Laser Metal Deposition (LMD)

Technical Principles, Industrial Applications and Collaboration with EXAFUSE

Intended audience:	Industrial partners and prospective customers
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Document purpose

This document provides a general technical introduction to Laser Metal Deposition (LMD), also known in coating applications as laser cladding. It explains the process principle, important operating parameters, industrial benefits, typical application fields, and the way EXAFUSE works with companies from initial assessment through engineering, manufacturing, and quality validation.

The information is intended to support an initial technical and commercial evaluation. A final process, material, cost, and lead-time recommendation requires a review of the actual component, base material, geometry, operating conditions, quality requirements, and current manufacturing or repair route.

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1 Executive Summary

EXAFUSE uses metal additive manufacturing to **generate, modify, repair, and coat metallic components**. Laser Metal Deposition is a directed-energy process in which metallic material is fed into a laser-generated melt pool and metallurgically bonded to a substrate. The process can be used for near-net-shape production, feature addition, dimensional restoration, local repair, and protective cladding.

Compared with complete component replacement or extensive material removal, LMD places material only where it is required. This is particularly attractive for large, high-value, or difficult-to-source components whose wear, damage, or functional requirement is concentrated in a limited region.

Typical objectives for industrial partners include:

- manufacturing new near-net-shape components or large additive structures;
- modifying existing components directly from revised CAD data;
- applying preventive protection against wear, corrosion, or elevated temperature;
- restoring damaged or worn regions while retaining the main component body; and
- reducing material waste, replacement lead time, unplanned downtime, and lifecycle cost.

EXAFUSE complements LMD with Selective Laser Melting (SLM), hybrid process routes, CAD redesign, material selection, process development, finishing coordination, and metallurgical quality validation. More than 40 alloy options are available for project-specific evaluation, including Fe-, Ni-, and Co-based material families.

Key message: LMD is not a universal replacement for conventional welding, machining, casting, or powder-bed fusion. Its value lies in combining targeted material addition, controlled heat input, strong metallurgical bonding, flexible automation, and application-specific engineering. The best process route is selected according to component function, geometry, material, production volume, quality target, lead time, and economics.

2 Terminology

The umbrella term *Directed Energy Deposition* (DED) covers additive manufacturing processes in which focused thermal energy melts material as it is deposited. In accordance with common industrial terminology, the principal variants are:

Other names encountered in industry include Laser Deposition Welding, Laser Powder Deposition Welding, Direct Metal Deposition, Metal Laser Deposition, and Laser Engineered Net Shaping. In this document, **LMD** is used as the general term, while **laser cladding** refers primarily to coating and surface-engineering applications.

Table 1: Common terminology for directed-energy deposition processes.

Term	Meaning	Typical use
DED	Directed Energy Deposition	General process family
LP-DED	Laser Powder Directed Energy Deposition	Powder-fed deposition using a laser heat source
LW-DED	Laser Wire Directed Energy Deposition	Wire-fed deposition using a laser heat source
LMD	Laser Metal Deposition	Common industrial name, frequently used for LP-DED
Laser cladding	Local deposition of a protective or functional layer	Wear protection, corrosion protection, repair, and surface modification

3 How the LMD Process Works

3.1 Formation of the Melt Pool

A focused laser beam heats a controlled area of the substrate. Once the local temperature exceeds the melting range of the material, a small melt pool is formed. Its size and stability are influenced by laser power, beam diameter, travel speed, material absorptivity, surface condition, and the thermal properties of the component.

3.2 Addition of Metallic Material

Metal powder is transported through a deposition nozzle by a carrier-gas stream and directed into the melt pool. The incoming powder melts, mixes with a controlled amount of substrate material, and solidifies behind the moving laser beam. Repeated tracks and layers create the required coating, repair volume, feature, or three-dimensional geometry.

A shielding-gas flow, commonly based on an inert gas such as argon, protects the molten material from excessive oxidation and supports stable process conditions. Depending on the application, the deposition path can be generated from a CAD model, a measured repair geometry, a scan, or a locally defined coating area.

