CHAPTER 3

LASER ENGINEERED NET SHAPING (LENS^{TM})

In the previous chapter, the literature for the Co-Cr-W alloy characterization, microstructural analysis and electrochemical behaviour are discussed in brief for both conventional and additive manufacturing processes. Different additive manufacturing (AM) techniques used on various metals and metal alloys, economic feasibilities of these methods are also presented. From the literature, it is observed that the LENS process stands out from the other AM processes with high influence on the quality, build time, ease of operation of the samples.

Laser Engineered Net Shaping (LENS) is a promising metal additive manufacturing process, which can build fully dense parts, near net shape and functionally graded components directly from 3D CAD model, Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and digital X-Ray images. LENS has many potential applications, including prototyping, tooling and dissimilar metal joining. LENS technology also found its place in medical applications. With its fast turnaround times and the design freedom it affords, LENS is an emerging solution for medical device manufacturing, including the development, prototyping and production of medical implants, such as dental, hip, knee and prosthetic joints.

The present chapter deals with the Laser Engineered Net Shaping (LENS) process, and its components. The working process of the LENS is discussed in detail. The LENS machine produces parts that are full strength metals and is a "true" direct-metal Rapid Prototyping process. It is developed by Sandia National Laboratories along with numerous other organizations based on the Cooperative Research and Development Agreement (CRADA). Unspoiled metal powders are used as build materials depending on the choice of the user. Optomec Design Company (USA) manufactures LENS750^{TM} (dimensions include, 12" x 12" x 12") and LENS850^{TM} (18" x 18"x 42") systems.

3.1 Layout of the Laser Engineered Net Shaping Machine

The complete layout of Laser Engineered Net Shaping (LENS) system is shown in Fig. 3.1. The machine set up is shown in Fig. 3.2 and the components of LENS inside build chamber are shown in Fig 3.3. The major components in the LENS machine are as follows:

i) Build chamber ii) glove box iii) laser head iv) build platform v) build substrate vi) argon gas circulator vii) powder hoppers and viii) work station.

