Study on the effect of laser process parameter rs on the cladding quality of camshaft

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Abstract. In order to study laser cladding parameters on the quality of laser cladding layer on the stability of influence, this article through the analysis of three great influence the result in the laser cladding process parameters (laser spot radius, cladding speed, laser power) of the different combination, in the WorkBench software to simulate and analyze the law of the cladding layer temperature change over time, sum up the best process parameter combination (P=1000W, V= 0.004mm/s, and R=5mm) for the actual laser cladding for guidance, to enhance the stability and reliability of the laser cladding layer.

1. Introduction
Laser cladding is a kind of technology that uses a laser to melt the coating material and the thin layer on the surface of the part substrate at the same time and quickly solidify to form a coating, thereby improving the corrosion resistance, wear resistance, oxidation resistance, etc. In our country is used to repair worn shaft parts. However, the optimization of process parameters and the quality stability of cladding layer affect the development of this technology. Therefore, the quality reliability of laser cladding coating has become a hot topic at home and abroad[1].

The selection of process parameters in laser cladding technology will directly affect the microstructure and forming quality of the cladding layer and affect the reliability and service life of the workpiece after laser cladding. Guo yongli[2] optimized the combination of process parameters by analyzing the influence of main laser cladding parameters on the width and quality of cladding layer. Dara Moazami Goodarzi[3] used single channel cladding layer to study the influence of laser cladding process parameters on the geometry of composite layer with laser power, cladding speed and powder loading speed.

This paper uses WorkBench software to simulate the laser cladding process, selects the best combination of technological parameters through the orthogonal test of laser cladding technological parameters, laser cladding power, laser cladding speed and laser spot radius. So as to provide certain
reference value for the combination of technological parameters of laser cladding and the cladding layer’s quality stability.

2. Laser cladding boundary conditions and select the heat source.

2.1. Laser cladding boundary conditions
Actually the process of laser cladding is a heat treatment process and its heat conduction process can be expressed by the nonlinear transient heat conduction governing equation of Fourier’s heat conduction law and energy conservation law[4].

\[ \frac{\partial}{\partial t} \left( k \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left( k \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left( k \frac{\partial T}{\partial z} \right) + q = \rho C_p \frac{\partial T}{\partial t} \]  

(1)

In this formula:
- \( t \) ——time
- \( X, Y, Z \) ——coordinate axes
- \( k \) ——heat conductivity
- \( \rho \) ——density
- \( C_p \) ——specific heat capacity
- \( q \) ——reservoir

Only by applying reasonable boundary conditions can test simulation guide the actual production. The initial temperature of the part model is room temperature or the preheating of the model can reach a relatively uniform temperature. The initial temperature is set as \( T_0 \), and the formula is as follows.

\[ T(x, y, z, t)|_{t=0} = T_0 \]  

(2)

Laser cladding is the process of solid - liquid - solid, this produces in the process of phase change latent heat and heat enthalpy method is the method of the default in ANSYS software to analyze phase change latent heat, its principle is based on the analysis to express the enthalpy change under different temperature, enthalpy of the said method is made up of heat capacity and material density on the integral of time, the formula is as follows.

\[ \Delta H(T) = \int_0^T \rho c(t) dt \]  

(3)

In the formula:
- \( H \) ——enthalpy
- \( \rho \) ——density of the material
- \( T \) ——absolute temperature
- \( c(t) \) ——specific heat capacity of a material, as a function of temperature

2.2. Selection of heat source in laser cladding
In the process of simulated laser cladding, the selection of heat source is the key factor affecting the quality of cladding and the correctness of the results. At present, the two ellipsoidal heat source model and gaussian heat source model are commonly used at China and abroad.

