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Simulation of SLM manufactured aluminum process and optimization of the parameters by computational fluid dynamics method

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Abstract. The additive manufacturing technology of metal components is an advanced technology in the field of mechanical engineering and material science. Laser selective melting (SLM) is one of the most widely used methods in additive manufacturing. The temperature field of SLM process is the key factor to determine the quality of additive, so it has important research value. In this paper, the influence of laser power and additive speed on the temperature field of aluminum alloy additive manufacturing is studied by CFD numerical simulation technology. The results show that the CFD model can well simulate the SLM process. The additive temperature decreases with the increase of additive speed and increases with the increase of laser power. By adjusting the additive manufacturing parameters, the quality of additive manufacturing can be corrected and improved.

Keywords: additive manufacturing, SLM, aluminum alloy, simulation

1. Introduction

In the last two decades, additive manufacturing technology has rapidly developed and is widely used in the medical, automotive, and aerospace fields [1-2]. Additive manufacturing technology, commonly known as 3D printing, integrates computer-aided design, material processing and molding technologies, digital model files as the basis, through software and numerical control system, unique metal materials, non-metal materials, and medical biomaterials, according to extrusion, sintering, fusion, light curing, spraying and other ways to stack layer by layer, manufacturing technology to create a solid object. In contrast to the traditional processing mode of removing, cutting, and assembling raw materials, this is a "bottom-up" manufacturing method of accumulating materials from scratch. This makes it possible to manufacture complex structural parts that were not possible in the past due to the constraints of traditional manufacturing methods.

SLM (Selective Laser Melting) is a significant technology in additive manufacturing of metallic materials, used in aerospace, medical, mold and die, nuclear industry, and other fields. SLM technology overcomes the problems associated with manufacturing metal parts with complex shapes by traditional techniques. It can directly form metal parts with nearly full dense and good mechanical properties. For 3D printing technology and SLM laser-selective melting technology, many researchers, in terms of experimental or numerical simulations, have already carried out research work.

Wang et al. reviewed the research progress of 3D printing technology in human organ repair and artificial organ preparation [3]. In the paper, the authors describe the methods and extent of application of bone repair, artificial liver fabrication, and 3D printing of blood vessels and nerves, and the authors point out that 3D printing technology will be quickly and universally applied in clinical medicine in the future. In response to the problems involved in SLM research, such as spheroidization, porosity, physical metallurgy, and material extensiveness, Ridi Li conducted a systematic and in-depth study on the universal theories of spheroidization [4], porosity formation, and control, and physical metallurgical mechanisms in the SLM process with AISI316L as the representative material, and proposed methods to improve the SLM forming quality: minimizing the oxygen content in the powder and forming atmosphere, and using a preheating system to make the melt have good wetting properties, which in turn can improve the forming quality. Yang et al. designed 3D models of typical geometrical features such as thin plates, sharp corners [5], cylinders, round holes, and square holes, and selected 316L stainless steel powder for laser-selective melting forming of these typical geometrical features. The experiments show that the main factors affecting the dimensional accuracy and laser-selective melting capability of the parts are laser spot constraint, step effect, powder adhesion, and deep laser penetration. The authors thus propose part design rules applicable to laser-selective melting to provide a reference for innovative product design. Wang et al. investigated the relationship between the process parameters, energy input, sample density, surface morphology and microstructure characteristics of laser-selective melting of 316L stainless steel powder [7]. The results show that: the scanning speed has the most significant effect on the forming effect; the sample density tends to increase gradually with the increase of laser energy density; the volume density is operable as the technical index of the selected laser melting process; the surface morphology is determined by the ratio of laser power to scanning speed. Zhang et al. analyzed the temperature field during laser-selective melting (SLM) of Al_2O_3 ceramics [7]. They investigated the effect of laser power and scan rate on the thermal behavior of the melt pool. The experimental results show that the maximum temperature of the melt pool is a direct factor affecting the value of the cooling rate when the scanning rate is fixed. The higher the maximum temperature of the melt pool (the higher the laser power), the higher the cooling rate. As the laser power increases or the scan rate decreases, the size of the melt pool gradually increases.

