Analysis of Influencing Factors and Experimental Study on Properties of Laser Cladding Layer

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Abstract. Laser cladding is an additive manufacturing or surface modification technique for parts. The quality of cladding layer is the key to determine the performance of cladding parts. The influence of pretreatment and post-treatment on the quality of cladding layer is analyzed. Through the experiment, the pretreatment process suitable for small, medium and large automobile moulds is explored. The effects of laser power, scanning speed, powder feeding speed and defocusing amount on the morphology, quality and property of the cladding layer were studied. With 45 steel material as the substrate and Fe15Cr1.9Ni1.2B1.23Si0.55Mo0.24C as cladding material to manufacture laser surface cladding. The samples with 50% cladding layer are made and the tensile tests are carried out. The mechanical properties of metallurgical bonding layer and cladding layer between matrix and cladding layer were studied, and the cladding quality of laser cladding of ferroalloy was explored. The test results are as follows: After laser cladding of 45 steel matrix, the metallurgical combination of matrix and cladding layer is good, the tensile strength of the metallurgical binding layer and cladding layer is greater than the tensile strength of the substrate.

1. Introduction

Common failure modes of automobile moulds are fracture failure, wear failure, fatigue failure [1], deformation failure and corrosion failure, among which wear failure is the most common in normal failure of moulds. Moulds wear will lead to friction heating between sheet metal and moulds surface, resulting in tumors, brushing, rupture and other damage, seriously affecting the quality of stamping parts. Moulds wear mainly occurs on key surfaces and parts such as profile and edge. Therefore, these key parts must have high precision, high quality and high performance [2]. In order to improve the performance of the above parts of the moulds and solve the problem of their wear failure, surface treatment technology is usually used to improve the performance of these parts and surfaces, that is, surface modification[3].

Laser cladding technology is a process that uses high-energy laser beam to clad a layer of metal alloy powder with high hardness and good thermal stability on the surface of metal materials to form a composite coating with special functions combined with matrix metallurgy, which can significantly improve the abrasion resistance, corrosion resistance, heat resistance, anti-oxidation and electrical characteristics of the base surface, thus achieving the purpose of surface modification and repair. It not only satisfies the requirement of specific surface properties of materials, but also saves a lot of precious elements. It is an efficient and practical surface treatment technology[4]. The laser cladding
layer has good metallurgical bonding with the matrix, smooth appearance, compact microstructure, small residual stress and other excellent characteristics. It is widely used in automotive die strengthening and repair, laser rapid manufacturing and biomedical manufacturing [5-6].

Automobile stamping dies are mostly made of high ductility and abrasion resistance cold working die steel, quenching cold working die steel and powder metallurgy cold working die steel. The use of these high performance die materials keeps the cost of moulds manufacturing high. At present, it is a very noticeable trend to select low-cost materials such as cast iron as the matrix and to modify the surface of large and medium-sized stamping dies by coating process of strengthening materials abroad [7]. Carbon structural steels although the cost was low, but the deficiency was low hardness, poor wear resistance. In laser cladding materials, iron-based alloys are suitable for parts requiring local abrasion resistance and easy deformation. Therefore, in this paper, 45 steel is used as matrix and iron-based alloy as cladding material. Combined with experiments, this paper analyzed the influencing factors and rules of the quality of the cladding layer before, after and during the laser cladding process. The metallurgical bonding quality between matrix and cladding layer, and the mechanical properties of metallurgical bonding layer and cladding layer were studied, which provided experimental support for the mould additives manufacture based on this material.

2. Analysis of influencing in quality of laser cladding layer
Laser cladding is a complex physical and metallurgical process, and the quality of cladding layer is the key to obtain high performance cladding parts. The main technological process of synchronous laser cladding is: substrate cladding surface pretreatment--feeding laser melting--post heat treatment. The quality of cladding layer is affected by various stages and factors.

2.1. Pretreatment
The proper treatment before cladding lays a good foundation for the full melting of cladding material and matrix material.