2.3. The double ellipsoid heat source model
The double ellipsoid heat source model is widely used in the finite element calculation in the
temperature field of various fusion welding. Including arc welding and laser cladding. Along the
direction of laser cladding, the double ellipsoid heat source model is divided into two ellipsoid parts.
The formula for the thermal generation rate along the first half of the X-axis is as follows.

\[
q(x, y, z) = \frac{6\sqrt{3}f_f\eta UI}{abc\pi^{1/2}} \exp\left(-3x^2\right) \exp\left(-3y^2\right) \exp\left(-3z^2\right)
\]  
(4)

The formula for the thermal generation rate along the latter half of the X-axis is as follows.

\[
Q(x, y, z) = \frac{6\sqrt{3}f_r\eta UI}{abc\pi^{1/2}} \exp\left(-3x^2\right) \exp\left(-3y^2\right) \exp\left(-3z^2\right)
\]  
(5)

In the formula:

- \(q\) —— thermal formation rate
- \(a_f, a_r, b, c\) —— shape parameters of the double ellipsoid heat source
- \(\eta\) —— thermal efficiency
- \(U\) —— voltage
- \(I\) —— current
- \(f_f\) —— energy distribution coefficient of the former part of the heat source model
- \(f_r\) —— energy distribution coefficient of the latter part of the heat source model

2.4. The gaussian heat source model

The gaussian heat source model is suitable for describing the surface coating of the part.

\[
q(r) = \frac{3Q}{\pi r_a^2} \exp\left[-3\left(\frac{r}{r_a}\right)^2\right] = q_m \exp\left[-3\left(\frac{r}{r_a}\right)^2\right] \quad r = \sqrt{x^2 + (y - vt)^2}
\]  
(6)

- \(r_a\) —— radius of the heat source zone
- \(r\) —— distance between the heat source and the workpiece
- \(v\) —— scanning speed of the laser
- \(Q\) —— power input by laser

The double ellipsoid heat source model needs more specific parameters, and the selection requires
repeated comparison calculation. The Gaussian heat source model parameters need to be clarified
contrast less than double ellipsoid heat source model, as long as input different laser power, laser spot
size and laser scanning speed can simulate the effects of various parameters on the laser cladding
process. So in this paper, by using the gaussian heat source model as a heat source model of laser
cladding simulation test.

3. Simulation study on the influence of laser cladding process parameters

3.1. Geometric model selection

Camshaft as an important component parts of engine, at the end of the engine lubrication system and
bear the impact load of cyclical, work with lifter instant contact stress is large, the relative sliding
speed is high, so the camshaft contact surface abrasion is more serious, so this paper choose the
research object of the camshaft to laser cladding. In order to facilitate the simulation of laser cladding
process, the camshaft used in this paper exists by default:

(1) No macroscopic cracks
(2) No degradation of part material  
(3) The working time of camshaft matrix is long enough to release residual stress  
(4) The initial temperature before laser cladding was 20°C

3.2. Select camshaft material and cladding material  
The camshaft material used in this paper is 15CrMn [5], a common camshaft material. The physical parameters are shown in table 1 below:  

| $T$, °C | $\lambda$, W (m · k) | $C_p$, J (kg · K)$^{-1}$ |
|---------|---------------------|-------------------------|
| 20      | 34.55               | 462                     |
| 200     | 34.23               | 499                     |
| 500     | 31.45               | 624                     |
| 700     | 28.42               | 843                     |
| 1000    | 33.08               | 708                     |

The laser cladding material used in this paper is Ni60 [6], because the nickel-based self-melting alloy powder has good corrosion resistance, and it is suitable for the laser cladding material used as the local abrasion resistance and heat resistance matrix. The physical parameters are shown in table 2 below:  

| $T$, °C | $\lambda$, W (m · k) | $C_p$, J (kg · K)$^{-1}$ |
|---------|---------------------|-------------------------|
| 20      | 29                  | 440                     |
| 250     | 35                  | 451                     |
| 500     | 43                  | 460                     |
| 750     | 54                  | 490                     |
| 1000    | 62                  | 510                     |

Annotation: $T$, $\lambda$, $C_p$ represent temperature, thermal conductivity, and specific heat capacity.