3.3 Layer-by-Layer Build-Up

Adjacent tracks are overlapped to create a continuous layer. Further layers can then be deposited on top. The resulting geometry is normally produced near net shape and finished by machining, grinding, or polishing when tight dimensional tolerances or a fine surface are required.

Indicative EXAFUSE LMD process and equipment envelope

- Laser power: approximately 500–5000 W

- Laser spot diameter: approximately 1.5–4.5 mm
- Powder feed rate: approximately 5–30 g/min
- Typical layer height in current applications: approximately 0.5–1.3 mm
- Demonstrated application-specific deposition rate: up to approximately 900 g/h
- Broader LMD reference range used in EXAFUSE process comparisons: approximately 500–2000 g/h
- Indicative powder/material efficiency for LMD: approximately 60–90 %

These figures describe general or demonstrated operating ranges, not guaranteed project specifications. The validated window depends on material, geometry, nozzle and laser configuration, target properties, quality requirements, and thermal strategy.

4 Important Process Parameters

LMD quality is governed by the interaction of several parameters rather than by a single setting. The most important variables are summarised below.

Table 2: Principal LMD process parameters and their influence.

Parameter	Primary influence	Typical considerations
Laser power	Melt-pool size, penetration, dilution, and available energy	Insufficient power can cause incomplete bonding; excessive power can increase dilution, heat input, distortion, and evaporation.
Travel speed	Energy input per unit length and bead geometry	Higher speed generally reduces heat input and bead size; lower speed increases melt-pool volume and thermal exposure.
Powder feed rate	Deposited mass, bead height, and powder utilisation	Must be balanced with laser power and travel speed. Excess powder may remain unmelted; insufficient feed reduces build rate.
Spot diameter and beam profile	Power density, melt-pool width, and process stability	A wider spot can support broader tracks; a smaller spot produces higher local intensity and finer features.

Parameter	Primary influence	Typical considerations
Track overlap	Layer continuity, flatness, and local remelting	Too little overlap can leave valleys or lack-of-fusion zones; excessive overlap increases remelting and heat accumulation.
Layer height / vertical step	Geometric accuracy and layer bonding	The programmed step must match the actual deposited height to maintain a stable nozzle distance and consistent layer quality.
Nozzle stand-off distance	Powder focus, capture efficiency, and repeatability	Variations can change the powder concentration at the melt pool and reduce deposition efficiency.
Carrier and shielding gas	Powder transport, oxidation control, and melt-pool behaviour	Gas type and flow must be stable and compatible with the material and nozzle design.
Preheating and interpass temperature	Thermal gradient, residual stress, hardness, and crack sensitivity	Particularly important for hardenable steels, high-hardness deposits, dissimilar materials, and crack-sensitive alloys.
Path strategy	Heat accumulation, distortion, overlap, and surface shape	Track direction, sequence, dwell time, and local cooling influence geometry and metallurgical properties.
Post-processing	Final dimensions, surface finish, residual stress, and microstructure	May include stress relief, tempering, machining, grinding, polishing, coating removal, and inspection.

For a circular, approximately uniform laser spot, the nominal irradiance can be expressed as:

$$q = \frac{P}{A} = \frac{4P}{\pi d^2}, \tag{1}$$

where q is the nominal power density, P is the laser power, and d is the spot diameter. Practical process behaviour also depends on absorptivity, beam profile, optical losses, powder attenuation, and movement of the melt pool. Typical operating points can therefore reach effective power-density levels in the order of hundreds of megawatts per square metre.

5 Role of the Laser Source and Automation

Industrial LMD systems require a laser source that provides stable power, controllable beam characteristics, and reliable delivery to the processing head. Diode-based and diode-pumped systems are attractive because they can combine high electrical efficiency, scalability, robust operation, and flexible beam shaping.

