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Additive manufacturing technology of laser metal deposition with high deposition rate based on Incone1718

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Abstract. Additive manufacturing technology is a new technique for making object entities, which is different from traditional machining technology. Laser metal deposition is a typical example of additive manufacturing technology. Compared with the traditional processing technology, laser metal deposition can effectively reduce the waste of raw materials, which is more suitable for the production of personalized parts processing. In this paper, the experimental system of the additive manufacturing of laser metal deposition with high deposition rate based on Incone1718 was studied, and the system requirements were analyzed in detail; the characteristics of the system and the characteristics of the powder materials used were also investigated; and the laser deposition process with high deposition rate based on Incone1718 was developed; the characteristics control of the process and the microstructure of the materials used were investigated and analyzed, so as to lay a solid theoretical foundation for the research of the additive manufacturing of laser metal deposition with high deposition rate based on Incone1718.

Key words. Incone1718, high deposition rate, laser metal deposition, additive manufacturing technology.

1. Introduction

Additive manufacturing is a new practical technology which is different from the traditional manufacturing technology. It is mainly through the gradual addition of materials and the accumulation of continuous form to produce a certain geometric properties of components. Compared with the traditional process, the components obtained by the process have more carrying capacity [1]. In addition to the enhanced carrying capacity, there are several other advantages [2]. For example, it can greatly reduce the waste of materials, and significantly shorten the production cycle. The production part of the product structure is more complicated, which is more able to meet the requirements of the production process and also more suitable for individual

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parts [3]. Because of these advantages, additive manufacturing technology has been widely used in many fields, such as space, aviation, automobile and ship [4].

Although the traditional additive manufacturing technology is relatively mature, it has the disadvantage of low deposition rate [5]. The traditional process is difficult to meet the current large-scale parts processing needs, and the production cycle is longer with relatively high cost. The demand for additive manufacturing technology is also constantly improved, so it is of great practical significance to develop additive manufacturing technology with high deposition rate [6].

2. State of the art

With the widespread application of additive manufacturing technology, the research on this technology is increasing year by year in China. Published papers on the technology of making materials are increasing year by year, and the research directions and fields are becoming more and more thorough [7]. Professor Huang Weidong of the Key Laboratory of Solidification Technology of Northwestern Polytechnical University has carried out many deep researches on the additive manufacturing of laser metal deposition with high deposition rate based on Incone1718, including the microstructure of the selected material, the mechanical properties of the material, the selection of the material and the differences in the solidification process of the material. And the research results have been widely used in various fields. For example, domestic C919 aircraft used additive manufacturing technology to print the main aluminum alloy crazy block overall window frame [8].

The research on additive manufacturing technology of laser metal deposition with high deposition rate based on Incone1718 has become more and more abroad [9]. Taking the research in Germany as an example, the Fraunhofer Laser Technology Research Institute has carried out the research on additive manufacturing technology for more than 30 years. The research fields are very extensive, including the study of additive manufacturing technology based on a variety of alloys, such as titanium alloy, IN718 alloy, and WC-CO alloy [10]. At the same time, they have made a comprehensive analysis and research on the equipment used, process control, and the choice of coating oxidation resistant gas in the additive manufacturing technology. In addition, they have established a simulation model to simulate the detection of a variety of research [11]. In addition, the United Kingdom and the United States have made thorough study on the additive manufacturing of laser metal deposition with high deposition rate based on Incone1718. The specific application of additive manufacturing technology of laser metal deposition with high deposition rate based on Incone1718 is mainly divided into four parts. The first is to design the 3D model which is suitable for the parts processing; the second step is to design the appropriate processing plan for the appropriate model, and do the concrete physical processing [12]; the third step is to scan the processed 3D model by laser, compare it with the designed CAD model for the adjustment and modification, and remove the unsuitable position [13]; finally, the precise machining of the part model results in the completion of the 3D physical entity of the qualified parts [14].

