ENGINEERING WHITE PAPER

Metal AM Material & DFM Guide

How to select alloys, design for laser powder bed fusion, and control cost, qualification risk, and production readiness.

Make better material and DFM decisions before the first build.

For design engineers, project directors, procurement leaders, product teams, and organizations moving complex metal parts from prototype to production.

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EXECUTIVE BRIEF

Material Selection Is a System Decision — Not a Material-Name Decision

Metal additive manufacturing (Metal AM) succeeds when alloy, geometry, build orientation, support strategy, heat treatment, machining, inspection, and commercial requirements are engineered as one manufacturing route.

The central question
What failure mode, cost driver, or qualification risk is most likely to prevent this part from meeting its real operating requirement?

Five Decisions That Determine Most Project Outcomes

Decision	What must be defined	Typical consequence if missed
1. Application duty	Load, fatigue, pressure, temperature, corrosion, wear, and life	Wrong alloy or heat treatment; field failure or over-specification
2. AM business case	Complexity, part consolidation, internal channels, weight value, and volume	AM used for a simple part that CNC could make faster or cheaper
3. DFM strategy	Orientation, supports, wall thickness, trapped powder, and machining access	Build failure, distortion, inaccessible supports, or uncleanable channels
4. Post-processing route	Stress relief, HIP, heat treatment, support removal, finishing, and CNC	Unexpected dimensional change, lead time, or qualification gaps
5. Acceptance plan	Critical dimensions, NDT, density, pressure test, documentation, and traceability	Disputes, repeat builds, delayed release, and hidden quality cost

What This Guide Delivers

- A practical alloy-selection framework for AlSi10Mg, 316L, 17-4PH / maraging steel, Ti6Al4V, and IN718.
- Indicative PBF-LB/M design rules for walls, channels, overhangs, machining stock, and powder removal.
- A production-ready view of orientation, thermal distortion, heat treatment, HIP, CNC finishing, and inspection.
- An RFQ checklist and anonymized composite cases that show how engineering decisions affect cost and risk.

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When Metal AM Creates Real Value

Metal AM is strongest when it removes a manufacturing constraint or creates system-level value—not when it merely replaces a conventional process one-for-one.

Strong Metal AM Candidates

Part consolidation
Multiple machined, welded, brazed, or fastened components can become one pressure-tight or structurally integrated part.

Internal flow performance
Conformal cooling, compact manifolds, lattice heat exchangers, and curved channels improve thermal or fluid performance.

Weight has economic value
Topology optimization and lattice structures reduce mass where every kilogram affects energy, payload, motion, or ergonomics.

Low-volume complexity
Complex geometry is required in prototype, bridge production, customized, or low-volume end-use quantities.

Lead-time compression
Tooling, casting development, or multi-supplier assembly can be replaced by a digital manufacturing route.

High-value material use
Near-net-shape production can reduce waste in titanium, nickel alloys, and other expensive materials.

When CNC, Casting, or Fabrication May Be Better

Part profile	Why conventional manufacturing may win
Simple plates, shafts, blocks, and prismatic brackets	Lower programming, build, support, and post-processing burden
High-volume stable demand	Casting, forging, stamping, or molding can amortize tooling over large quantities
Large solid parts with little geometric complexity	Metal AM build time and powder inventory may dominate cost
Very tight tolerance on most surfaces	Extensive CNC finishing may remove the economic benefit of AM
No value from consolidation, channels, or weight reduction	AM becomes a more expensive shape-making method rather than a system improvement

Gate 1 — Business case
Before selecting an alloy, quantify the value of complexity: fewer parts, lower mass, improved flow or cooling, less tooling, shorter lead time, or reduced supply-chain risk.