Important characteristics include:

- **Near-infrared wavelength:** suitable coupling with many engineering metals; the exact wavelength depends on the laser architecture.
- **Controlled intensity distribution:** a relatively uniform beam profile can reduce local hot spots and support a stable melt pool.
- **Precise beam delivery:** fibre delivery and purpose-designed optics enable repeatable positioning and adaptation of working distance and spot size.
- **Fast power control:** dynamic adjustment can respond to changes in geometry, heat accumulation, or travel speed.
- **Flexible motion:** multi-axis robotic deposition provides access to large components, curved surfaces, and locally defined regions.

At EXAFUSE, laser control is combined with robotic motion, CAD-based path generation, process monitoring, and data-driven parameter development to improve repeatability and application flexibility.

6 Selecting the Appropriate Manufacturing Route

EXAFUSE uses LMD, SLM, and hybrid process chains as complementary technologies. The choice is based on component size, geometry, required resolution, material, existing substrate, production volume, and economic target.

Hybrid process routes can combine the deposition speed and scalability of LMD with the geometric resolution of SLM, conventional machining, heat treatment, or finishing. EXAFUSE develops a process-selection roadmap rather than forcing every project into a single technology.

7 Industrial Benefits and Application Fields

7.1 Near-Net-Shape Manufacturing

LMD builds only the required material volume and can therefore reduce raw-material consumption and machining time compared with routes that begin from a large billet or casting. This is especially relevant for large components, expensive alloys, and low-to-medium production quantities.

Table 3: General comparison of LMD and laser powder-bed fusion.

Criterion	LMD / LP-DED	SLM / LPBF
Manufacturing approach	Powder delivered directly into a local laser-generated melt pool	Powder distributed across a build layer and selectively melted
Typical component scale	Larger components; no strict build chamber, although reach and handling remain limiting factors	Small-to-medium components; EXAFUSE reference up to approximately 400 mm height at 400 mm diameter
Feature / layer scale	Track and precision depend on beam diameter; reference commonly 1–2 mm; typical layer height in current EXAFUSE LMD applications 0.5–1.3 mm	Typical layer thickness approximately 20–100 µm, enabling finer details and internal features
Indicative production rate	Approximately 500–2000 g/h, depending strongly on configuration and application	Approximately 50–500 g/h, depending on system, material, layer thickness, and part layout
Material use	Targeted deposition; indicative LMD material efficiency approximately 60–90 %	Unmelted powder can generally be recovered and reused subject to material-control requirements
Primary strengths	Repair, cladding, component modification, large parts, and near-net-shape build-up	Complex geometries, lattice structures, undercuts, and internal channels
Existing-part integration	Direct deposition onto an existing component or prepared substrate	Normally produces a new component on a build platform
Surface and finishing	Rougher as-built surface; machining is commonly required	Finer as-built detail, although support removal and finishing may still be required

7.2 Repair and Refurbishment

Worn or damaged regions can be removed to a controlled preparation geometry and rebuilt by deposition. The component is then machined or ground to its required dimensions. This route can retain most of the original part, shorten the wait for replacement components, and reduce downtime for critical equipment.

7.3 Laser Cladding for Wear, Corrosion, and Temperature Resistance

Laser cladding places a selected alloy only on the regions exposed to wear, corrosion, or high temperature. A suitable balance of hardness and toughness is required to limit cracking while achieving a low wear rate. Local coating can extend service intervals and improve total cost of ownership without manufacturing the complete component from an expensive high-performance alloy.

7.4 Geometric Modification and Functional Features

LMD can add teeth, ribs, bosses, interfaces, local reinforcements, or revised functional surfaces directly to an existing component. Design changes can be transferred from the updated CAD model without a dedicated casting or forming tool, allowing faster and more iterative modifications.

7.5 Material and Property Tailoring

EXAFUSE evaluates more than 40 alloy options for specific requirements involving temperature, corrosion, mechanical load, wear, and manufacturability. Available material families include high-alloy Fe-, Ni-, and Co-based systems, with further materials selected according to the LMD or SLM process route. Dissimilar-material combinations are possible, but require careful assessment of dilution, thermal expansion, phase formation, hardness, and cracking risk.

