Study on Misalignment of Focus Position in Laser Metal Deposition Shaping Processing

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Abstract. In order to investigate the effect on manufacturing quality of focus position misalignment between laser beam and powder convergence in laser metal deposition shaping (LMDS) processing, several experiments including single-track monolayer, straight thin-wall and ring thin-wall were made. The measurements and analysis on shape, size and surface quality of the experiment parts were carried out. An omnidirectional detecting method to check the misalignment of focus position was brought forward and tested. The results indicate that the misalignment of focus position directly affects the quality of shaping parts and shows the regularity, the detecting method can easily detect the focus position misalignment on random direction and angle and guide the adjustment on them.

Introduction

Laser metal deposition shaping (LMDS) is a new rapid manufacturing technology that melts metal powder entering the molten pool made by the laser beam’s melting on the surface of substrate metal to produce functional metal workpiece line by line and layer by layer with low dilution ratio between the layer and substrate, whose shaping trace can be controlled by NC system. Base on the shaping principle of discrete accumulation and additive manufacturing, LMDS technology—which combines with CAD, laser cladding and rapid prototyping—breaks through the traditional rapid shaping technology in manufacturing and is one of new manufacturing technologies with more study and development [1-2]. The powder feeding by side-injection has been studied and become more familiar, but it is inapplicable to the 3D manufacture. The feeding by coaxial-injection overcomes the deficiency of side-injection and can processes 3D manufacture, so it has been being a more interesting study [3-5]. The powder feeding by coaxial-injection needs alignment of the focus position between laser beam and powder convergence, which can adapt the change of scanning trace and whose feeding powder has isotropic character. Laser cladding by coaxial feeding can get homogeneous and uniform layer because the coaxial feeding eliminates the effect of feeding direction on cladding layer figure. In the past experiments of laser metal deposition shaping, elaborate analysis has been made on process parameters and samples, but there are scarce studies and reports on misalignment of focus position between laser beam and powder convergence [1-9].

Experiments and Results

Several experiments of LMDS including single-track monolayer, straight thin-wall and ring thin-wall were made. The powder is Ni60A and the particle size is from -150 to 300 mesh. The process parameters were as follows: laser power, 1.3kw(GLS-IIIB CO\textsubscript{2} laser); scanning speed, 3.0mm/s; laser beam diameter, 3.0mm; powder feeding velocity, 15 g/min; and the shielding gas, argon gas.

There exist obvious differences of surface quality between two sides of the single-track monolayer samples and straight thin-wall samples. Fig.1a is the single-track monolayer sample, the left side is clean and smooth, but the right is coarse and rough and there adhere lots of metal particles with different sizes. Fig.1b is the smooth side of straight thin-wall sample, the surface is...
clean and well-bedded. Fig.1c is the coarse side of straight thin-wall sample, the surface is rough and ragged, most clinging particles can be removed by simple manual processing while the less weld on the surface that severely affect the quality.

![Image of sample surfaces](image)

(a) single-track monolayer (X20)   (b) smooth side (X20)   (c) coarse side (X20)

Fig.1 Comparison of two sides of experiment samples

Except the surface quality between two sides, the height and thickness are evidently different. The length of straight thin-wall sample is 80mm, however, the height difference of two edges reaches 13mm, as shown in Fig.2. To the ring thin-wall sample, the height of circle sides is like a saddle—front and rear sides are higher than two lateral sides, the thickness of the higher sides is bigger than the two lower corresponding sides and the biggest difference is 0.9mm, but the thickness of two points where the diameter line intersects with the circle is the same, as shown in Fig.3.

![Images of height differences](image)