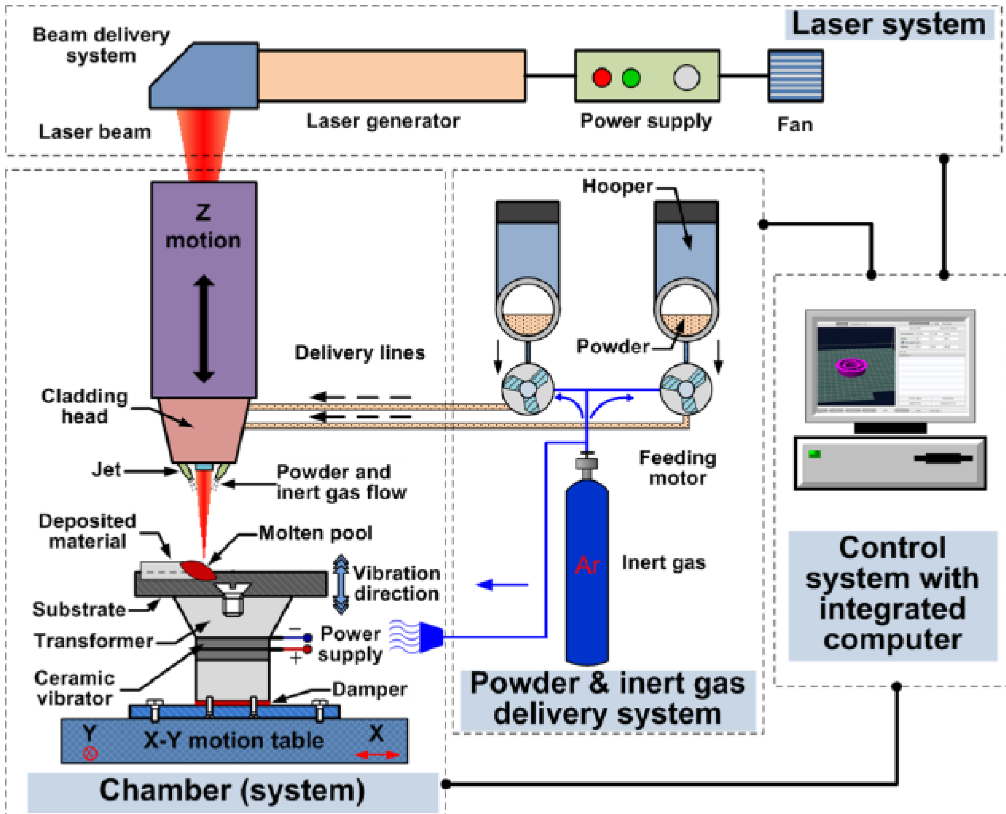

Figure 3.1: Complete layout of LENS system

Figure3.2: LENS machine setup

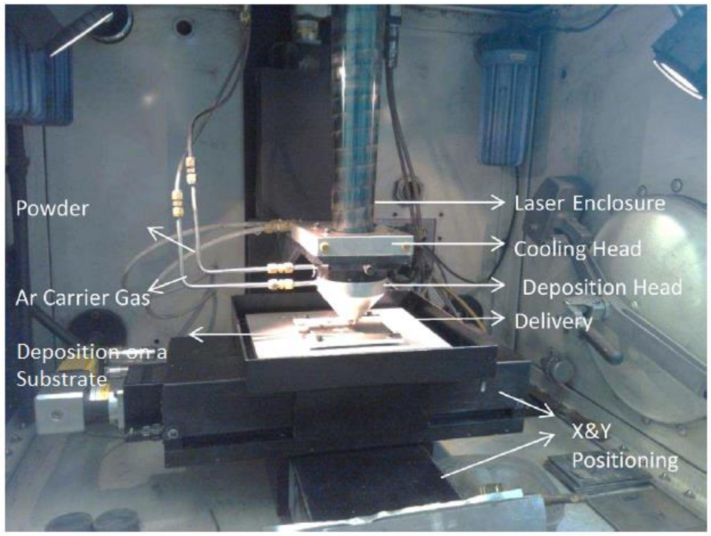

Figure 3.3: Components of LENS machine inside the build chamber

3.1.1 Laser Unit and Laser Head

LENS750^{TM} machine uses Nd: YAG (Neodymium: Yttrium Aluminium Garnet) laser of 500W. Several lenses are employed to focus the laser beam on a location at the point of deposition. The laser head is surrounded by four equi-spaced nozzles through which the powder is deposited exactly at the point where the laser beam is focused. The laser head can move in a vertical direction (*Z*-axis up and down).

3.1.2 Build Chamber

The dimensions of the build chamber in LENS750^{TM} are 12"×12"×12" in which the process of deposition takes place. This chamber is hermetically sealed and is connected to the glove-box with a small door. The system provides two rubber gloves for handling powder/components and making required arrangements inside the chamber.

3.1.3 Glove Box

The glove box, situated adjacent to the build chamber, plays the role of a conduit between the build chamber and the operator. It has two doors, the inner one facing the build chamber and the outer one open to the atmosphere. The working materials, like substrate powder, required in the build chamber are transferred through the outer door into the glove box. After shutting the outer door, the material is transferred to the build chamber through the inner door. The glove box, thus, shields the build chamber from contamination.

3.1.4 Build Platform

A platform, rectangular in shape, is provided in the build chamber for horizontal X-Y directional movement. The platform is slotted with threaded holes to attach the substrate of various sizes.

3.1.5 Build Substrate

The component which is being fabricated and the build substrate plate, preferably, should be of the same material. Essentially, the component is welded to the substrate, thereby restricting any movement or deformation during the process of building. A 2mm thick plate of appropriate material is adequate to be used as substrate. As and when the first layer deposition takes place, it is almost welded to the surface on which it is deposited. The plate that is used in-between deposition head and build platform is called the substrate.