3. Methodology

With the further development of science and technology in China, every industry in our country has been greatly improved and the overall strength has been improved. Especially in the related industries of machining, more technologies have gradually begun to be applied and have brought some positive effects to the development and progress of our country industry, which has enhanced the overall level of our country industry continuously, and has gradually increased the economic output value of China's industry [15]. As one of the important technologies in the development of some fields, the additive manufacturing technology has become more and more perfect, and the development of some trades in our country has been greatly influenced. Some studies have been done on the relevance of the economic output value of China's aviation industry and the improvement of additive manufacturing technology (results shown in Fig. 1). The results show that there is a positive correlation between the manufacturing output value of China's aviation industry and the improvement of China's additive manufacturing technology. With the continuous improvement of the related theories in China, the application of the industry has been gradually enhanced, and the manufacturing output value of the aviation industry in China has been increasing year by year. Therefore, from the point of view of the examples, the application of additive manufacturing technology can effectively promote the further development of related industries in China, greatly improve the relevant industry in China's economic strength, bring positive impetus to the overall strength of China's national economic promotion, and finally realize China's overall level and the improvement of international status.

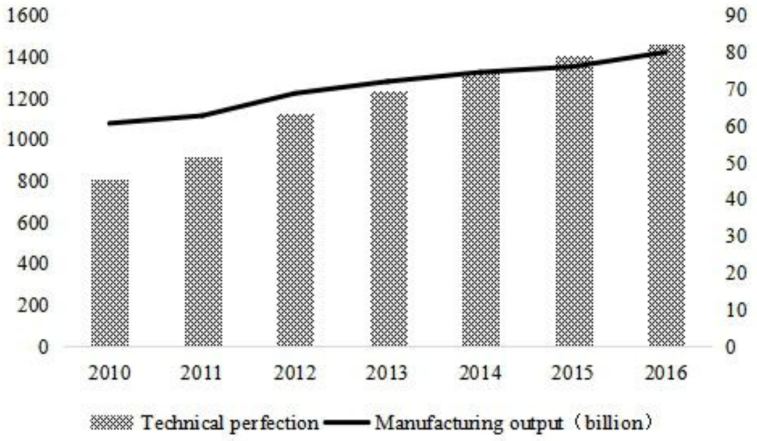

Fig. 1. Correlation analysis of manufacturing output value of aviation industry in China and the improvement of additive manufacturing technology

With the introduction and combination of the additive manufacturing technology in various fields of our country, great progress has been made in various fields. Many scholars in our country have begun to put forward some advanced science

and technology in the current era and gradually combine with the traditional additive manufacturing technology, thus forming a relatively new additive manufacturing technology. Through the improvement of this emerging technology, higher economic benefits for enterprises can be obtained, and our enterprises have more competitive performance. Laser technology with high deposition rate based on Incone1718 is one of the innovative technologies in the world manufacturing industry. The development of this technology has a positive impact on the improvement of additive manufacturing technology. Many researchers have begun to improve the two technologies and theories. At the same time, the organic integration of the two technologies is further realized to obtain some results, which brings important positive impetus to the development of manufacturing enterprises and the level of economy. In this trend, scholars in China have begun to improve the theory and application of this technology. However, due to the shortcomings of our scholars in the knowledge level, there are still some deficiencies in the related technology combination, which makes the actual performance of the technology still have some shortcomings. This indirectly affects the further development of related enterprises in China to some extent. In this study, the related theory and technology application of the additive manufacturing of laser metal deposition with high deposition rate based on Incone1718 were discussed. The research aims at providing the theoretical basis and reference for the development of the industry and the improvement of the new technology. The main methods of this study are as follows: The traditional additive manufacturing technology cannot meet the demand of high deposition rate in the production process. First of all, the requirements of all aspects of the additive manufacturing technology with high deposition rate were analyzed, so as to determine the actual needs of related technology development. On this basis, according to the actual needs of building materials, the additive manufacturing technology and related links with high deposition rate were constructed. The stability of the related system was verified on the basis of the determination of related technologies and links. The characteristics of powder spraying and laser output in the additive manufacturing technology with high deposition rate were studied and calculated. The relevant formulas are as follows:

$$v_1 = \frac{d_1}{\Delta t},\ v_2 = \frac{d_2}{\Delta t}\,, \tag{1}$$

where v_1 and v_2, respectively, indicate the velocity of powder particle ejection and the velocity of entering molten pool, and Δt is the time of powder movement.