Fig.2 Height difference of metal thin-wall sample

Fig.3 Height and section feature of ring thin-wall sample

**Experimental Analysis**

In LMDS processing, there are two circles on the shaping surface of substrate—laser beam circle (the circle that shaping surface of substrate intersects with laser beam focused by convex) and powder convergent circle (the circle that shaping surface of substrate intersects with reverse taper powder flow converged by coaxial nozzle), the diameter of powder convergent circle is little bigger than that of laser beam circle, as shown in Fig.4. The laser beam focus is the center of laser beam circle and the powder convergence focus is the center of powder convergent circle. All powders can be injected into the molten pool created by laser beam on substrate shaping surface as covering style when the focus position between laser beam and powder convergence is coincident, thus the sintering area is the full area of laser beam, as shown in Fig.5. When the focus position is misalignment, the sintering area is intersection part of two circles, as shown shadow in Fig.6, and there are some powders remaining at the right side that can’t be sintered fully.
When single-track clad, actual sintering width is little less than the diameter of laser beam circle and alters with change of scanning trace if the focus position is misalignment. There have excessive powders that can't be completely sintered to accumulate and adhere on the side near to the powder convergence focus to form the rough surface, meanwhile, the side near to laser beam focus has no surplus powders to form the smooth surface. When straight thin-wall clad, the lower edge of sample has less powders entering molten pool to accumulate due to the focus position misalignment (convection can't create in full molten pool since temperature change velocity is about $10^4$-10$^5$°C/s).

When ring thin-wall clad, the actual cladding trace is the same as the shown trace in Fig.7 when two circles scan on the ring scanning trace. The thickness presents non-uniform and periodic change and there exit dimension errors between internal ring and external ring. Compared Fig.3 with Fig.7, the morphology change of thickness is the same—the lower part (thin wall) of sample is corresponding to the minor axis direction of the sintering area where has less powders entering molten pool to accumulate while the higher part (thick wall) is corresponding to the long axis direction of the sintering area to buildup, which displays that the misalignment of focus position brought about the rough side, thickness non-uniform and dimension errors.

**Detecting Method**

The above analysis is the focus position misalignment along X axial. In order to check the focus position misalignment on random direction and angle, an omnidirectional detecting method can be adopted. The detecting method is that eight single-track monolayer layers with certain length whose scanning direction separately intersects angle of 0°,45°,90°,135°,180°,225°,270° and 315° with X
axial are made, as shown in Fig. 8a. To each layer, the height and width of three points shared on the layer are measured, then focus position misalignment on random direction and angle can be analyzed and calculated according to the above analysis.

After the adjustment of the focus position, experiment of the omnidirectional detecting method was finished. The powder is Ni60A and the particle size is from -150 to 300 mesh, cladding length is 50mm. The process parameters were as follows: laser power, 1.0kw(GLS-IIIB CO₂ laser); scanning speed, 5.0mm/s; laser beam diameter, 2.0mm; powder feeding velocity, 10g/min; and the shielding gas, argon gas. Fig. 8b is the sample and Table 1 is the measure results. The height and width are nearly same and external appearance is quite similar. Standard deviation of cladding height is 0.0105mm and standard deviation of width is 0.0209mm. The experiment indicated the adjustment of focus position according to the above analysis satisfied the shaping requirement, furthermore, it can demonstrate that cladding quality by coaxial feeding did not affect by scanning direction.

![Image](a) Sketch of omnidirectional detecting method   (b) Actual cladding sample

**Fig. 8 Experiment on omnidirectional detecting method**

| Angle[°] | Measured value | Average | Standard deviation | Measured value | Average | Standard deviation |
|---------|---------------|---------|--------------------|---------------|---------|--------------------|
| 0       | 0.357         | 0.362   | 0.364              | 0.361         | 0.361   | 0.0036             |
| 45      | 0.373         | 0.380   | 0.381              | 0.378         | 0.378   | 0.0044             |
| 90      | 0.352         | 0.352   | 0.355              | 0.353         | 0.353   | 0.0017             |
| 135     | 0.371         | 0.369   | 0.376              | 0.372         | 0.372   | 0.0036             |
| 180     | 0.358         | 0.360   | 0.362              | 0.360         | 0.360   | 0.0020             |
| 225     | 0.372         | 0.374   | 0.379              | 0.375         | 0.375   | 0.0036             |
| 270     | 0.348         | 0.353   | 0.352              | 0.351         | 0.351   | 0.0027             |
| 315     | 0.353         | 0.356   | 0.356              | 0.355         | 0.355   | 0.0017             |
| Average | 0.363         | 0.0105  | 1.953              | 1.938         | 1.937   | 0.0209             |

**Table 1**  Datasheet of omnidirectional detecting experiment

**Conclusions**

Through experiments and analysis, the misalignment of focus position between laser beam and powder convergence has direct influence on shaping figure, size and surface quality, which showed some regularity. The omnidirectional detecting method can easily analyze and study the focus position misalignment on random direction and angle, which guides the adjustment of focus position.
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