2.1.1 Substrate surface pretreatment
The cladding and non-cladding surfaces operated by oil removal and derusting. Oil removal generally uses heating method, that is, the surface of the base material is heated to about 300-450 degrees Celsius to remove oil, but also can be wiped with detergents, commonly used detergents are alkali liquor, trichloroethylene, dichloroethylene and so on. Derusting usually uses sandblasting, grinding wheel or sandpaper grinding. Among them, sandblasting is more suitable for the treatment of cladding surface before cladding, because it has the following advantages: (1) texturing the cladding surface, increasing the absorption of laser, which is conducive to the adhesion of spraying powder. (2) changing the stress state of the matrix surface, increasing the bonding strength of the cladding layer, and improving its mechanical properties.

2.1.2 Preheating
Preheating refers to heating the whole or surface of the substrate to a certain temperature and then cladding. The results show that with the increase of substrate temperature and the decrease of temperature gradient, made the cladding structure more uniform and dense, and reduce the thermal stress during laser cladding. For carbon steel, the martensitic transformation induced cracks in the cladding layer can be prevented [8].

However, in actual production, it has always been a problem in the industry that which preheat treatment process for different volumes of substrate can reduce preheating time and improve cladding quality. The experimental results show that the in-situ preheating is rapid and easy to destroy the surface to form keyhole effect, so it is not suitable for metal workpiece cladding pretreatment. The back preheating temperature of workpiece with preset tension stress is uniform, which can effectively reduce the crack sensitivity, which greatly reduces the crack sensitivity. The time interval between preheating process and powder feeding cladding process is greatly shortened, which is very suitable
for the cladding of small and medium-sized parts. Flame preheating can be used for large workpieces, although the preheating time is longer, the temperature range and the divergence of the preheating area are larger, it has good effect on reducing the lacuna rate and improving the compactness of the cladding layer.

2.2. Post-treatment
Laser cladding is a rapid cooling and heating process, which results in large residual stress in the material, but also the problems of porosity and cracks, which affect the performance of the cladding layer. The post-treatment of laser cladding, namely heat treatment, is a kind of heat preservation method. Because the phase and structure of laser cladding coating will change after heat treatment, the mechanical properties of the coating will change accordingly after heat treatment. The results show that with the increase of heat treatment temperature, the grains of cladding layer become more fine and uniform, and the number becomes more. With the increase of the holding time, the grain nucleation continues to grow, the number of grains becomes smaller, it can be seen that heat treatment can refine the microstructure, and have an effect on the phase and structure of the laser cladding layer, and then on the mechanical properties of the cladding parts [9].

2.3. Effect of laser cladding process parameters on morphology and properties of cladding layer
Laser cladding process parameters mainly include laser power, scanning speed, powder feeding speed, defocusing amount and so on. They have great influence on the surface morphology, structure compactness and mechanical properties of the cladding layer. In order to study the effects of process parameters on the morphology and properties of the cladding layer, we setted the parameters, including laser power of 1500W-3000w, powder feeding speed of 20-30g/min, scanning speed of 8-10mm/s, defocusing amount of 18-22mm. Combination test of different parameters of 45 steel as matrix and iron-based alloy powder as cladding material was carried out.

2.3.1 laser power
Laser power has a great influence on the quality of cladding layer. It is most important to select appropriate laser power to avoid the occurrence of blowhole and cracking.

The height H, width W and remelting depth h of the cladding layer increase with the increase of laser power in a certain range when the scanning speed and powder feeding amount are constant. Among them, the increase of cladding layer height H is gentle, and the increase of remelting depth h is the most intense. When laser power is greater than 2000 W, h/H is greater than 1, which indicates that the depth of the cladding layer has exceeded the height of the cladding layer. Moreover, the laser power increases from 1500W to 2800 W, and the overall macro-morphology of the cladding layer becomes better and better. However, as the laser power continues to increase, the overall macro-morphology of the coating gradually deteriorates. This shows that in a certain range, with the increase of laser power, the cladding layer with better morphology can be obtained. We setted the parameters, laser power of 1500W and 2800w, powder feeding speed of 30g/min, scanning speed of 12mm/s, protective gas flow of 6L/min, defocusing amount of 20mm. The morphology of the cladding layer as shown in Fig.1.