The mathematical model of the process technology for the additive manufacturing technology with high deposition rate was established. Then, based on the related theories, different additive manufacturing techniques and models with high deposition rate were studied. The mathematical model established in this paper is as follows:

$$A_{\mathrm{T}} = \frac{2\theta}{2\pi} \times \pi R^2 - \frac{d_{\mathrm{L}}}{2}\left(R - \frac{d_{\mathrm{L}}}{r_{\mathrm{A}}}\right), \tag{2}$$

where, A_{T} represents the area size of the entire plating cross section, d_{L} represents the diameter of the spot produced by the laser emission, and r_A represents the ratio of the width and height of the coating.

For the quality of the coating, the relevant models are constructed as follows:

$$A_{\mathrm{T}} \times L \times \rho = \eta \times m \times t\,, \tag{3}$$

where,L,ρ,η and m, respectively, indicate the length of the coating, the density of the metal material used, the deposition efficiency in the powder deposition process and the weight of the powder.

The research finally analyzed and discussed the related technologies of this research from the point of view of examples. The advantages of this technique were confirmed by using actual cases. And a theoretical reference and foundation for its popularization and application was provided.

3.1. Result analysis and discussion

The additive manufacturing technology is a new kind of new manufacturing technology based on laser cladding technology. First of all, the additive manufacturing technology uses the laser to melt the metal powder, and the melted metal powder forms a molten pool on the base material. Then the laser spot moves, and then goes into the molten pool. The molten metal powder gradually solidifies, and forms metallurgical bonding with the base material. Then 3D physical entities are slowly formed in layers. Because the coating is easy to oxidize in the air, the inert gas, such as helium and argon, is used as the protective gas in the process, so as to avoid the oxidation of the coating.

There are two forms of powder feeding, namely, coaxial feeding and side feeding, as shown in Fig. 1. The principle of coaxial feeding is that the powder beam formed by laser beam and powder is the same central axis, so it is called coaxial feeding powder. There are two patterns in the process of making materials: lateral pollination and coaxial pollination, the powder beam is very concentrated in front of the nozzle, so the precision is relatively high, which is more suitable for the repair of parts and other processing technology. The side feeding is completely different from the central axis formed by the laser beam due to the powder being sent from side to side in the dissolution bath, so it is called side feeding. The lateral feeding system has a strong directionality, and there are different processing techniques in all directions. Moreover, the powder beam formed before the nozzle is not concentrated as coaxial feeding powder, but rather skewed to the rectangular shape. Therefore, the machining precision is relatively weak, but the powder feeding rate is obviously improved. Therefore, it is often used in the manufacture of metal cladding of tubular parts, which plays a role in strengthening the wear resistance of tubular parts. Material making technology in the process of physical objects as shown in Fig. 2. From Fig. 3 left, it can be found that the powder beam formed by coaxial feeding is more concentrated and more inclined to be cone shaped. In Fig. 3 right, the powder beam formed by the side feeding powder is relatively loose, and tends to be rectangular or banded, but the powder feeding rate is obviously larger.