7.6 Time-Critical and High-Value Components

LMD is well suited to urgent repairs and components with long procurement lead times. A repair or modification can sometimes be completed in days rather than the months associated with a new casting or specialised replacement. Actual turnaround depends on data availability, material procurement, process qualification, finishing, and inspection requirements.

8 Selected EXAFUSE Application Examples

The following examples illustrate the range of possible LMD applications. Each new project still requires its own technical and economic assessment.

9 Technical Feasibility Factors

A successful LMD project begins with the component function and failure mechanism, not with a laser parameter. The following topics are normally evaluated:

- base-material grade, chemical composition, heat-treatment condition, and current hardness;
- component geometry, mass, accessibility, and the exact region to be deposited;
- dominant requirement or failure mechanism, such as abrasive wear, adhesive wear, corrosion, thermal fatigue, plastic deformation, cracking, or dimensional change;
- operating temperature, load, contact conditions, atmosphere, lubrication, cooling, and duty cycle;
- compatibility of the deposition alloy with the substrate and any subsequent heat treatment;
- required preheat, interpass-temperature control, cooling rate, and post-deposition treatment;
- acceptable dilution, heat-affected-zone width, residual stress, and distortion;

Table 4: Selected project examples from EXAFUSE application work.

Application	LMD approach	Industrial value
Modification of a steel casting	A tooth structure was deposited directly onto an available cast component from revised CAD data. The layer-by-layer build created bonding across the deposited cross-section.	Added functionality without a dedicated tool; design changes could be implemented iteratively, with manufacture and delivery measured in days rather than months.
Wear-resistant valve-seat rings	A wear-resistant Co-based alloy was applied locally. Preheating and post-heating were used to support crack-free deposition at high hardness, followed by limited finishing.	Longer service life, lower use of expensive wear-resistant material, and improved maintenance economics.
Repair of copper-based energy components	Worn regions were rebuilt with matching material in multiple layers. Substrate temperature was monitored and held below an agreed limit before the surfaces were finish-machined.	Restoration of high-value conductive components while retaining the original body and controlling the effect of heat input.
Repair of a worn shaft groove	The damaged region was removed, rebuilt by LMD, and machined back to fit. A suitable material was selected so the shaft could be returned to service without an additional heat-treatment step in that project.	Faster completion than ordering a new part and avoidance of extended production downtime.

- machining allowance, dimensional tolerance, and final surface-finish requirement; and
- inspection, documentation, and acceptance criteria for the completed component.

Material selection must address the actual service condition. A very hard layer may resist abrasion but can be unsuitable when the principal limitation is impact loading, thermal-fatigue cracking, or insufficient toughness. EXAFUSE therefore considers the complete material-process-component system.

10 How EXAFUSE Works with Industrial Partners

EXAFUSE provides an integrated service from the first sketch or damaged component through final quality inspection. Metallurgists, mechanical engineers, and additive-manufacturing specialists work together to develop a project-specific solution rather than simply operating a standard machine programme.

1. **Application and business assessment.** Clarify the functional problem, current process route, lead time, production volume, quality target, and cost objective.
2. **Process-selection roadmap.** Compare LMD, SLM, a hybrid route, or a conventional alternative and select the option with the best technical and economic fit.
3. **CAD redesign and engineering.** Adapt existing models or create additive-friendly geometry, repair volumes, machining allowances, and deposition paths.
4. **Material consultation.** Screen more than 40 alloy options and select candidates for strength, durability, corrosion, temperature, wear, and process compatibility.
5. **Parameter and process development.** Establish laser, powder, motion, thermal, and path parameters using structured trials and design-of-experiments methods.
6. **Manufacturing, cladding, or repair.** Produce the near-net-shape part or rebuild the prepared region with controlled process monitoring.
7. **Finishing and validation.** Coordinate heat treatment and machining and, where required, perform dimensional inspection, hardness testing, metallography, porosity evaluation, or non-destructive testing.
8. **Industrial evaluation.** Compare performance, service life, lead time, and total cost against the existing reference route before wider implementation.