3.1.6 Argon Gas Circulator

Most of the metals tend to oxidize at higher temperatures. To mitigate the issue of oxidation, an inert gas needs to be circulated throughout the material deposition process. Usually, argon is the gas of choice as it is readily available at a low cost. A gas circulation unit constantly pumps the gas inside the build chamber to maintain an inert atmosphere. The gas is reused after cleaning in a separate unit.

3.1.7 Powder Hoppers

The cylindrical-shaped hoppers store the powder to be fed for deposition. The LENS machine has two hoppers with a feeder mechanism to supply the powder to the nozzles from the hoppers. If alloys or functionally graded components need to be fabricated, the hoppers are stocked with the appropriate metal powders. The glass doors are used to monitor the quantity of powder in the hoppers.

3.1.8 Workstation

The LENS machine uses a workstation that reads .STL files. The workstation is equipped with software that reads CAD, CT Scan and MRI scan data. If required, the files can also be edited by the software. An Uninterrupted Power Supply (UPS) system and a generator are provided to prevent defects arising due to fluctuations in power supply.

3.2 Build Materials on LENS

Standardization contributes to simplifying, reducing and organizing issues which tend to become more diverse, complex and chaotic if not controlled. It is a system for creating, distributing and enforcing standards. Value is created at several levels. The formulation of standards is the outcome of standardization.

In 2009, the ASTM F42 Committee for Additive Manufacturing Technologies was formed and created the F2924 Specification for Additive Manufacturing of Ti-6A1-4V (Titanium alloy with 6% Aluminum and 4% Vanadium) with Powder Bed Fusion. Other important standards were also created, such as ASTM F2792 (standardized AM terminology) in 2009 and ASTM F2915 (Specification for AM File Format) in 2011. This AMF format permits the transfer of designs across varied software and hardware systems to support material gradients with microstructure and multi-material geometries. The present building materials include various steels, Titanium Alloys, Nickel Alloys, Cobalt Alloys, etc., have a wide LENS operational database.

3.3 Working Process of LENS

The LENS system comprises a Neodymium-doped Yttrium Aluminium Garnet (Nd: YAG) laser, a glove-box in which the atmosphere is controlled, a powder feeding mechanism and a triple-axis CAD controlled locating system. The locating stages position within the glove box and charged with argon gas having a purity level less than10 ppm of oxygen. The beam is focused onto the glove-box by means of an opening, fixed above the glove-box and guided on to the target region by using a planoconvex lens having a focal length of six inches. The nozzle of the powder dispersion unit is devised for directly injecting the stream of powder inside the directed laser beam and the nozzle and the lens travel as a single unit. A CAD model is sequentially layer-deposited and converted into a sequence of tool path networks for the creation of each layer. Every layer is developed by initially generating a framework of the main features of the component and then immersing the cross-sectional segment with a rastering method. The .STL file is employed to run the laser system to generate the desired partforming one layer at a time, beginning from the lowermost layer.

The *X* and *Y*-axis movements caused by the transverse travel of the rectangular platform table and the *Z*-axis movement provided by an up and down movement of the deposition head together constitute the system’s movement in three dimensions. This movement can fabricate basic to fairly complex 3D components. But components having free-hanging surfaces or internal overhangs are difficult to fabricate, since they need rigid supports. The maximum overhang inclination from vertical presently achievable is about 18^o degrees. The manufacturers are working towards improving this angle in order to fabricate even more intricate geometries.

3.4 Process Parameters in LENS for Deposition of Components

The process characters can be regulated according to the requirements of the user. Typical parameters are laser output power, powder feed rate, scan speed, laser beam diameter, powder particle size, laser pointer and the deposition point distance, raster angle, layer thickness, etc.

