# Laser-Based Additive Manufacturing of Metals

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**Abstract.** For making metallic products through Additive Manufacturing (AM) processes, laser-based systems play very significant roles. Laser-based processes such as Selective Laser Melting (SLM) and Laser Engineered Net Shaping (LENS) are dominating processes while Laminated Object Manufacturing (LOM) has also been used. The paper will highlight key issues without going into details and try to present comparative pictures of the aforementioned processes. The issues included are machine, materials, applications, comparison, various possibilities and future works.

## Introduction

Additive Manufacturing (AM) is another name of Layer Manufacturing or Rapid Manufacturing/Prototyping in which a product is made layer-by-layer. Each layer corresponds to a cross-section of 3D CAD model of the product. The core problem in AM lies in making layers and joining successive layers. AM started with using plastics because of ease of processability and aim of making just visual prototypes. The process has grown to include all types of materials. But it is not so successful with ceramics, and plastics have limited applicability in high-strength applications resulting into faster growth of AM of metallic materials.

There are many AM processes for metals. Significant among them are: Selective Laser Sintering/Melting (SLS/M), Laser Engineering Net Shaping (LENS) and its variants, Laminated Object Manufacturing (LOM), Electron Beam Melting (EBM) and Ultrasonic Consolidation (UC). The predominance of laser-based processes (SLS/M, LENS, LOM) shows the wider utility and acceptability of lasers in AM. Both SLS/M and LENS uses powder as a building unit, the former in a powder-bed while the latter in a blown-powder technique. LOM uses metallic foil as a basic building unit [1-4]. Among all three, powder-bed techniques are more researched/applied and are the subject of the present paper. The potential of LOM has yet to be fully exploited. The paper deals with various aspects such as materials and properties, machines, comparison and challenges of the processes. Fig 1 shows schematic diagrams of SLM and LENS processes.
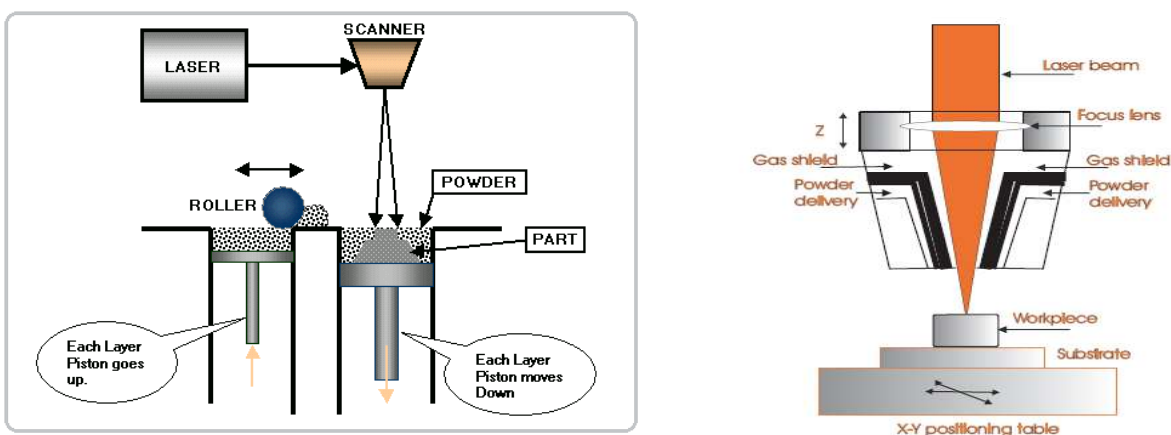


*Fig 1* Schematic diagram of SLM [5] and LENS processes [6]

## Materials & Properties

In both SLM and LENS, powders are fully melted by laser beam. Processing leads to the formation of small grains, non-equilibrium phases and new chemical compounds depending upon the composition of the powders resulting into mechanical properties (yield strength, ultimate tensile strength, ductility) better than corresponding wrought products. In SLS, a mixture of metallic powders are designed in such a way that some of the powders could be melted to hold other powders together and give rise to an integrated product. SLM is preferred over SLS for obtaining high-strength products.

Both SLM and LENS furnishes comparable strength, accuracy (50 to 100μ) and surface roughness (<10μ). Although, it exactly depends upon the machine type, materials and geometry of the products.

The metals used by SLM are various types of steel (stainless steel 316L, hot-work steel, tool steel, maraging steel), Titanium CP, titanium-based alloy (Ti-6Al-4V, Ti-6Al-7Nb), Inconel 718, Inconel 625, Aluminium-based alloy (Al-12Si, Al-Si-12Mg, Al-Si-10Mg), Cobalt-based alloy, Gold, Cu etc. Besides, there are many patented powders for SLM which are machine-specific and their exact compositions are not known. LENS uses mainly iron-, titanium- and nickel-based alloys. The metals used by SLM are significantly more than LENS. This is because SLM is able to make far more geometries than possible by LENS resulting in more products for varied applications [6-11].

## Applications

The processes are useful for making once-off product (spare parts), customized and complex products, low volume production and cheap high-value products (medical implants). There are also certain products which were impossible through conventional means such as mould with conformal cooling channel could be conveniently fabricated. These have found applications notably in the following fields: medical, aerospace, automotive, jewellery and tooling [6-11]. Fig 2 shows the SLM and LENS parts made.

