MODELING OF LASER BASED DIRECT METAL DEPOSITION PROCESS

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Abstract

Fabrication of metallic prototypes and functional parts is now possible using the Laser Based Direct Metal Deposition (LBDMD) process. It makes realistic components with dimensional accuracy of 0.25 mm. This process is suitable for making metallic components as well as composites. Hence LBDMD is the one of the useful technique to repair dies and aircraft components. This paper explains the design and fabrication of nozzle suitable for DMD. It also describes the various components of LBDMD process and their functions. It also gives the applications and advantages of LBDMD process.

Index Terms— Additive manufacturing, Coaxial nozzle, CNC unit, LBDMD process, Powder feeder.

I. INTRODUCTION

LBDMD is an additive manufacturing process in which the parts are made from metal powder by laser melting and solidification. This process is similar to conventional rapid prototyping process but the difference is that metal powder and even tool steel can be melted rather than plastic polymers. The production or reconfiguration of parts, molds and dies that are made out of the actual end material, such as tool steel or aluminium is possible with LBDMD.

In LBDMD process wastage of material is less and manufacturing of functional components directly from the CAD model is possible. Hence the overall cost of manufacturing is reduced and time taken for manufacturing components like die can be reduced up to 40%. LBDMD incurs lower tooling costs due to factors including the reduction of labor and capital equipment costs. The components produced have higher quality when compared to the conventional processes and usually the parts produced by direct metal deposition are generally 0.025mm oversized for a quick clean-up. The above advantages indicate the importance of the LBDMD. The wastage can be reduced by reuse of the metal powder that is unused during deposition. Hence this process is economical as well as environment friendly.

II. LBDMD PROCESS

In LBDMD process, high power laser builds parts layer-by-layer out of gas atomized metal powder. This process is the combination of five technologies: lasers, computer-aided design (CAD), computer-aided manufacturing (CAM), sensors and powder metallurgy. The resulting process creates parts by focusing a Nd:YAG laser beam onto a flat toolsteel work piece or preformed shape to create a molten pool of metal.

LBDMD system consists of a CNC-controlled overhead gantry to control the co-axial nozzle and focusing optics associated with Nd:YAG laser according to the CAD model geometry. Metallic powder which may be a tool alloy or pure copper is moved from on-board powder feeders by an inert gas at pre-defined rate to the nozzle. The metallic powder is added to the melt pool by a traversing beam energy source in an inert gas shielded environment.

This results in a layer by layer metal deposition and finally we get a 3D part identical in shape and geometry exactly similar to that of the CAD model. The cooling rates associated with this process make tool steel deposition structure similar to that structure obtained by quenching. Figure 1 shows the schematic representation of Laser Based Direct Metal Deposition Process [6].

Fig 1: Schematic representation of Laser Based Direct Metal Deposition Process
A. Characteristics of LBDMD
The following are the characteristics of LBDMD process:

- It has a dimensional accuracy of 0.25 mm.
- Fully dense metal components can be produced.
- Microstructure can be controllable using this process.
- It is capable of fabricating Heterogeneous materials.
- It also has the Control over internal geometry.

III COMPONENTS OF LBDMD

A. Nd:YAG LASER:
Nd:YAG (Neodymium-doped Yttrium Aluminium Garnet; Nd:Y3Al5O12) is a crystal that is used as a lasing medium for solid-state lasers. The dopant, triply ionized neodymium Nd(III), replaces a small fraction (1%) of yttrium ions in the host crystal structure of the Yttrium Aluminium Garnet(YAG), since the two ions are of similar size. The neodymium ion provides the lasing activity in the crystal. The wavelength of light emitted by Nd:YAG laser is typically 1064 nm, in the infrared. This type of lasers are used in manufacturing for engraving, etching, or making a variety of metals and plastics and are also used in metal surface enhancement processes like laser peening. They are extensively used for cutting and welding steel, semiconductors and various alloys. Today they are used in the non-conventional rapid prototyping process like Laser Engineered Net Shaping (LENS), Laser Based Direct Metal Deposition (LBDMD), etc., This laser requires power levels of typically 1 to 5 KW is used for LBDMD process. This laser is used in our PSG laser cutting machine.