Figure 1. Effect of different laser power on the morphology of cladding laser.
Figure 2. Effect of scanning speed on the morphology of cladding laser.
At the same time, the related research shows that, in a certain range, with the increase of laser power, the heat per unit area increases gradually in unit time and the convection in the molten pool increases, which is helpful for the gas escaping from the molten pool. The liquid metal around the cladding fluctuates violently and solidifies dynamically, so that the number of pore is gradually reduced, even eliminated, and the cracks are gradually reduced. But beyond this range, the laser power is too large or too small, can not achieve the desired quality of surface cladding [10].

2.3.2 Scanning speed
When the laser power and powder feeding amount are constant, only the scanning speed is changed. The results show that the height H, width W and depth of cladding layer h decrease with the increase of scanning speed, while the ratio of width to height of cladding layer increases gradually. However, when the scanning speed increases to a threshold, the changes of the three will tend to be flat. It can be seen from the experiment that the influence of scanning speed on the ratio of h/H is far less obvious than that of laser power. Moreover, as the scanning speed increases, the overall macro-morphology of the cladding layer becomes worse and worse. However, the scanning speed was too low, resulting in overburning of powder, loss of alloying elements, and large heat input of the substrate, which will increase the deformation. It can be seen that too high or too low scanning speed can not achieve the desired cladding effect, so the control of scanning speed is a key factor. We setted the parameters laser power of 1500W, powder feeding speed of 8mm/s and 10mm/s, defocusing amount of 20mm. The morphology of the cladding layer was obtained as shown in Fig.2.

Relevant studies have found that: In a certain range of scanning speed, with the increase of scanning speed, the morphology of cladding grains composed of cell crystal, columnar crystal and equiaxed grains change slightly, but the size becomes smaller and smaller, the martensite content in the structure increases, the retained austenite content decreases, the hardness increases, and the crack tendency decreases. Therefore, the amount of martensite and retained austenite can be changed by adjusting the scanning speed properly, and a crack-free and hardness suitable coating can be obtained, which can effectively control the structure and mechanical properties of the coating [11].

2.3.3 Powder feeding rate
The powder feeding rate has a crucial influence on the forming quality of the cladding layer. The results show that when the laser power and scanning speed are constant, the height of the cladding layer increases linearly with the increase of powder feeding, the width of the cladding layer increases slightly, while the remelting depth and h/H value of the cladding layer decrease slightly. It can be seen that the larger powder feeding speed and the more powder accumulated in a certain area per unit time, the transmittance of laser beam will decrease, the supply of laser energy is insufficient, the heating degree of cladding material will decrease, and the laser energy received by matrix material will decrease. If the feeding speed increases to a certain extent, the matrix material does not reach the melting temperature, resulting in the cladding powder and the matrix can not form an effective metallurgical bonding, the bonding strength weakens, and the cladding effect is poor.

With the increase of powder feeding speed, the energy absorbed by the matrix decreases, resulting in a shorter cooling time and faster cooling speed of the molten pool, smaller grain size, finer structure, higher microhardness and wear resistance of the cladding layer.

2.3.4 Defocusing amount
The defocusing amount directly determines the spot size and energy density. The size of the spot determines the width of the cladding layer. The larger the defocusing amount, the larger the width of the cladding layer.

The different defocusing amount will cause the change of the surface capability distribution of the cladding layer, and the morphology and structure properties of the cladding layer obtained are quite different. The lower the defocusing amount and the higher the laser energy density, the better the quality of the cladding layer and the metallurgical bond layer was obtained. However, the hardness of
the cladding layer decreases with the decrease of the defocusing amount. Too much defocusing and too small energy density lead to weak metallurgical bond between the substrate and the cladding layer, some powder particles cannot be fully melted and attached to the surface of the cladding layer, resulting in poor quality of the cladding layer. When other parameters are constant, the appropriate defocusing amount can obtain fine and uniform structure. Fine grains can ensure high hardness, good wear resistance and corrosion resistance.