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Select the Alloy from the Failure Mode Backward

Start with the Operating Requirement

Requirement	Engineering questions	Selection implication
Static strength and stiffness	What is the load path, safety factor, and allowable deflection?	High tensile strength alone may not solve buckling, local stress, or stiffness limits
Fatigue and vibration	How many cycles, at what mean stress, environment, and surface condition?	Orientation, surface finish, residual stress, HIP, and machining can matter as much as alloy
Temperature	Continuous temperature, peak temperature, thermal cycles, and load at temperature?	IN718, tool steel, Ti64, or aluminum may be appropriate for very different thermal regimes
Corrosion / media	Water, chloride, fuel, oil, acid, cleaning agents, or galvanic contact?	316L, Ti64, and nickel alloys solve different corrosion mechanisms
Pressure / leak tightness	Working pressure, proof pressure, fluid, channel geometry, and leakage limit?	Density, surface condition, heat treatment, machining, and pressure testing must be specified
Wear / hardness	Sliding, impact, abrasion, tooling contact, or erosion?	17-4PH, maraging/tool steel, coatings, or replaceable inserts may be required
Mass and inertia	Is mass reduction worth more than material and qualification cost?	AlSi10Mg or Ti64 may justify redesign and topology optimization

Do Not Treat Datasheet Values as a Part Guarantee

- Mechanical properties depend on machine, parameter set, layer thickness, build orientation, heat treatment, and test standard.
- Down-facing surfaces, support scars, internal channels, and as-built fatigue surfaces may govern performance before bulk tensile properties do.
- Critical programs should define the material-process-condition combination—not only the generic alloy name.

Procurement translation

"Ti6Al4V" is not a complete purchase specification. A robust RFQ also defines material grade, process, heat treatment, HIP status, build orientation controls, machining, inspection, and required documentation.

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Core Metal AM Alloy Comparison

Representative values below are indicative examples from EOS PBF-LB/M material/process data. They are not universal design allowables. Confirm the selected supplier's qualified machine, parameter set, heat treatment, orientation, and inspection plan.

Alloy / condition	Density (g/cm³)	0.2% yield (MPa)	UTS (MPa)	Elong. (%)	Best-fit applications
AlSi10Mg — T6 example	≥2.67	230–250	300–310	≈10	Lightweight housings, brackets, thermal structures, complex channels
316L — as-built example	≥7.97	470–530	540–640	40–54	Corrosion-resistant manifolds, process equipment, fluid and medical components
17-4PH — H900 example	—	1,180–1,245	1,350–1,360	13–14	High-strength industrial parts needing corrosion resistance
Maraging steel MS1 — aged	—	≈2,000	≈2,070–2,100	4–4.5	Tooling inserts, conformal cooling, high-strength fixtures
Ti6Al4V Grade 5 — heat treated	≥4.4	1,000–1,020	1,100–1,110	≈15	High specific strength, aerospace, motorsport, corrosion-resistant structures
IN718 — heat treated	≥8.15	1,200–1,250	1,430–1,500	12–15	High-temperature, fatigue, creep, pressure, energy, and aerospace components

Fast Selection Logic

If the dominant requirement is…	Start by evaluating…	Watch-outs
Low mass + moderate strength + thermal conductivity	AlSi10Mg	Heat treatment changes strength/ductility; threads and sealing faces often need machining
Corrosion + ductility + complex flow paths	316L	High density; rough internal channels affect pressure drop and cleanability
High strength + moderate corrosion resistance	17-4PH	Heat-treatment condition and dimensional change must be controlled
Tooling hardness + conformal cooling	Maraging / tool steel	Heat treatment, cracking risk, distortion, and final machining plan
Maximum strength-to-weight + corrosion resistance	Ti6Al4V	Higher material and post-processing cost; oxygen control and qualification matter
Strength / creep at elevated temperature	IN718	Mandatory heat-treatment route, support removal, machining, and inspection cost

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Alloy-by-Alloy Engineering Guidance

AlSi10Mg Use for lightweight brackets, housings, heat sinks, and fluid parts where geometry adds value. Plan CNC stock on bearing seats, threads, O-ring grooves, and datum faces. T6-type heat treatment improves ductility but reduces as-built tensile strength.	**316L** Use where corrosion resistance, ductility, weldability, and integrated channels matter. Specify media, chloride exposure, cleanliness, passivation, and pressure test. Internal roughness may dominate flow performance.
17-4PH Use for high-strength industrial parts that still require corrosion resistance. Define solution/aging condition and account for heat-treatment dimensional change before final machining.	**Maraging / Tool Steel** Use for conformal-cooled tooling, inserts, wear-resistant fixtures, and high-load parts. Age hardening can produce very high strength; preserve machining access and plan distortion control.
Ti6Al4V Use when mass reduction, corrosion resistance, and high specific strength justify premium cost. Heat treatment is normally required; HIP and fatigue-critical surface finishing may be program-specific.	**IN718** Use for elevated-temperature, fatigue, creep, and pressure applications. The manufacturing route should include qualified solution and aging treatment, machining strategy, and NDT appropriate to risk.