Wenshu studied the temperature and stress field changes during SLM processing: with the increase of laser power, the melt pool width [8], depth, and length increase, and the melt pool tend to be slender; with the increase of scanning speed, the melt pool width and depth decrease, and the length remain unchanged, and the melt pool also tends to be slender; the final melt layer during SLM processing shows tensile stress, and the residual stress of its melt layer is more considerable more significant near the substrate, and the cumulative processing temperature is beneficial to reduce the residual stress of the formed parts. Wu et al. investigated the technical points of three critical selective laser melting subsystems: laser, powder spreading, and scanning [9]. It was shown that the continuous descent accuracy of the forming elevator, the rotary eccentricity of the powder laying rollers, and the radial runout all have signific essential effects on achieving the minimum powder laying thickness control. Combined with the scanning speed comparison test, the scanning characteristics of the scanning system are analyzed, and it is concluded that the use of fast scanning speed is an essential feature of the selective laser melting process. And in addition, a suitable scanning strategy should be used to overcome thermal distortion. Yin et al. described the basic principle of a new type of rapid prototyping (RP) technology [10], the selected area laser melting technology, which has emerged in recent years; introduced in detail the research results of the equipment, process, and metal powder materials for forming related to the selected area laser melting technology at home and abroad; and further discussed the application of the selected area laser melting technology and its development direction.

According to the current literature review and the development trend of SLM technology, the two parameters that have the most critical impact on the processing accuracy of SLM technology are scanning speed and laser power. Because they have the most significant effect on the processing temperature of additive manufacturing, therefore, this paper simulates the temperature field of metal

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SLM technology by numerical simulation method, focusing on the influence of scanning speed and laser power on the processing temperature and the control method.

2. Model description

This study is based on the simulation of FLUENT software. An aluminum plate model with length, width and thickness of 100*60*10 mm is established and the aluminum plate is placed flat. The model is shown in Figure 1. A laser head emitting laser is placed above the aluminum plate, and the aluminum plate moves relative to the laser. The SLM laser additive manufacturing process is simulated by computational fluid dynamics (CFD) model, and the additive process is simulated by the relative motion of the laser heat source and the material to be added. The left side of the model plate is the direction of additive speed. Wherein the heat source area on the aluminum plate due to laser heating is about 10 mm^2.

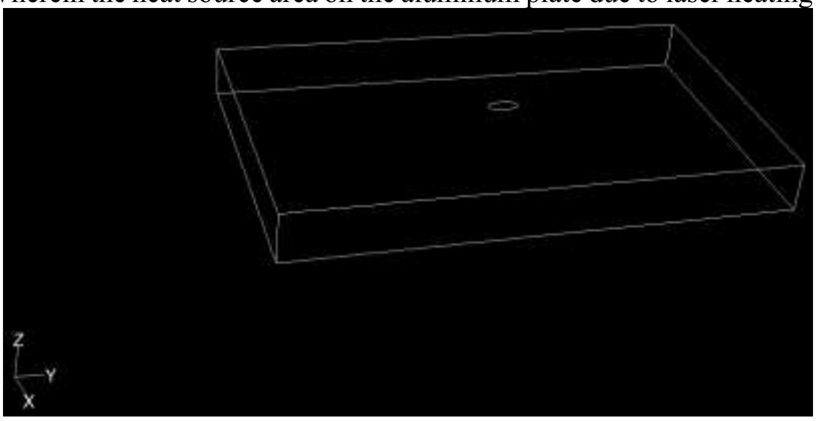

Figure 1. SLM simulation area description.

Totally 9 cases were simulated, the laser power in the range of 200W to 400W, and the setting of laser power is shown in Figure. 1. The laser power values of the nine groups were 200W, 225W, 250W,275W, 300W, 325W, 350W, 375W and 400W, respectively. Seven groups of laser scanning rates with values of 0.001, 0.0025, 0.004, 0.0055, 0.007, 0.0085 and 0.01 m/s were also simulated in this work. The range of laser scanning speed should be 0.001-0.01m/s. The setting of laser additive scanning speed is shown in Figure 2.