The above laser cladding process parameters have complex and interactive effects on the quality. In recent years, many researchers have deeply studied the effects of various process parameters on the quality of cladding layer. The results show that the specific energy (P/DV), power density (P/S, S is spot area), linear energy (P/V), absolute powder feeding rate (VF/V), coverage rate, action time (D/V), specific energy per unit mass of cladding material and actual input specific energy per unit time are introduced [12]. It is more meaningful to comprehensively investigate the influence of process parameters on the quality of cladding layer.

3. Experimental study on mechanical properties of cladding layer and metallurgical bonding

3.1. Experimental instrument
Laser cladding is accomplished by high-power five-axis laser cladding forming equipment. The equipment is equipped with Laserline LDF6000-100 semiconductor lasers and GTV PF 2/2 Dual-barrel Powder Feeder produced by Germany GTV Company.

3.2. Experimental materials
matrix material: 45 steel
Cladding materials: The main chemical composition of XY-26F-104 ferroalloy powder is shown in Table 1.

| powder       | hardness | chemical composition | particle size (II) |
|--------------|----------|----------------------|--------------------|
| XY-26F-104   | 55       | Mo 0.55 Ni 1.9 Si 1.23 Fe bal. | C 0.24 Cr 15.31 B 1.2 Mn 1.45 100-270 |

3.2.1 Matrix pre-treatment
The surface of the matrix is sandblasted to ensure that the roughness of the sandblasting surface is uniform. The matrix belongs to small workpiece, the back preheating treatment process with preset tensile stress is adopted.

3.2.2 Selection of cladding parameters
According to the relevant literature and experimental conditions, the cladding process parameters are selected as follows: laser power of 2000 W, powder feeding speed of 30 g/min, scanning rate of 10 mm/s, defocusing amount of 20mm, single layer cladding. There is inert gas protection in cladding process and compressed air blowing protection in external optical system.

3.2.3 Macro-inspection for quality of cladding layer
The area of laser cladding layer is 150 mm×220 mm. The surface of the cladding layer is inspected by coloring penetrant to determine that there are no cracks, pore and other defects on the surface of the cladding layer.
3.2.4 Testing and analysis of mechanical properties of bonding between cladding layer and matrix

Reference to GB/T_228.1-2010 standard, the laser cladding sample is adjusted in proportion and processed into the required mechanical properties test sample. As shown in Fig. 3, samples with 50% cladding layer. Tensile tests are carried out. The results are shown in Fig. 4.

![Figure 3. Sample size](image)

![Figure 4. Tensile test results](image)

It can be seen from the tensile test results that the samples are partially fractured in the matrix, indicating that the tensile strength of the metallurgical bond layer between the cladding layer and the matrix and the tensile strength of the cladding layer are both greater than the tensile strength of the matrix. The results show that, after laser cladding of iron-based alloy on 45 steel substrate, the metallurgical bonding between the matrix and the cladding layer is good. The tensile strength of both the metallurgical bonding layer and the cladding layer is greater than that of the matrix.

4. Conclusion

(1) The problem of preheat treatment in laser cladding processing of matrix materials with different volumes was solved by experimental study. The results shown that medium and small workpieces were suitable for back preheating with preset tensile stress, and large workpieces were suitable for flame preheating.

(2) The main process parameters of laser cladding, such as laser power, scanning speed, powder feeding speed and defocusing amount, were studied through experiments, and the influence of these parameters on the morphology, quality and performance of the cladding layer was obtained.

(3) 45 steel was used as substrates, iron-based alloy powder with Fe15Cr1.9Ni1.2B1.23Si0.55Mo0.24C composition was used as cladding material, made samples with 50% cladding layer, and tested the mechanical properties. The results shown that the metallurgical bonding between the matrix and the cladding layer is good after laser cladding of 45 steel. The tensile strength of both the metallurgical bonding layer and the cladding layer is greater than that of the matrix.

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