Material Substitution Questions

- Can AlSi10Mg meet the load case before Ti64 is selected?
- Can 17-4PH provide sufficient strength and corrosion resistance before IN718 is selected?
- Does 316L solve the environment, or is chloride, acid, temperature, or fatigue performance driving a different alloy?
- Is high-performance alloy cost justified by field value, or is the real problem geometric stiffness, local stress concentration, or inspection strategy?

Gate 2 — Material trade study

Ask suppliers to quote a baseline alloy, a performance-upgrade alloy, and a cost-down alternative. Require each option to state heat treatment, machining, inspection, lead time, and the risk it addresses.

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DFM Rules for PBF-LB/M Geometry

The numbers below are screening values—not automatic acceptance limits. Final rules depend on alloy, machine, parameter set, orientation, feature length, and supplier capability.

Feature	Indicative screening guidance	DFM rationale
Structural wall	Prefer ≈1.0–2.0 mm for robust walls; thinner features require review	Thin walls distort, overheat, or become fragile during support removal
Qualified minimum wall	Some validated processes report ≈0.3–0.5 mm capability	Capability does not equal robust production design; geometry and alloy matter
Internal channel	Prefer ≥3–5 mm hydraulic diameter for powder removal and inspection	Small curved channels trap powder and are difficult to clean or verify
Powder escape	Provide multiple accessible escape paths and cleaning access	A printable channel is not necessarily a cleanable or certifiable channel
Unsupported overhang	Treat <≈45° from horizontal as support-sensitive unless supplier data proves otherwise	Down-skin quality, heat accumulation, and distortion worsen as angle becomes shallower
Hole orientation	Vertical or angled holes usually print better than horizontal circular holes	Horizontal holes can ovalize, close, or require support
Machining stock	Common starting point: 0.3–1.0 mm per surface, project-dependent	Allows removal of roughness, distortion, and datum variation
Minimum gap	Allow enough separation for powder removal, heat flow, and non-fusion	Close parallel features can fuse or trap powder

Design Features That Improve Build Success

- Use gradual transitions instead of abrupt thick-to-thin volume changes.
- Add radii at stress and thermal concentration points.
- Design self-supporting channels such as teardrop or diamond profiles where flow permits.
- Create removable support interfaces and tool access for cutting, EDM, grinding, or milling.
- Add machining datums, sacrificial pads, and inspection features early—do not “find” them after the build.

Critical channel rule

If powder cannot be removed, cleanliness cannot be verified, or the channel cannot be inspected, the design is not production-ready—even if it can be printed.

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Orientation, Supports, and Thermal Distortion

Orientation Is a Multi-Objective Decision

Orientation objective	Benefit	Trade-off
Protect fatigue-critical surfaces	Moves critical faces away from rough down-skin or support scars	May increase height, support volume, or machining access difficulty
Reduce supports	Lowers material, removal labor, and surface damage	Can worsen distortion or move anisotropy into the primary load path
Reduce build height	Shortens recoating cycles and exposure time	May increase cross-sectional area, thermal stress, and supports
Improve dimensional control	Aligns stable datums and minimizes long unsupported features	May increase post-machining stock on other surfaces
Enable powder removal	Creates gravity-assisted drainage and cleaning access	May conflict with minimum-support orientation

Residual-Stress and Distortion Controls

- Balance cross-sectional area through the build; avoid sudden volume jumps.
- Use ribs, fillets, scan-aware orientation, and support paths to create controlled heat flow.
- Keep long thin flanges and sealing faces mechanically supported until stress relief is complete.
- Sequence stress relief, plate removal, HIP, solution treatment, aging, and rough/final machining intentionally.
- Use sacrificial stock and datum pads where distortion must be removed by machining.

