical properties — conforming to DIN SPEC 4864 and ASTM E3499.

Imprintec GmbH | Konrad-Zuse-Straße 18, 44801 Bochum, Germany | +49 (0)234 970 414 04 | info@imprintec.de | www.imprintec.de