3.4.1 Laser Power

The melting of the metals bears a direct relation to laser power supplied. The machine supplies 150-500W of laser power at the substrate. Laser power needs to be appropriate to the properties of the metal powder being deposited. Too low or too high laser power could result in incomplete inciting of the metal or vaporization of metal, respectively. Both these extremes could result in poor deposition. Hence, correct selection of laser power is vital for LENS deposition.

3.4.2 Scan Speed

The relative movement between the material deposition table and laser head is called the scan speed. The maximum scan speed of LENS750™ is 60mm/s. If the scan speed is too low, the material is exposed to the laser longer and more heat is generated and heat affected zone also increases. If the scan speed is too high, the metal will not melt. The scan speed should be selected preferably within or nearer to the specified scan speed range depending on the properties of the powder material being used.

3.4.3 Powder Feed Rate

Most of the powder sprayed through the four nozzles does not melt completely, resulting in wastage and scatter. However, the powder feed rate cannot be kept too low as strong and dense parts require sufficient powder at the point of deposition for fabrication. Therefore, a suitable feed rate as required for the specific metal should be selected.

3.4.4 Powder Particle Size

The material flow to the nozzles and spray rate relies primarily on the particle size of the powder. At the micron level, the particle size varies in a range of sizes. It has been identified experimentally that the powder in the range 40–150μm is most appropriate for LENS deposition.

3.4.5 Laser Beam Diameter

The road width of the raster and the laser beam diameter are proportional to each other. If the beam diameter is too low, thin rasters are deposited requiring a number of lines. If beam diameter is high, the deposition accuracy reduces. Therefore, an optimal laser beam diameter should be selected.

3.4.6 Distance between Laser Pointer and Incident of Deposition

As the distance between the laser pointer and the incident of deposition increases, the effectiveness of the deposition decreases (Fig 3.4). The design of the LENS machine ensures that the distance is self-optimized by the machine itself, subjectto the variation of other parameters like laser power, scan speed etc.

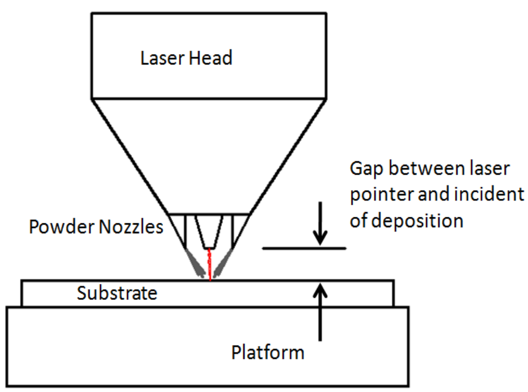

Figure3.4: Distance between laser end point and incident of deposition

3.4.7 Layer Thickness

If the layer thickness is reduced to a desired part height, the number of layers would increase and thereby the deposition time. When a layer thickness is required to be high, the staircase effect will increase for curved parts in *Z*-direction (Fig.3.5). The layer thickness depends on the particle size of the powder too.

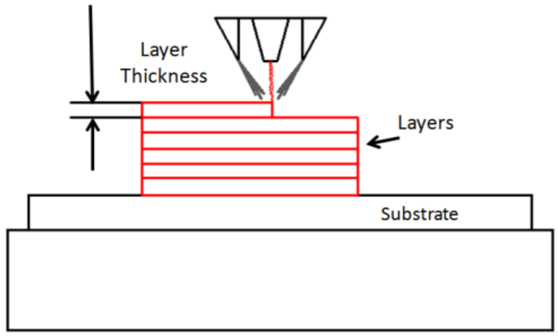

Figure3.5: Layer thickness in depositing the samples

3.4.8 Raster Angle

When high strength components are built, the angle of deposition in all the layers is varied by 30°, 60° or 90° (Fig. 3.6). This is because the change of raster angle causes changes of transverse and longitudinal directions of layers; thereby increasing strength in that direction.