The additive manufacturing system of laser metal deposition with high deposition rate based on Incone1718 includes the powder feeding system (powder feeder, powder distributor, powder spraying, and various connected devices), laser system

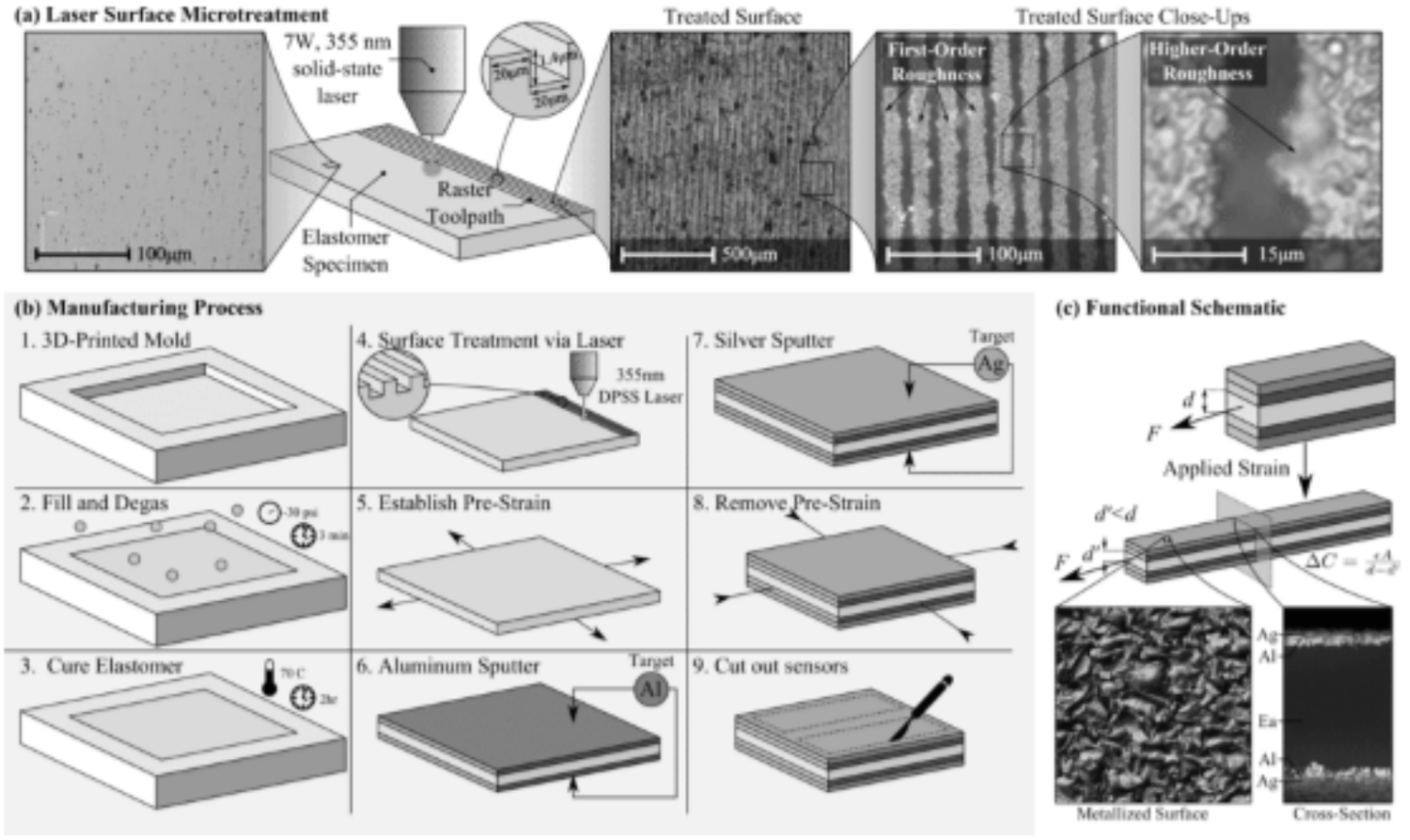

Fig. 2. Principal schematic diagram of additive manufacturing technology: top–powder feeding system of coaxial additive manufacturing technology, bottom–powder feeding system of lateral additive manufacturing technology

