Discussion scanning mode of direct laser fabrication quality influence

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\textbf{Abstract.} The titanium alloy direct laser fabrication process, the collapse of a side issue has interference and preventing the forming quality and forming precision. This thesis mainly contain with of temperature field analysis and actual observation, by changing the scanning mode to solve this issue. The new scanning mode, dam-type, has a good property and proves that the direct laser fabrication parameters can be complete without change through the whole forming process, and puts the process of control simply.

\textbf{Introduction}

Direct laser fabrication (DLF) in titanium alloy parts manufacturing is widely used, and the process does not need any modules or cutting tools. DLF is a developed kind of advanced manufacturing technology in 1990s, it belongs to Rapid Prototyping, combining Rapid Prototyping (RP) technology and Laser Cladding (Laser Cladding) technologies, from the CAD files directly produce a variety of complex near net form metal parts, full dense, high flexible manufacturing, production cycle is short, lower-cost advantages, getting a lot attention from the academic and manufacturing [1]. Titanium alloy DLF technology is coming after rapid prototyping manufacturing, which can realize from three dimensional design to meet the requirements of the use of large-scale titanium alloy parts a promising technology. This technology is comprehensive used at laser repair and functionally gradient materials preparation in aviation industry [2].

This technology is promising and wildly used [3]. Now there are a large number of problems have to be solved, such as disposable forming, precise forming, reduce the residual stress, deformation, and avoid cracking and get the satisfactory microstructure, etc. Many scholars research on how to reduce defect such as residual stress and deformation [3-6]. A large number of new technologies have been used for DLF, such as ultrasonic vibration and electromagnetic stirring to alter and reduce residual stress. But now discussing about one-time molding and precise forming are also less [7].

This paper discussed precise forming, the primary solution to the volume of the molding of the edge collapse, and thus the molding of precision and quality. Whether by reciprocating scan or using reciprocating crisscross scan, in the edge of the scanning prone to energy density too high or low phenomenon, even with the right energy density will be because of the energy accumulation that the temperature becomes too high, produce the edge collapse phenomenon. The collapse of a serious side of shaping quality and reduce the molding’s utilization rate of the edge. With high temperature monitor system, and real-time adjustment of laser power, equipment requirement is high, and difficult to come true. In order to solve the problem, in a single word of the scanning for reference, the application experience in the forming process of volume, namely first external outline or the outline of bias scan, and in the internal reciprocating scanning and obtain the better molding effects. We can define it dam-type way. This paper studies the materials for including temperature field finite element model is established, experiment, results and discussion, conclusions, and the references.
Temperature field analysis

Using finite element software MSC.MARC temperature field simulation, through which gets the temperature of the space and time distribution in different path by the finite element model. Through comparing the result of simulation of temperature field of change, and get a different path of temperature distribution characteristics, and get the reason for a different path of volume that made contour shape change. Some important parameters using in the simulation such as scanning speed [mm/s] 3, laser power [W] 2000, Laser source form gauss heat source, convection heat transfer coefficient [W/(m²·℃)] 37.5, and radiation rate 0.34 use in the three scanning type-reciprocating scanning, reciprocating crisscross scanning and dam-type are the same. The three scanning types’ path are showing in figure 1.

In fig. 1 (a) we can easily see that the path begin at the left bottom reciprocating to the right up, and every layer is in the same way, that is the reciprocating canning way. In fig. 1 (b) the black line is the first layer path, and the gray line is the second layer path, the two layers in turn become the reciprocating crisscross scanning. And the third is fig. 1 (c) the path of dam-type, the outline in every layer is first scanning in clockwise from the left bottom, and the gray line is the path without laser; the reciprocating path in the inner just like fig. 1 (a).