LENS gives an added advantage of modifying/refurbishment of the surface of product if it is required in its life-cycle. Besides, the composition of the powder could be changed from one location to others during processing to make products of varied composition. This could also lead to the possibility of fabrication of Functional Graded Materials (FGM) [12-14].



*Fig-2* SLM steel insert with conformal cooling [9], SLM tool inserts with conformal spiral cooling [7], LENS Titanium hip stem [12]

**Machines**

There are five main companies which fabricates SLM machines. These are EOS, 3D Systems, Concept, MTT and Phenix. For LENS type machines, there are three significant companies: Optomec, POM and Accufusion [7-14]. The build volume, laser type, power and other details of these machines are given in Table 1. Metallic powders has higher absorptivity for Nd:YAG laser than $CO_2$ laser and so most machines use lasers (fibre, disc) of nearer wavelength to Nd: YAG laser. Better beam quality is the reason for the popularization of the fibre laser.

| Company | Model | Build volume (mm x mm x mm) | Laser | Other |
|---------|-------|-----------------------------|-------|-------|
| EOS [7] | EOSINT M 270 | 250 x 250 x 215 | Fibre, 250 W | Max scan speed 7 m/s |
| 3D System [8] | DM 125 | 125 x 125 x 125 | Fibre, 100, 200 W | Max scan speed 1 m/s |
| 3D System [8] | DM 250 | 250 x 250 x 320 | Fibre, 200, 400 W | Max scan speed 1 m/s |
| Concept [9] | M1 Cusing | 250 x 250 x 250 | Fibre, 200 W (cw) | Max scan speed 7 m/s |
| Concept [9] | M2 Cusing | 250 x 250 x 280 | Fibre, 200 W (cw) | Max scan speed 7 m/s |
| Concept [9] | M3 Linear | 300 x 350 x 300 | Fibre, 200W (cw) Solid state laser, 100 W (cw + pulse) | Max scan speed 7 m/s, Laser erosion and marking facility |
| MTT [10] | SLM 125 | 125 x 125 x 215 | Fibre, 100 W, 200 W | |
| MTT [10] | SLM 250 | 250 x 250 x 300/400 | Fibre, 200 W, 400 W | |
| Phenix [11] | PM 100 | Dia 100 x 100 | Fibre, 50 W | Max scan speed 3 m/s, max substrate temp $900^{O}C$ |
| Phenix [11] | PXL | 250 x 250 x 200 | Fibre | |
| Phenix [11] | PM 250 | Dia 250 x 300 | Fibre, 100 W | |
| Optomec [12] | LENS 750 | 300 x 300 x 300 | Nd:YAG, 500 W Fibre, 1 kW, 2 kW | Closed-loop control, standard 3- axes |
| Optomec [12] | LENS 850-MR7 | 900 x 1500 x 900 | Fibre, 1 kW, 2 kW Other optional laser | Closed-loop control, upto 7 axes deposition |
| POM [13] | DMD 105D | 300 x 300 x 300 | Diode, disc, 1 kW | Closed-loop control, 5 axes deposition |
| Accufusion [14] | LC 105 | 450 x 450 x 450 | Nd:YAG, 5 kW | Control and monitoring system, 5 axes motion |

*Table 1* Important details of SLM and LENS machines

**Comparison & Challenges**

SLM machines are of almost the same size and lack versatility in size. It hinders them to be energy-efficient while making a product of smaller size. Requirement of high amount of powders is also a problem, though this problem could be overcome by using inserts in powder containers and build cylinder of the machine. The ideal solution could be the miniaturization of the machine which could then truly fit into an image of 'Desktop 3D Printer'. The bigger SLM product that is made is roughly half than LENS one.

Upscaling the SLM machine could help making bigger automotive engine blocks (which are generally made by casting) or assembled parts (it could be a major application of AM). However,

bigger product without complex features would be the non-optimum use of AM and won't be eco-friendly.

LENS machines are equipped with feedback control which helps maintain quality and desired mechanical properties of the product. This type of control in SLM machines are yet to be commercially implemented.

The maximum scan speed obtained in SLM is 7 m/s which is quite low in comparison to obtained (1000 m/s) in another comparative process, i.e. Electron Beam Melting (EBM) [15]. The increment of scan speed could increase the productivity and add value to the process.. In case of integrating sensors during the build-up in SLM, LENS, EBM, these processes are not suitable unlike another comparative AM process, i.e. Ultrasonic Consolidation (UC) [16].

SLM, LENS and EBM are not inexpensive for easy-to-machine materials i.e. aluminium and magnesium alloys. UC and LOM are quite suitable in these cases because they start with metallic sheets instead of powder and  secondly, machining is another recurring steps in these processes.

**Future Direction**

The absorptivity of the powder to the laser is not high. There could be a search of better laser source which could help increase absorptivity. In this regard, our institution is developing a 2 μ wavelength laser which could possibly make laser processing more energy-efficient. The wire-based LENS furnished excellent results, it holds promise for future work. If the present SLM, LENS machines would be equipped with optional machining facility then it could help make better products with added values and precision.

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