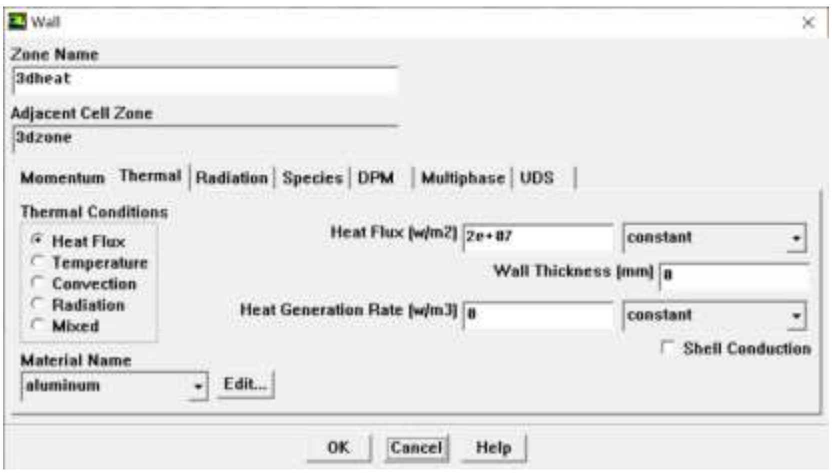

Figure 2. Setting of the laser powers.

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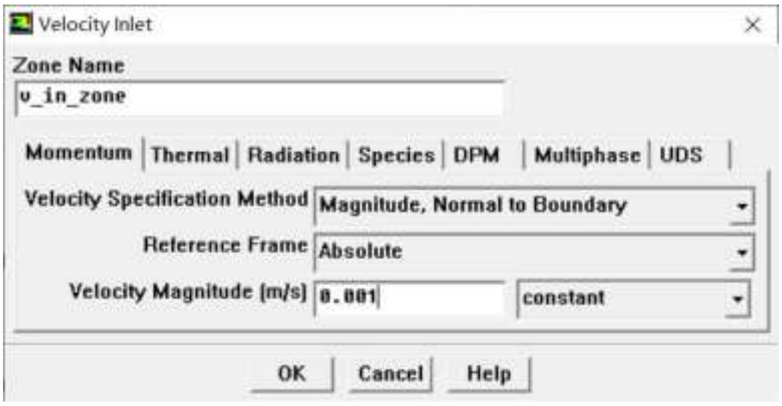

Figure 3. Setting of the laser velocity.

By simulating the processing process of laser striking on the surface of aluminum plate, the temperature field distribution on the surface of aluminum plate is obtained, and the influence of different parameters on the SLM processing is analyzed and compared. Through the analysis, the influence of parameters is studied, and the additive manufacturing process under this condition can be adjusted and optimized.

3. Results and discussion

According to the second part of the model introduction, a total of 15 groups of simulation calculations are completed. The simulation results are analyzed below.

The first is the analysis of the influence of laser power. The maximum temperature range of the plate surface obtained from the experimental data under various working conditions is about 600-700 K.