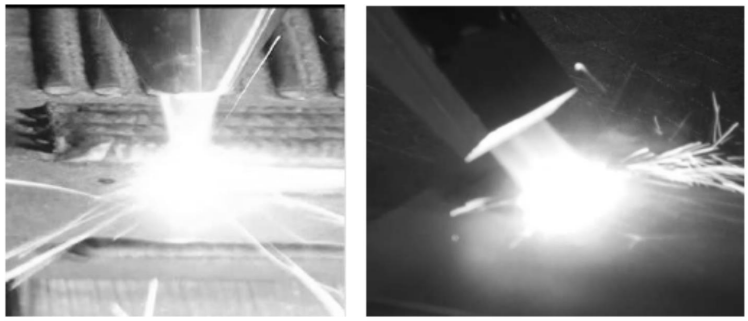

Fig. 3. Powder feeding system diagram with different additive manufacturing technologies: left–powder feeding system of coaxial additive manufacturing technology, right–powder feeding system of lateral additive manufacturing technology

(laser light source, optical system and optical fiber connection) and auxiliary system (machine, inert gas, cooling system and other monitoring system). The requirement analysis of the three systems is carried out, and each system is deeply studied. The research of powder feeding system mainly focuses on how to realize high feeding powder. The realization of high feeding powder is the necessary condition to meet the high deposition rate, and the key to realize the high feeding powder is the improvement of the component of the powder nozzle. First of all, the problems existing in the traditional material making process are analyzed. The main problems are the low powder output, the low powder mixing and powder gathering ability, and the relatively low thermal capacity. The forming state of the powder beam is studied in the case of different powder feeding rate. The results show that the powder agglomeration capacity of the powder beam is better when the feed rate is small. However, with the increase of the powder feeding rate, the powder nozzle gradually losses the power of powder gathering. In view of the above problems, a high deposition rate LMD powder nozzle is developed. The main improvements are as follows: firstly, the new nozzle should increase the distance between the inner and outer rings and adjust the internal mixing system, in this way, the damage to the inner and outer walls of the system can be avoided effectively; secondly, the new nozzle should extend the focal length of the powder beam, which can reduce the thermal load and effectively prevent the particles from sticking to the front of the nozzle; at the same time, the position of the protective mirror of the shower nozzle should be adjusted properly, so that the lens is more favorable for the protection of the lens; in addition, the aperture at the top of the nozzle should be enlarged to better adapt to the laser spot. Through the improvement above, the power of powder gathering can be strengthened under the condition of high powder feeding. As shown in Fig. 4, the top of the improved nozzle is enlarged and the focus of the powder is longer, and the beam formed by the powder is more concentrated, which can meet the requirements of precision machining.

The quality of powder material is the most important index of the quality of

the process, and the physical and chemical characteristic of the powder material is an important evaluation index to evaluate the quality of the powder material. The physical and chemical properties of powder materials seriously affect the material gain, manufacture technology and technological performance of powder. The physical and chemical properties of powder materials include the percentage of chemical elements, porosity and morphological characteristics of powder. Firstly, the percentage of chemical elements in the powder material can be measured by ICP-AES analysis. The N and O elements in the non-oxides of non-metallic elements can be obtained by means of a gas transport heat extraction (CGHE) method. C and S elements are usually selected by incineration for determination and analysis. By using the above three methods, the percentage of chemical elements in a powder material is analyzed (Table 1). From the table, it can be found that the main components of Incone1718 are Ni, Fe, Mo and Mn, and these four elements have significant influence on the LMD characteristics of the material.

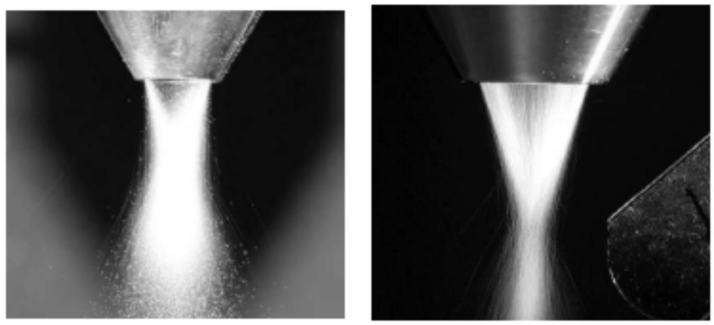

Fig. 4. Comparison of powder beam morphology between conventional powder nozzle and high deposition rate powder nozzle under high powder feeding condition: left–powder beam morphology of high deposition rate powder nozzles