The finite element establish to simulation for given priority to different scan route temperature distribution. In order to save the modeling and simulation time the small size of the finite element should have been modeled (Fig. 1 (d)). After the modeling, follow three groups of simulated results. Reciprocating scanning and reciprocating crisscross scanning first layer:

Fig. 2(a) The bigen way
At Inc 20

Fig. 2(b) The right turning
At Inc 190

Fig. 2(c) Amplification right turning
At Inc 190

Fig. 2(d) The lift way
At Inc 254

Fig. 2(e) Amplification right turning
At Inc 254

Fig. 2(f) The last way
At Inc 470
Reciprocating crisscross scanning:

Fig. 3(a) Second way begin At Inc 520
Fig. 3(b) Intermediate process At Inc 696
Fig. 3(c) Second way end At Inc 980

Dam-type:

Fig. 4(a) The outside way At Inc 180
Fig. 4(b) Inside right turning At Inc 366
Fig. 4(c) Inside left turning At Inc 320
Fig. 4(d) Inside scanning At Inc 390
Fig. 4(e) Inside last beginning At Inc 468
Fig. 4(f) Inside last scanning At Inc 480

We can see that the different scanning type stability degree a little effect to the weld pool. But, through the result pictures the weld pool temperature distribution can be distinguish. The fist scanning line of reciprocating scanning and reciprocating crisscross scanning are have the same symmetrical temperature distribution along scanning direction (Fig. 2(a), Fig. 3(a), Fig. 4(a)). From the Fig. 2(f), Fig. 3(c), Fig. 4(d), the temperature distributions are deflect to the unformed direction. And In the actual titanium alloy direct laser fabrication, because weld pool is a deflection of forming thickness uneven, have already formed in the direction of the thick, and another direction of forming thin. We also can fund that at the end of the scanning way the temperature will be higher than others’, that because the end boundary conditions are lack of a direction of metal, but instead of heat transfer of heat convection boundary conditions; and when on the turning scanning time (Fig. 2(b)-(e), Fig. 3(b)), this conditions have to hold a while, even worse the temperature distributions are deflect to the outside. So the weld pool will outward flow. On the dam-type way, on the turning time (Fig. 4(b), Fig. 4(c)), the temperature distributions are deflect to the inside, although on the scanning way the temperature distributions are still deflect, but when begin the last inside scanning (Fig. 4(e), Fig. 4(f)), the deflection before will be corrected.

Experiment

The experimental material is Ti-6Al-4V spherical powder, Grain size from-100 to 200 mesh and oxygen levels for 0.07% and the material composition is list at table 1. The substrate is complete Ti-6Al-4V (TC4), and the dimension is 110*60*10 [mm]. Prior to deposition, the plates were lapped on both sides by surface grinding and polishing and degreased using acetone and alcohol.
Table 1

| The material composition of TC4 | H    | O    | Al   | N    | C    | V    | Si   | Fe   | Ti   |
|---------------------------------|------|------|------|------|------|------|------|------|------|
| TC4 (W%)                        | 0.009| 0.16 | 6.02 | 0.027| 0.056| 4.00 | 0.039| 0.15 | bal  |

The use of the equipment including: 5kW carbon dioxide laser de inspire; the light path and focus lens; vacuum protection case and vacuum get system; powder feeding and coaxial powder feeding nozzle; and 3- axis workbench. The equipment also includes computer control software which can input G-code that take the part into layers and the layers into lines. We can input the G-code define the scanning way which we hope. For these we can make out reciprocating scanning, reciprocating crisscross scanning and dam-type.

Before these experiment a lot of work have to make sure the experimental parameters, and we got some appropriate parameters which are list at temperature field analysis; and other parameters like powder feeding rate is 1 °s, each layer is built 0.8 mm, and overlap rate is 10%. The equipment sketch maps follow fig. 5.