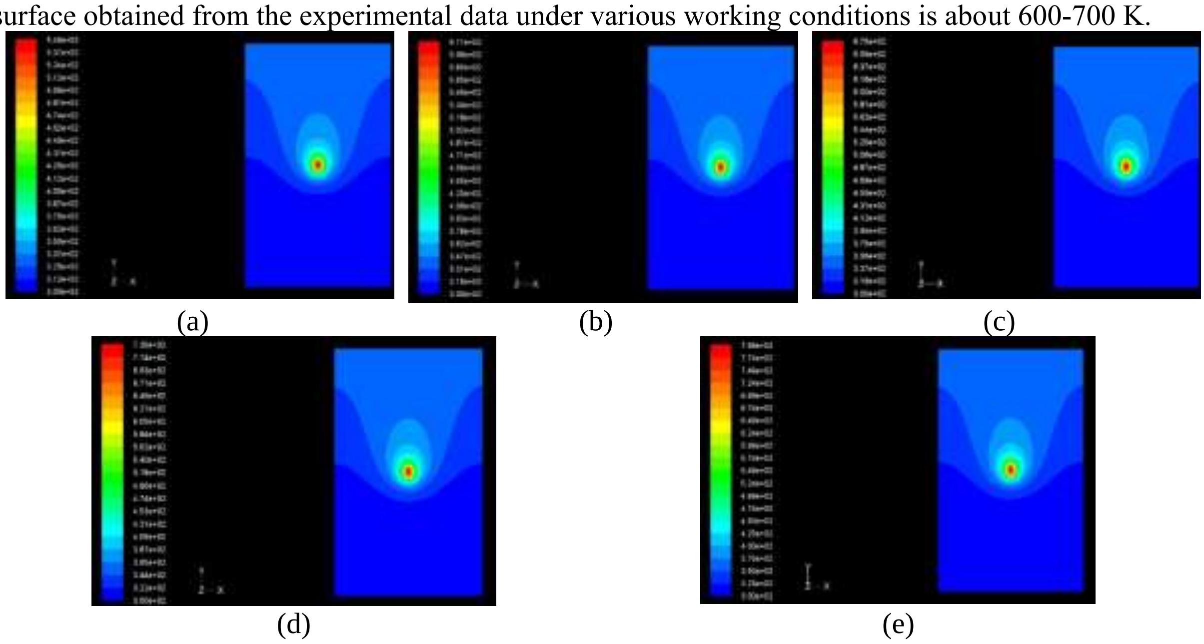

Figure 4. Temperature fields at the top surfaces of the simulated cases.

Fig. 4 (a) - (e) are cloud diagrams of the temperature on the top surface of the plate with the laser scanning speed of 0.0055 m/s and the laser power increasing in order of 200 W, 250 W, 300 W, 350 W and 400 W, respectively, among which the highest temperature is 549 K, 611 K, 675 K, 736 K and 799 K. In the cloud diagrams, the blue area is low temperature and the red area is high temperature. The temperature distribution curves of the five working conditions are roughly the same. The distribution of temperature field is symmetrical about the scanning centerline. The red high-temperature area is the core area of SLM additive molding, and the green is the sub high-temperature area, which is the heat affected zone (TAZ, HAZ).The temperature distribution on the upper surface of the additive manufacturing plate

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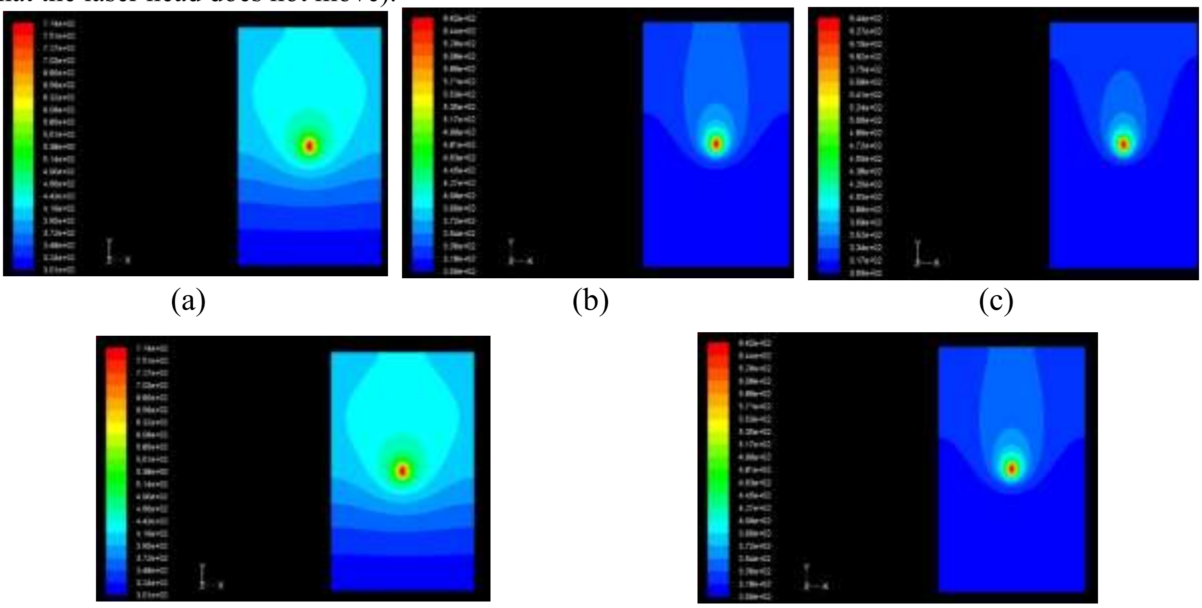
gradually decreases from the laser center to the periphery, and the isotherm is elliptical; The temperature of the area scanned by the laser is higher than that of the area not passed by the laser. The boundary line is parabolic, and the opening direction is opposite to the moving speed direction of the plate (assuming that the laser head does not move).