Table 1. Percentage analysis results of chemical elements in powder

Ni (%)	Cr (%)	Nb (%)	Mo (%)	Ti (%)	Al (%)	Co (%)
51.3	19.2	5.2	3.0	0.99	0.56	0.038
Fe (%)	Si (%)	P (%)	Mg (%)	Cu (%)	B (%)	Mn (%)
19.0	<0.06	<0.01	<0.001	0.016	<0.005	0.037
Se (%)	Ta (%)	Ca (%)	O (%)	N (%)	C (%)	S (%)
<0.002	0.019	0.004	0.008	0.018	0.056	0.004

In this paper, the laser energy used in the calibration of the laser and the caustic curve were analyzed. It can be found that the laser source connected to the control system can effectively receive the voltage signal used by the system. The signal can also receive the output power of the laser source. Therefore, the mapping relation can be obtained by scaling the output power. Firstly, the diameter of the original

light spot of the laser optical system is set to 3 mm, and then the original dispersion curve and the laser capacity distribution at the focal point of the laser optical system are shown in Fig. 5. Caustic curve of laser optical system is symmetric hyperbolic curve style. The narrowest point of the curve is where the focus of the laser is.

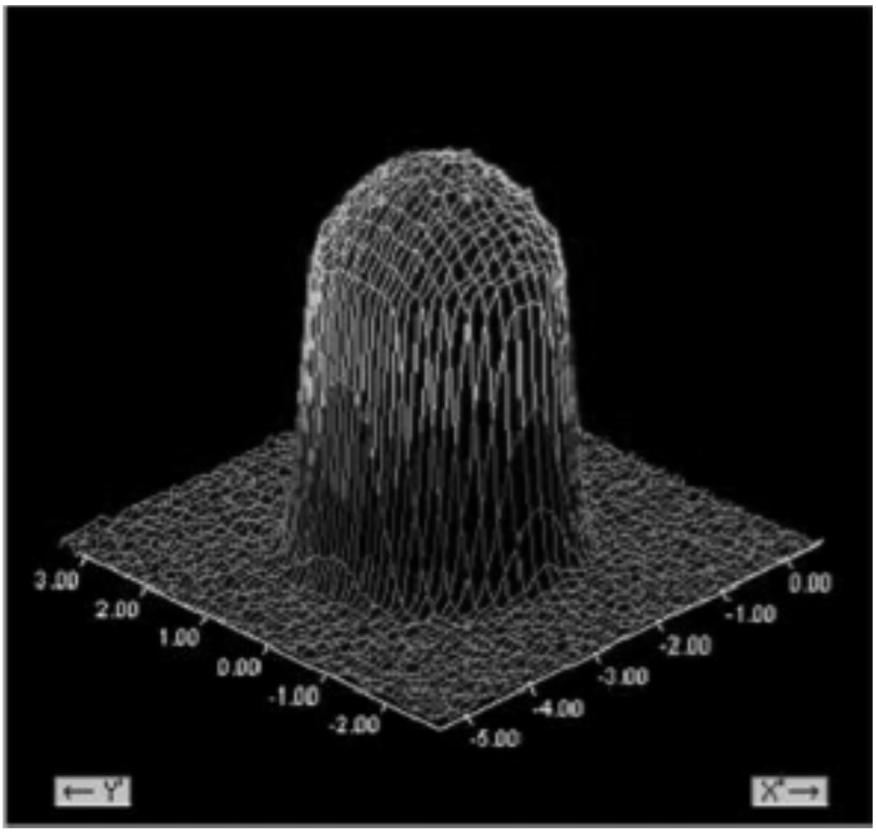

Fig. 5. Energy distribution curve and the original facula of non-zoom optical system in the focal point

The original laser spot is set to 4 mm, the distribution of laser forming caustic curve is a type of state Gauss style. Similarly, the symmetry is better, but the original spot is relatively decreased, as shown in Fig. 6.