1) Laser Specification:
- Laser type : Pulsed Nd:YAG laser
- Wavelength :1.064 μm
- Max. Energy :50 J
- Avg. power :150 W
- Pulse width :1 ms-20 ms
- Mode quality :Multi-mode
- Beam Diameter :10 mm
- Divergence : 6 m rad

B. CNC Unit
The CNC unit has a CNC-controlled overhead gantry and it is used to control a nozzle and focusing optics associated with a Nd:YAG laser according to CAM tool path data associated with the CAD model geometry. For the fabrication of complex parts CNC unit with 5-axis CNC gantry is preferred. Now we are using SIEMENS-SINUMERIC control for 3-axis movement of the CNC laser cutting machine. The CNC unit used to control the 3-axis movement is shown in the figure 2.

Fig 2: CNC unit for 3-axis LBDMD

C. X-Y Table
This is the worktable on which a substrate to be coated is placed and the layer by layer deposition occurs in the x-y plane. These 2-D layers are fused together to form a 3-D component. This work table is available in the CNC laser cutting machine itself. The size of the work table is 1600 X 600 X 20 mm³. The work table for LBDMD process is shown in figure 3.

Fig 3: X-Y work table

D. Powder Feeder
Powder feeder used for LBDMD process is gravity feed powder feeder in which the powder flows down by gravity from the hopper. Then it is made to fall on the disc which has two slots, the disc rotates the motor is switched on. The rotating disc spreads the powder uniformly and it is mixed with the carrier gas when it falls into the slot. Usually argon is used as carrier gas. The amount of powder flow increases with increase in the speed of rotating disc. The amount of gas flow and its pressure depends on the nature of the powder. The powder feeder is manufactured by Ion Arc private limited, Mumbai. Then the single flow is divided in to four equal flow using flow splitter and finally the four tubes are attached to the coaxial powder feeding nozzle. The particle size of 45 to 200 μm can be used in LBDMD. The
gravity feed powder feeder to supply metal powder to the coaxial nozzle is shown in the figure 4.

Fig 4: Disc type gravity feed powder feeder

E. Co-axial Nozzle

The powder delivery subsystem consists of powder feeders and a radially symmetric nozzles arrangement plays a very important role in the process. The nozzle arrangement, as a part of the laser deposition head, is the key component of the powder delivery system. A proper nozzle design allows the cladding process to be completed in a single step. Figure 5 shows coaxial nozzle arrangement used in the powder delivery system of LBDMD [1]. The deposition head provides laser light, powder, and protection gas. The powder, carried by the inert gas through four radially symmetrical nozzles is injected into the molten pool created by the laser beam. The powder feed rate ranges from 0.3 g/min to 50 g/min as governed by the rotational speed of the powder feeder rotating discs.

There are three different methods of powder injection:

a. Off-axis powder injection (a single powder stream is fed laterally into the laser beam)

b. Continuous coaxial powder injection (a powder stream cone is produced that encloses the laser beam)

c. Discontinuous coaxial powder injection (three or more powder streams are fed coaxially to the laser beam).

The off-axis powder injection nozzle is suited only for 2D applications, because the clad track depends on the scan direction. Applications for the coaxial powder injection nozzle are 2D and 3D part reconditioning processes since many of the parts (e.g. airfoil tips) require small tracks. The major advantage of the discontinuous coaxial powder injection is the potential to tilt the deposition head without influencing the powder stream. This feature allows multi-axis deposition. For LBDMD continuous coaxial nozzle is used [1].

Fig 6: methods of powder injection

IV NOZZLE DESIGN

A. Lateral Nozzle

Nozzle suitable for LBDMD process is continuous coaxial powder feeder nozzle. In order to withstand high temperature up to 950°C, copper is used as raw material for making the nozzle. First a prototype lateral feed nozzle arrangement was designed and it is made up of mild steel. It consists of three parts as shown in figure 6. The inner part is a laser nozzle of diameter 3mm. Outer part is for powder feeding it consists of a lateral powder supply tube of diameter 2mm. There is a pipe to attach this nozzle to the laser head. The gap between the inner and outer nozzle allows the powder flow and it will be in the shape of the cone. When laser beam is switched on it will melt the powder and it forms the melt pool in the substrate material. Then the layer by layer deposition will occur and it results in formation of component as specified in the 3-D CAD model.

1) Methods of powder injection:
available. The powder from the powder feeder is carried to the nozzle by Argon gas. The powder flow is divided into four equal flows for the powder feeding nozzle using flow splitter. The flow rate is adjusted by controlling the speed of the disc. Thus the layer by layer deposition occurs based on the movement of the table and laser head. Figure 8 shows the design for coaxial nozzle.