(a) (b) (c)

(d) (e)

Figure 5. Temperature fields at the top surfaces of the simulated cases.

Fig. 5 (a) - (e) are the temperature nephograms of the top surfaces of the plate when the laser power is 300 W and the laser scanning speed is 0.001m/s, 0.007m/s and 0.01m/s, respectively. The highest temperatures are 774 K, 662 K and 644 K in order. When the laser power is constant, the maximum temperature of the plate gradually decreases with the increase of the laser scanning speed. The temperature distribution images of the three working conditions are obviously different. The high temperature range in the edge area in Fig. 5 (a) is significantly larger than that in Fig. 5 (b) and Fig. 5 (c). The low temperature range in the edge area in Fig. 5 (c) is the largest and the temperature is the lowest. The temperature distribution lines of the three images are almost elliptical, of which the ellipse in Fig. 5 (a) is the largest and the ellipse in Fig. 5 (c) is the smallest.

Fig. 6 (a) shows the change of the maximum temperature of the plate surface with the laser scanning speed, and Fig. 6 (b) shows the change of the maximum temperature of the plate surface and the laser heating power. As can be seen from Fig. 6 (a), when the laser heating power is constant, the maximum temperature of the plate decreases with the increase of the laser scanning speed. The larger the difference between adjacent speeds, the faster the temperature decreases; As can be seen from Fig. 6 (b), when the laser scanning speed is constant, the maximum temperature of the plate increases with the increase of the laser heating power. The surface temperature of the plate changes linearly with the above two variables.

Through the above simulation experiments and analysis of experimental data, it can be known that the laser heating power and laser scanning speed have a significant impact on the temperature of the machined surface of the plate in the actual working process of additive manufacturing SLM. The maximum temperature of the plate surface increases with the increase of the laser heating power and decreases with the increase of the laser scanning speed. However, the overall temperature of the experimental data is relatively low compared with the actual working process. If we want to optimize the additive manufacturing process, we must optimize the working environment and improve the working temperature. Therefore, in order to improve the working temperature, the author suggests using a larger laser heating power and a smaller laser scanning speed in the actual processing process.