Support type / location	Engineering purpose	Removal consideration
Base supports	Anchor the part, conduct heat, resist recoater and residual-stress forces	Saw, wire EDM, or machining; plate-removal sequence matters
Down-skin supports	Stabilize shallow overhangs and control melt-pool behavior	Can leave pits and fatigue-sensitive scars
Internal supports	Enable channels or cavities that are not self-supporting	Avoid unless fully accessible; trapped supports can make a part unusable
Machining tabs / pads	Provide clamping, datum, and metrology references	Define removal and final surface acceptance in the drawing

Gate 3 — Build strategy review
Approve the proposed orientation and support plan before production. It affects cost, anisotropy, critical surfaces, powder removal, distortion, and CNC access.

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Tolerance, Surface Finish, and CNC Finishing

Use a Capability Hierarchy

Requirement level	Recommended manufacturing route	Typical examples
As-built functional	Print + support removal + stress relief + basic finishing	Non-critical housings, brackets, flow passages, protective features
Controlled AM dimension	Print with DFM allowance and targeted inspection	General mounting features, envelope dimensions, non-critical channels
Precision interface	Print near-net + CNC machine from defined datums	Bearing seats, O-ring grooves, threads, dowel holes, sealing and mating faces
Fatigue / sealing critical	Machine, grind, polish, shot peen, or chemically finish as validated	High-cycle surfaces, pressure boundaries, fatigue notches, fluid interfaces

Surface Condition Must Be Specified by Location

- Up-skin, vertical, down-skin, support-contact, and internal surfaces can have materially different roughness.
- As-built 316L examples may be around Ra 9–15 μm, while shot peening can reduce roughness below Ra 5 μm in reported EOS data; actual results remain process-specific.
- Internal channel roughness affects pressure drop, heat transfer, contamination retention, and cleaning validation.
- Blanket “smooth all surfaces” requirements create unnecessary labor and can make internal features impossible to finish.

Drawing Strategy

Mark on the drawing	Why it matters
Critical-to-function dimensions and datums	Focuses machining and inspection on value-creating requirements
As-built versus machined surfaces	Prevents quote ambiguity and over-finishing
Machining stock and sacrificial features	Protects the intended datum strategy after heat treatment
Surface roughness by face or zone	Avoids applying premium finish to the entire part
Thread class, insert, and sealing requirements	Separates printable pilot geometry from final functional features

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Post-Processing Is Part of the Manufacturing Route

Operation	Primary purpose	Key decisions before quotation
Stress relief	Reduce residual stress before plate removal or machining	Temperature, hold, atmosphere, fixturing, sequence, dimensional risk
Solution / aging heat treatment	Develop alloy microstructure and target properties	Standard, furnace qualification, coupon strategy, dimensional change
HIP	Close internal porosity and improve fatigue / ductility for selected applications	Is it required by risk or standard? What happens before and after HIP?
Support and plate removal	Separate part and remove thermal/structural supports	Wire EDM, saw, manual, robotic, or machining access; surface damage risk
Shot peening / blasting	Clean and homogenize external surface; modify residual surface stress	Coverage, intensity, contamination, dimensional effect, masking
CNC finishing	Achieve datums, tolerances, sealing surfaces, threads, and interfaces	Clamping strategy, stock, tool access, sequence after heat treatment
Polishing / flow finishing	Reduce surface roughness and pressure loss	Reachability, material removal, geometry change, inspection method
Passivation / coating	Improve corrosion, wear, appearance, or functionality	Alloy compatibility, masking, thickness, adhesion, validation

Recommended Process-Route Logic

1. Freeze the alloy, machine, parameter set, and build orientation.
2. Define stress relief and whether the part remains on the plate during treatment.
3. Remove the part and supports using a method that protects critical surfaces.
4. Apply HIP or alloy-specific heat treatment when required by performance or qualification.
5. Rough machine, finish machine, and surface-finish in the sequence that controls distortion.
6. Perform final inspection, pressure testing, NDT, cleaning, and documentation release.

Commercial impact

The printed build may be only one-third to one-half of the complete manufacturing route for a precision or qualified part. Quote comparisons must use the same post-processing and inspection scope.