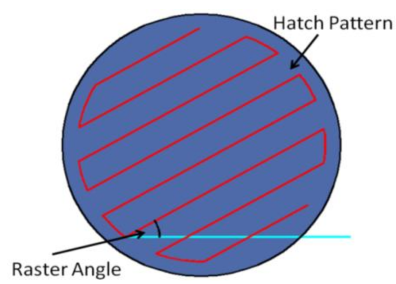

Figure3.6: Hatch pattern and raster angle in layer deposition

3.5 Post Processing

As mentioned in section 3.1.5, after completing the process, the part needs to be physically separated from the substrate. At present, LENS parts have comparatively rough surfaces. So, a certain amount of machining may be needed as well. This will depend upon the requirement. Moreover, there is no need for final peening or curing, since the pans have full power and density on building culmination. LENS fabricated components are strong enough to be employed as final products, hence direct metal prototypes may be engaged for product authentication, testing or injection molding tooling. A special function of the LENS process, as described in the earlier chapter, involves repairing of a metal part while on the source material. The parent material, due to low heat generated in the process, exhibits fewer adverse effects. This feature of repair capability ensures that expensive components, e.g., aircraft parts are not discarded but refurbished for reuse.

3.6 Accuracy

The LENS system follows certain specifications described by the system vendor. They are as follows and shown in Table 3.1 below,

Table 3.1: LENS build system specifications

Dimensional accuracy	± 0.020″
Repeatability	± 0.005″ in *X*-*Y* plane ± 0.020″in *Z*-axis
Layer thickness	± 0.001″-0.040″
Width of deposition line	0.01″-0.1″ and 1in^3/h

3.7 Advantages and Disadvantages of LENS Process

Advantages:

- The powder-streaming laser nozzle offers superior control for the following patterns: (i) 3-D Cartesian movement, (ii) 4-D movement that includes a rotating stage and (iii) 5-D articulated designs of industrial robots, permitting true freeform with high accuracy, the fifth dimension being tilt and rotation to deposit on the vertical surfaces.
- The powder liquefies as it reaches the focal zone of the beam and forcefully clads to the work piece. This molten metal spray clads to a highly compact matrix as it merges with the work piece, resulting in the creation of excellent structural strength.
- The manufacturing time is reduced with the scope of significant cost benefits in the production of components. Typically, several steps and bulky production equipment are needed to manufacture the finished product. The usage of such methods is warranted and beneficial only in mass and large-batch production. However, when the component is intricate in shape, has complicated internal sections or needs to be produced in a small lot, then there is a rapid rise in the time and cost. Hence, in such scenarios, adopting LENS proves to be advantageous.
- Additional savings can be achieved because of efficient material usage as compared with any other method of material removal.
- LENS process can be utilized in applications other than purely additive jobs. It can be utilized to develop wear-resistant layers of items subject to frequent wear, such as mechanical equipment having moving parts that require rework and titanium

parts in the aircraft. For instance, gas turbines are repaired by LENS-oriented refurbishment, which greatly enhances their service life.

- LENS is environmental-friendly since hazardous material is contained during processing in an inert atmosphere.

Disadvantages:

- If a flexible method of repair and cladding repair job is required, then the LENS process would demand highly skilled operators, advanced controls and perhaps a 4-D to 5-D control settings for the nozzle.
- The size of the particles of the powder employed in the process could be risky if inhaled, since the powder is grained to fine particles with a high density.
- The process needs a high-powered laser, which is expensive. Fiber coupling for increased flexibility would further increase the cost.
- Since parts are created freestanding, supports may be required for complicated structural parts.

From the above study, it has been identified that LENS process can be conveniently used for analysis of proposed Co-Cr-W alloy by optimizing the parameters of the technique. The process parameters selected are laser power, powder feed rate and scan speed. To identify the optimum process parameters a series of tests will be conducted on the deposits and will be evaluated.

The present chapter is an attempt to give a brief description of LENS machine, layout, components and working processes. The following chapter focuses on the experimental setup required for deposition and testing of the samples.