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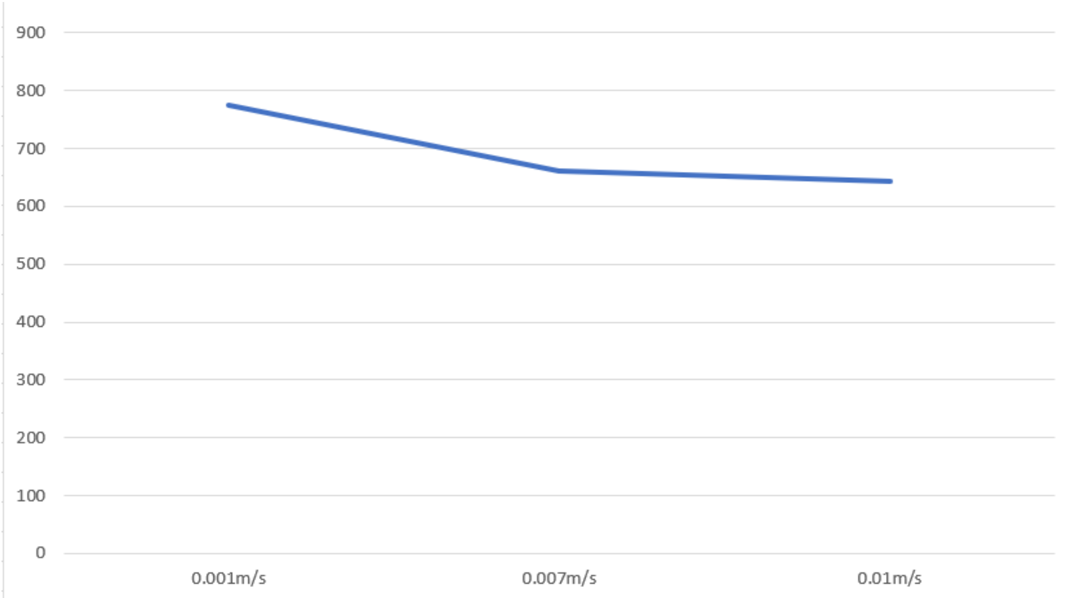
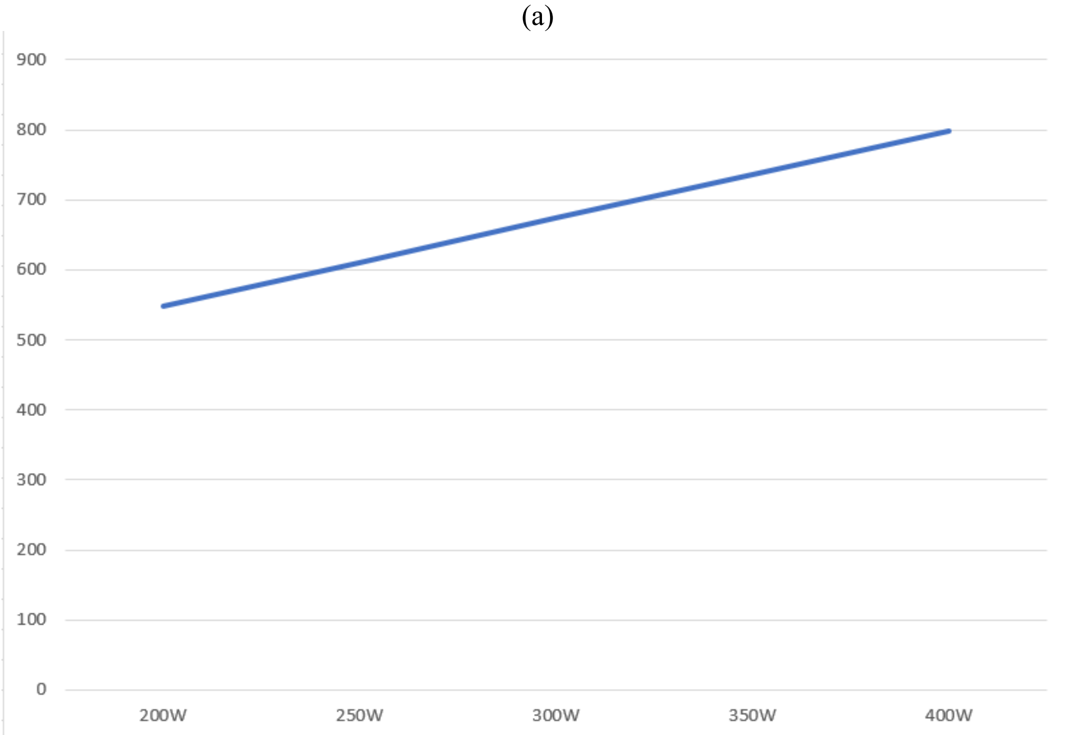


(a)



(b)

Figure 6. Peak temperatures versus additive manufacture parameters.

4. Conclusion

The CFD model can well simulate the SLM process. The corresponding temperature field, distributions and the relationship between them are obtained. The main conclusions are summarized as the following:

1. The maximum temperature of the temperature field increases with the increase of the laser heating power, and the temperature distribution gradually decreases from the center to the periphery.

2. The maximum temperature of the temperature field decreases with the increase of the laser scanning speed, and the temperature distribution is symmetrical along both sides of the intermediate axis.

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3. In order to improve the working temperature, the author suggests using a larger laser heating power and a smaller laser scanning speed in the actual processing process.

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