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Quality, Inspection, and Qualification

Match Evidence to Part Risk

Risk level	Typical part	Recommended evidence
Low	Non-critical prototype or fit-check part	Material identification, basic dimensional check, visual acceptance, process statement
Medium	Functional industrial part or low-volume end-use component	Build record, heat-treatment certificate, critical dimensions, density / coupon data as agreed, surface acceptance
High	Pressure, fatigue, flight, medical, energy, or safety-relevant part	Qualified process route, powder traceability, witness coupons, NDT, pressure / leak testing, full dimensional report, controlled post-processing, lot release

Inspection Options

Method	What it can confirm	What it may not confirm alone
CMM / dimensional inspection	Machined and accessible geometry	Internal channel condition, subsurface defects, material properties
CT scanning	Internal geometry, trapped powder, some porosity and defects	Material chemistry, all crack types, functional pressure performance
Metallographic density / coupons	Process density and microstructure samples	The exact condition of every location in every production part
Dye penetrant / magnetic particle	Surface-breaking indications on compatible alloys	Internal defects and leak performance
Pressure / leak test	Functional pressure boundary performance	Full structural life, fatigue, or material condition
Tensile / fatigue coupons	Process-property evidence under defined conditions	Geometry-specific stress concentration and surface-condition effects

Relevant Standards to Discuss

- ISO/ASTM 52911-1 for design guidance for laser-based powder bed fusion of metals.
- ASTM F3318 for AlSi10Mg, F3184 for 316L, F2924 / F3302 for Ti6Al4V, F3055 for IN718, and F3607 for maraging steel.
- ISO/ASTM 52901 for purchased AM part requirements; ISO/ASTM 52904 and 52908 for critical-process and post-processing / inspection considerations.

Standards listed are discussion starting points. Applicability, revision, customer specification, and regulatory obligations must be confirmed for each program.

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Cost Model and Procurement Strategy

TOTAL DELIVERED COST = POWDER + BUILD TIME + SUPPORTS + HEAT TREATMENT + SUPPORT REMOVAL + CNC + FINISHING + INSPECTION + DOCUMENTATION + LOGISTICS + RISK

Primary Cost Drivers

Driver	Why it matters	Cost-down question
Build height and occupied volume	Recoating and exposure time dominate the build	Can orientation reduce height without increasing risk?
Support volume and contact area	Adds powder, scan time, removal labor, and surface repair	Can geometry become more self-supporting?
Part count per build	Affects utilization, scheduling, and repeatability	Can multiple parts nest without creating thermal risk?
Alloy and powder control	Premium alloys and controlled powder lifecycle add cost	Is the alloy requirement functional or habitual?
Heat treatment / HIP	Adds external process, queue time, fixtures, and documentation	Is HIP required by risk, standard, or assumption?
CNC and finishing	Often the largest hidden cost after printing	Can precision be localized to critical interfaces?
Inspection and quality documents	High-risk parts need evidence, not only geometry	Which tests release real risk, and which are redundant?

RFQ Questions Procurement Should Require

- Which machine, process, layer thickness, and material grade are quoted?
- What build orientation and support strategy are assumed?
- Which surfaces are as-built, blasted, polished, or machined?
- Which heat treatments, HIP, cleaning, and passivation steps are included?
- What dimensional, NDT, pressure, material, and traceability documents are included?
- What assumptions could create a change order after DFM review?

Better quote request

Ask for three options: minimum viable functional route, performance-optimized route, and production-qualified route. Compare total delivered cost, risk, and lead time—not only build price.

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Anonymized Composite Engineering Cases

The following cases are representative composite scenarios based on common Metal AM project patterns. They are not customer testimonials or guaranteed performance outcomes.

Case A — Integrated 316L Fluid Manifold

Before DFM	Metal AM route	Engineering result
Seven machined blocks, fittings, tubes, and brazed joints	One PBF-LB/M 316L body with curved internal channels; machined sealing faces and ports	Part count reduced from 7 to 1; fewer potential leak joints and less assembly coordination
Straight drilled passages created pressure loss and dead zones	Channel radii and junctions redesigned for smoother flow and powder removal	Improved hydraulic path while preserving clean-out access
Inspection was undefined until late in the project	CT for channel verification, dimensional inspection on interfaces, and proof / leak test agreed at RFQ	Clear acceptance criteria and fewer supplier assumptions

Key lesson

The value came from integration and flow performance—not from replacing one machined block with a printed block.