B. Coaxial Nozzle Design

The design for coaxial nozzle was done and it is based on the literature survey and it is similar to the nozzle of DMD 105 D available at CMTI, Bangalore. The coaxial nozzle is a single part it consists of inner laser nozzle of 2 mm diameter and four powder feeder nozzle. The nozzle design and arrangement of the coaxial nozzle is shown in the figure 7. The dimensions are based on the laser nozzle already available.
V MATERIAL SELECTION

- Nozzle material: copper
- Substrate material:
  - Mild steel
  - Aluminium
  - Ceramics
- Process material:
  - Aluminium
  - Copper and its alloys

VI FABRICATION OF COPPER NOZZLE

Copper nozzle was manufactured as per the design specifications. The inner part was machined to fit the laser head. The inner part is the laser nozzle and it has the same dimensions as the existing laser nozzle. Then the nozzle was checked for its dimensions and it is well within the specified limits. It also fits well with the laser head. The nozzle and laser head assembly is shown in figure 9.

VII ALTERNATE NOZZLE DESIGN

Alternate nozzle design is based on the prototype nozzle and the only difference is that the powder flow will be continuous and coaxial. Alternate design for coaxial nozzle is annular and it is shown in figure 10. As there is difficulty in making holes at 54° angle for 30 mm length the coaxial nozzle will be made based on the alternate nozzle design.

VIII LASER METAL DEPOSITION

A. Laser Deposition of Al

An experiment using Al powder was done. Al powder was spread on the mild steel plate of thickness 1.6 mm and laser is made to pass through the layer of the powder. The Al powder partially melted and deposition of a single layer of length 65 mm and width 1 mm occurred as shown in figure 11.

B. Laser Deposition of Copper

1) Experiment 1:

An experiment was carried out on Mild steel work piece as shown in figure 12. Copper powder was applied on the top surface of the work piece as shown in figure 13. Then laser sintering was done. The current was set at 250 A.
2) Observation:
The laser beam is made to pass through the single layer of copper powder applied on the top surface of mild steel work piece. The feed rate was given as 100 mm/min. First vaporization of copper powder occurred. Then the feed rate was increased to 200 mm/min. This time partial vaporization of copper powder occurred. Only small amount of powder gets sintered.

3) Experiment 2:
This time current was reduced from 250 A to 150 A. Again the same experiment was repeated with feed rate of 200 mm/min.

4) Observation:
In this experiment copper powder was fully sintered and single layer deposit on substrate was made as shown in figure 14.

5) Experiment 3:
This time same experiment was repeated on the side surface of the work piece which was shown in figure 15 with same parameters as mentioned in the second experiment. Then the laser sintering of first layer was done as shown in figure 16 and second layer of copper powder was applied and sintered as shown in figure 17. The first layer deposit was made in X-direction and the second layer deposit was made in y-direction i.e. perpendicular to the first layer. Similar experiment was carried out on different materials with different geometries and it resulted in multilayer deposition of copper as shown in figure 18.
C. Comparison of Vickers Hardness Value:

<table>
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<th>S No.</th>
<th>Current (A)</th>
<th>HV S1</th>
<th>HV S2</th>
<th>HV S3</th>
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<td>53.72</td>
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<td>150</td>
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Fig. 19: Comparison of Vickers Hardness value for three different specimens

D. Microscopic images of single layer copper deposition

Fig. 20: Microscopic images of single layer deposited copper at different magnifications

d.

IX RESULT AND DISCUSSION

From these experiments we observed that direct metal deposition of copper and aluminium was possible with the Nd:YAG laser of average power 150 W. From the graph shown in figure 19 the hardness value decreases as the number of layers increases. This is due to oxidation. From the microscopic images shown in figure 20 the copper layer deposited is porous. This is also due to oxidation. So the parameters should be optimized to improve the layer strength and deposition should be done in the inert gas atmosphere.

X CONCLUSION

Thus the laser cutting machine was converted in such a way that it will do direct metal deposition. We have modified the nozzle suitable for LBDMMD process. The future work will be the fabrication of components with different metals and alloys in inert gas atmosphere and test their properties. The current process is semi automatic, but we have to automate the process to reduce error and time consumption.

REFERENCES