Fig. 5 Equipment simple plan

Before doing experiment should check the laser and powder coaxial and make sure that the whole system can work. At the beginning of the DLF has to get really empty by vacuum pumping, when pressure in the vacuum chamber less than 10 Pa, filled vacuum chamber with argon, like that the pressure slightly higher than the atmospheric pressure, to keep off the air. Because without a complete vacuum state-the pipeline contact the chamber and the tester has no way to vacuum suction oxygen content, when filling the argon into the vacuum chamber the level of oxygen about 1%, so a little high about the content of oxygen, gradually declined, finally it can achieve 4 PPM. At the beginning of experiment, because the phenomenon of Ti-6Al-4V spherical powder bound, and in the laser the column can see dazzling particles in beating; at the same time there is a lot of powder hop outside of the pool, some fell on to the already process of surface, this forming cause bad effect of next layer, that the probability of between inclusion level will increase. So after each layer use the air from nozzle, which is used for blow away the floating powder on the surface. This can avoid the stranded powder caused the forming thickness non-uniform and the inclusion. To avoid flow on impact to feed powder, stopping between forming a layer and layer, and moving workbench, can move according to the forming of the size of the arrangement, make the surface of powder are forming be blown away. The process of the path is shown in figure 1.
Results and Discussion

After the experiment we can get three volumes TC4 works.

Fig. 6(a) Reciprocating scanning (b) Reciprocating crisscross scanning (c) Dam-type

Form the three pictures we can clearly see the different of form; the dam-type quality is satisfactory. In the dam-type path of the shape at the outline is closed, through to the processing of the observation and evaluation, the surface quality and the molding of vertical level are satisfactory. It mainly depends on the fabrication process no edge, also is not appear border path or turn-back paths end in the same side (Fig. 6 (a), Fig. 6(b), Fig. 7 (a), Fig.7(b)), even if an end of outline in all around is similar to a side have just molding. In the end of the process in other situations with quite, so shaping quality is also the same. When internal reciprocating scanning, past the edge of scanning has now become a internal, outside the molding of just a thin wall, in order to prevent the edge collapse appeared because power density flow of molten pool; and for a long time continuous processing the accumulation of heat caused by high temperature result in strong liquidity edge and collapse edge phenomenon. We also found that in the experiment, the outline of molding in contour line have to turn to the place appears easily superfluous edge(Fig. 8), this is a bad reason for processing quality, caused by the powder in single channel layers of contour scanning forming. However the dam-type, after the outline scan, high power density of internal reciprocating scan or because of heat accumulation of high temperature, which cause of molten pool liquidity will whisk off the bumps of the outline scan at the corner. The scanning mode, make full use of two kinds of scanning mode of advantages and shortcomings, using single channel layers of contour shape the scanning as the internal reciprocating scanning outline of the border, and improve the quality of the molding; Use the edge of the reciprocating crisscross scanning
overheating phenomenon to remove the bumps of outline. The combination of the two kinds of scanning mode ensures the quality and improves the efficiency of the molding at the same time in molding.

The union conditions between layer and layer. The improvement of the collapse promotes the effective and cuts down the molding process time, and the surface shape from approximate circular arc form (Fig. 6(a), Fig. 6(b), Fig. 7(a), Fig. 7(b)) into the same basically horizontal flat surface (Fig. 6(c), Fig. 7(c)), reduce the surface processes in the cave, and for the next layer of forming to create a good combination between layers of the condition. Each layer is built by first making an outline of the section and then filling it in with slightly-overlapping parallel-line deposits. The lines in each successive layer are deposited parallel to those in the previous layer to minimize variations in build height within the part. On the other hand, this method improves the surface shape for coaxial nozzle to feed powder, layering, even the utilization ratio of the thickness of the creation favorable conditions. When rough surface, present arc shape, spherical powder falls bounce tend to fall out of the pool, so that will reduce the external layer thickness and will be provided where the other not forming molding of powder in advance by bouncing, is likely to cause the uneven layer after layer between the porosity and combining with a drop in the quality. When the contour model and reciprocating scanning mode becomes no edge collapse, the surface is improved the quality of the combination between layers and surface quality.

Conclusions

Form this paper we can get some conclusions.
(1) The dam-type model improves overall shape approximation degree, effectively and avoids the edge collapse phenomenon.
(2) This scanning way gets two different paths together, and so we achieve a better new path.
(3) During the whole process, using the same parameter, we can still get satisfactory works, although the temperature rising because of the heat accumulation.
(4) Dam-type, this scanning path, can appropriate increase power density, so as to effectively reduce the surface roughness and the overall smoothness.

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