3.3. Temperature field simulation  
In the SoildWorks software, the required cladding part of the camshaft is simplified as an axis with a radius of 10mm and a width of 10mm. The lower part of the camshaft is simplified as a substrate with a length of 20mm and a width of 10mm. The thickness of the cladding layer is set as 2mm. Imported the WorkBench software for laser cladding simulation, the surface mesh density of the camshaft requiring cladding is 0.5mm, and the remaining mesh density is 1 mm. This is shown in figure 1 below;
The optimum bonding strength of laser cladding is determined by using three parameters: laser cladding power, laser cladding speed and laser radius.

The cladding power parameters in this paper selected as $P_1: 1000\, W$, $P_2: 1500\, W$, and $P_3: 2000\, W$. The speed parameters of laser cladding selected as $V_1: 0.002\, mm/s$, $V_2: 0.004\, mm/s$, and $V_3: 0.005\, mm/s$. The laser radius selected as $R_1: 3\, mm$, $R_2: 4\, mm$, and $R_3: 5\, mm$. Through the combination of these three parameters, 9 different parameter combinations are obtained, as shown in Table 3 below:

| Serial number | P ($W$) | V ($mm/s$) | R ($mm$) |
|---------------|---------|------------|----------|
| A             | $P_1$   | $V_1$     | $R_2$    |
| B             | $P_1$   | $V_2$     | $R_3$    |
| C             | $P_1$   | $V_3$     | $R_1$    |
| D             | $P_2$   | $V_1$     | $R_3$    |
| E             | $P_2$   | $V_2$     | $R_1$    |
| F             | $P_2$   | $V_3$     | $R_2$    |
| G             | $P_3$   | $V_1$     | $R_3$    |
| H             | $P_3$   | $V_2$     | $R_2$    |
| I             | $P_3$   | $V_3$     | $R_1$    |

The cladding results are shown in figure 2 below;
Figure 2. The result diagram of 9 parameters calculation.

- **Number A**
- **Number B**
- **Number C**
Figure 2 is the cladding curve of 9 different maximum and minimum temperatures obtained by orthogonal test of three process parameters in the cladding process. The maximum temperature of each parameter combination is shown in table 4 below;

| Serial number | The highest temperature (°C) |
|---------------|------------------------------|
| A             | 1598.3                       |
| B             | 2004.6                       |
| C             | 3078.4                       |
| D             | 4048.7                       |
| E             | 4985.1                       |
| F             | 3348.8                       |
| G             | 8565.3                       |
| H             | 4865.8                       |
| I             | 3493.8                       |

In the process of laser cladding, temperature control is the primary factor. If the temperature is too high, the cladding material is easy to be sintered, the internal stability of the material is destroyed, and the quality of the cladding layer is not reliable. It is find that the melting point of cladding material $N_{f60}$ was 1027°C, and the camshaft substrate material $15C_rM_r$ had no solid solubility. Therefore, according to the evaluation standard of $C_r$ melting point 1857°C, P1, V2 and R3 (P=1000W, V=0.004mm/s, and R=5mm) are the most appropriate cladding process parameters in the 9 groups of data by comparing the highest temperature of laser cladding in the 9 groups of data.

Conclusion
(1) For camshaft model in this paper, through the Workbench software simulation, process parameter of laser cladding contrast obtained when laser power is $1000\, W$, the laser spot radius is $5\, mm$, the laser cladding speed is $0.004\, mm/s$, camshaft model of cladding effect is the best result, the quality of the cladding layer is the most stable and reliable, for camshaft laser cladding provides the certain reference value.

(2) Among the three parameters, the power has the greatest impact on the quality of cladding layer. Too much power will destroy the internal stability of cladding layer material, and too little power will not achieve the cladding effect. The second is the laser spot radius and cladding speed, the laser spot radius is too large, the laser cannot be concentrated, the material melting time becomes longer, the laser spot radius is too small, if the speed is slow that will lead to excessive melting, resulting in the waste of material, the quality of the cladding layer is not reliable.

References

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