4. Conclusion

In this paper, Incone1718 was used as the main material of research, and the additive manufacturing technology of laser metal deposition with high deposition rate based on Incone1718 was studied through the combination of theoretical literature and experimental research. The results show that the physical entity of Incone1718 used in this study is superior to the entity obtained by traditional methods in terms

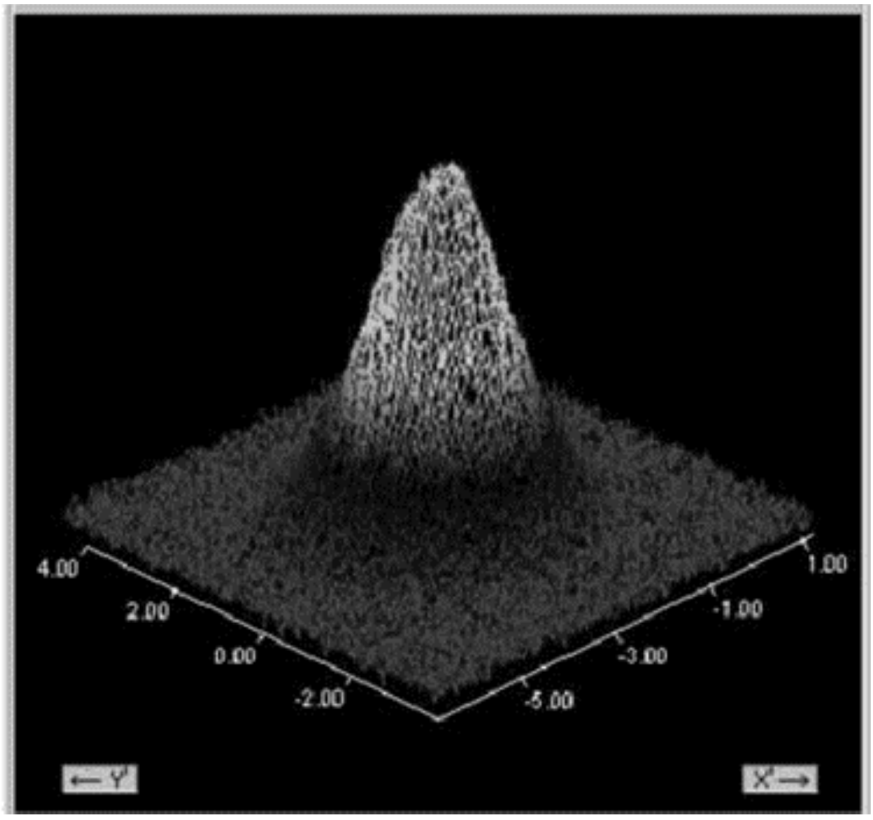

Fig. 6. Energy distribution and the original facula of zoom optical laser system in the focal point

of mechanical properties at normal temperatures, hardness of materials and ductility of materials. Firstly, the experimental system of the additive manufacturing technology of laser metal deposition with high deposition rate based on Incone1718 was studied and designed. The system has the advantages of better flexibility and high powder output. Secondly, the characteristics of powder injection and the laser characteristics of laser system were analyzed deeply. The results show that the powder beam formed by coaxial feeding powder is more concentrated and more inclined to be cone shaped, while the powder beam formed by the side feeding powder is relatively loose and tends to be rectangular or banded, but the powder feeding rate is obviously larger. Compared with the traditional process, the additive manufacturing technology of laser metal deposition with high deposition rate based on Incone1718 is improved by about 20 times. Moreover, the opening at the top of the improved nozzle is enlarged, and the focus of the powder is longer, and the beam formed by the concentrated powder is more concentrated, which can satisfy the requirement of precise processing. The research results of this paper can lay a solid theoretical foundation for the research of the additive manufacturing technology of laser metal

deposition with high deposition rate based on Incone1718.

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