Case B — Lightweight AlSi10Mg Motion Bracket

Original concept	DFM change	Resulting manufacturing logic
Solid CNC bracket with high material removal and multi-side access	Topology-led load paths, hollow sections, generous transitions, and CNC pads	Lower moving mass and fewer machining operations on the final part
Tight tolerance applied to the entire model	Only two datums, bearing interfaces, and dowel holes retained as precision features	As-built geometry used where function allowed; machining localized
No allowance for heat-treatment and clamping distortion	Stress relief, T6-type route, sacrificial pads, and machining sequence defined	More predictable dimensional release after post-processing

Case C — Maraging-Steel Conformal-Cooling Insert

Traditional route	AM redesign	Decision controls
Straight drilled cooling lines could not follow the cavity surface	Conformal channels placed near the thermal load with accessible powder-removal paths	Potential cycle-time and temperature-uniformity benefit
Tooling hardness treated as a material-only requirement	Age-hardening, machining stock, polishing, and dimensional change included in the route	Tool performance linked to process condition, not alloy name alone
Cleaning and repair were not considered	Channel access, pressure test, CT / flow check, and repair strategy defined	Production readiness improved before the first insert was built

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Pre-RFQ Metal AM Material & DFM Checklist

Function and failure

- ☐ Primary function and worst credible failure mode are defined.
- ☐ Static, fatigue, pressure, temperature, corrosion, wear, and life requirements are separated.
- ☐ AM value is quantified through consolidation, performance, mass, tooling, or lead time.

Material and process

- ☐ Alloy grade, heat-treatment condition, and required standards are stated.
- ☐ Baseline, performance, and cost-down material options may be evaluated.
- ☐ Machine / parameter / layer-thickness assumptions will be disclosed by the supplier.

Geometry and build strategy

- ☐ Wall thickness, overhangs, channels, powder escape, supports, and machining access are reviewed.
- ☐ Build orientation protects the critical load path and critical surfaces.
- ☐ Sacrificial pads, datums, machining stock, and support-removal access are included.

Post-processing and inspection

- ☐ Stress relief, HIP, heat treatment, plate removal, support removal, CNC, and finishing are sequenced.
- ☐ As-built, finished, and machined surfaces are identified on the drawing.
- ☐ Dimensional, NDT, pressure, material, and traceability requirements match part risk.

Commercial scope

- ☐ Quotation includes the full delivered route, documentation, packaging, and logistics.
- ☐ Assumptions and exclusions are written before purchase order release.
- ☐ Prototype validation and production qualification are treated as separate gates.

Release gate

Do not release the build until the material-process-condition, orientation, support plan, post-processing route, machining plan, and acceptance evidence are aligned.

CONCLUSION

Turn Metal AM from a Print Order into an Engineered Manufacturing Route

Successful Metal AM programs do not begin with “Which alloy is strongest?” They begin with a quantified application requirement, a credible reason to use additive manufacturing, and a manufacturing route that connects design, material, process, post-processing, machining, inspection, and procurement.

What Unionfab Can Review

Material & process trade study AlSi10Mg, stainless steel, tool steel, titanium, nickel alloys, and alternatives—evaluated against function, cost, lead time, and risk.	**DFM and build strategy** Orientation, supports, thermal risk, channels, powder escape, wall thickness, consolidation, topology, and machining access.
Post-processing route Stress relief, heat treatment, HIP, support removal, CNC finishing, surface treatment, cleaning, and inspection sequence.	**Production and sourcing plan** Prototype validation, low-volume production, quality documentation, repeatability, cost structure, and delivery planning.

Technical Data Notes and References

1. EOS Aluminium AlSi10Mg material and process data
2. EOS StainlessSteel 316L material data sheet
3. EOS Titanium Ti64 Grade 5 material data sheet
4. EOS NickelAlloy IN718 material data sheet
5. ASTM F42 additive manufacturing standards overview
6. ISO/ASTM 52911-1 design guidance for PBF-LB/M
7. Materialise SS316L design guidelines

All material properties and design limits are process-specific. Use this guide for engineering screening only; final design allowables, compliance, and acceptance criteria must be confirmed for the selected supplier, system, process, and application.