11 Recommended Feasibility and Qualification Route

A structured development route reduces technical risk and creates a traceable basis for an industrial decision.

1. **Select a representative application.** Choose a component with a clearly defined requirement, wear pattern, damage condition, or design objective.
2. **Collect baseline data.** Record material, heat treatment, geometry, operating conditions, current lifetime, current manufacturing or repair route, lead time, and cost.
3. **Define measurable targets.** Establish the required function, property, dimensional tolerance, inspection criteria, target lifetime, acceptable lead time, and economic objective.
4. **Screen candidate process routes and materials.** Evaluate LMD, SLM, hybrid manufacture, cladding, or repair and select one or more material candidates.
5. **Develop the process window.** Use coupon and geometry trials to study bonding, dilution, porosity, cracking, bead shape, hardness, microstructure, and distortion.
6. **Produce a demonstrator or repaired component.** Apply controlled preheating, interpass temperature, path planning, and process monitoring.
7. **Finish and inspect.** Apply the required heat treatment and machining, followed by dimensional, visual, hardness, metallographic, porosity, or non-destructive inspection as agreed.

8. **Conduct an industrial trial.** Compare quality, service performance, lead time, material use, and total cost against the current reference process.

11.1 Information Requested for an Initial Assessment

The following information enables EXAFUSE to prepare a focused first feasibility discussion:

- component drawings, CAD data, scans, or photographs, including the region of interest;
- base-material specification, heat-treatment condition, and available certificates;
- target and measured hardness or other required material properties;
- description and measurements of wear, damage, corrosion, or the desired design modification;
- component dimensions, mass, accessibility, and handling constraints;
- operating temperature, load, atmosphere, lubrication, cooling, and duty cycle;
- current manufacturing, replacement, coating, or repair process route;
- dimensional tolerances and required surface finish after processing;
- batch size, annual demand, desired lead time, and urgency; and
- economic target, such as required lifetime increase, avoided downtime, or acceptable repair cost.

12 The EXAFUSE Approach

EXAFUSE has worked with Laser Metal Deposition since 2017 and has developed its capabilities from an initial three-axis system to a self-developed six-axis robotic LMD platform. The current approach combines equipment development, application engineering, material science, and quality validation.

Key capabilities include:

- ✓ Custom six-axis robotic LMD systems for flexible component access;
- ✓ LMD, SLM, and hybrid process-selection support;
- ✓ laser, powder, motion, and path-parameter development;
- ✓ CAD-based slicing, redesign, and deposition-path generation;
- ✓ real-time process monitoring and data-driven control development;
- ✓ systematic parameter optimisation using design of experiments;
- ✓ material consultation across more than 40 alloy options;
- ✓ metallographic, hardness, porosity, and microstructural evaluation;

- ✓ repair preparation, near-net-shape deposition, cladding, and finishing coordination; and
- ✓ application-specific engineering from initial concept to final quality inspection.

The objective is not to apply a standard coating or printing strategy indiscriminately, but to develop a process chain that matches the component, material, service conditions, quality requirements, and business target.

13 Conclusion

Laser Metal Deposition provides a flexible route for local metal addition, repair, surface protection, component modification, and near-net-shape manufacturing. Its principal advantages are targeted material use, comparatively high deposition rate, localised processing, strong metallurgical bonding, and direct integration with existing components.

Together with SLM, hybrid processing, CAD engineering, material selection, and metallurgical validation, LMD enables companies to address complex geometries, long replacement lead times, wear-critical surfaces, high-value repairs, and material-efficiency targets through one coordinated project route.

EXAFUSE works with industrial partners to identify the most suitable application, qualify the material and process, manufacture or repair the component, and evaluate performance against the current technical and economic reference.

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