Finite Element Analysis and Experimental Study of Laser Cladding WC/Ni Powder for Repairing Cold Work Die Steel

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Abstract

Laser cladding technology is the focus of the development in the field of mold repair. It has the characteristics of uniform and dense coating, high bonding strength, small thermal impact on the substrate and easy to realize automation. In order to repair the damaged parts of cold stamping die, a finite element analysis model of laser cladding WC / Ni powder repair for cold working die steel was esTab. lished based on MSC Marc life and death element method. The temperature field under different laser power process parameters was solved, and the thermal impact range of laser energy on the substrate was predicted. According to the simulation results, the cladding process was esTab. lished, the influence of process parameters on the microstructure and properties of the coating was studied, the microstructure of the substrate and the microstructure and composition distribution of the cladding coating were characterized, the repair position obtained better wear resistance and hardness, and the high quality repair of the die surface was realized.

Keywords

Laser cladding; mold repair; wear resistant coating; finite element analysis; microstructure.

1. INTRODUCTION

Mold processing is one of the advanced and efficient processing methods in modern mechanical manufacturing industry, which has the characteristics of complex manufacturing process, long production cycle and high production cost. Under the action of high pressure and high impact force, with the increase of service times, the surface of the die or punch is prone to different degrees of scratches, pits and other wear, affecting its service life and processing accuracy, reducing product quality [1-2]. Laser cladding is a technology that the cladding material is added to the substrate surface through additive manufacturing, and the cladding material and the substrate surface are melted at the same time by using high-energy density laser beam to form a high-strength metallurgical bonding coating with the substrate [3-4]. Compared with other repair processes, laser cladding can use cladding materials to repair the local failure parts of the mold quickly. The process is simple, the efficiency is high, and it is easy to realize automation. Simultaneously, the laser cladding coating has the advantages of compact structure, concentrated energy and little thermal effect on the substrate, so it has a broad application prospect and practical value in the field of mold repair [5].

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In this paper, WC / Ni alloy coating was prepared on 3Cr2NiMo die steel by laser cladding technology. The temperature field under different laser power was solved by using life and death element method through nonlinear finite element analysis software MsC Marc [6-7]. According to the simulation results, the cladding process was esTab. lished, the V-groove multi-layer coating was prepared, the influence of different laser power on the microstructure and properties of the coating was studied, the microstructure and composition distribution of the cladding coating were characterized, the wear-resistant coating with good combination with the substrate was obtained, and the high-quality repair of the die surface was realized [8-9].

2. EXPERIMENTAL MATERIALS AND PROCESS PARAMETERS

As shown in Fig. 1, the morphology of WC / Ni powder alloy powder is selected as the composite powder of WC / Ni coating type. The mass fraction of WC Ceramic Powder accounts for 25%, and the rest is Ni fusion alloy powder.

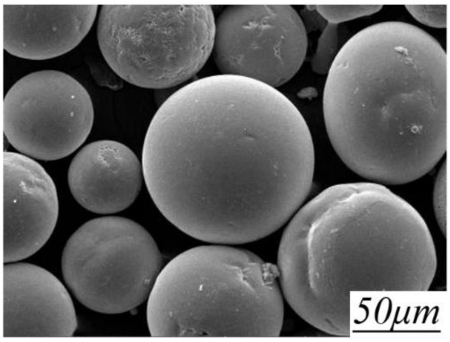

Fig 1. SEM appearance of Ni / WC powder

The chemical composition of WC / Ni powder alloy powder is shown in Table. 1.

Table 1. Chemical composition of Ni/WC alloy

Element	C	Si	Mn	B	Cr	Mo	Wc	Ni
wt(%)	1.12	0.42	0.43	3.5	8.05	0.84	25	Bal.

The experimental base material is 3Cr2NiMo die steel, and the chemical composition is shown in Table. 2.

Table 2. Chemical composition of 3Cr2NiMo steel

Element	C	Si	Mn	Cr	Mo	Ni	Fe
wt(%)	0.26	0.18	1.45	1.28	0.58	1.08	Bal.

YLR-3000 semiconductor laser and FHPF-10 synchronous powder feeder are used to transport the powder to the cladding surface with N2 as carrier gas. The V-groove is laser cladding with multi-layer filling method, and the constant process parameters in the test are shown in Table. 3.

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Table 3. Processing Parameter of laser cladding

Parameter	Value
Laser spot diameter (mm)	2.0
Powder feeding rate (r/min)	3
Flow rate of powder gas (L/min)	4
Protective Pressure (Mpa)	0.2

3. FINITE ELEMENT ANALYSIS OF LASER CLADDING

3.1. Geometric Model and Physical Parameter Setting

Based on MSC Marc finite element analysis software, the geometric model is esTable. lished. The size of the substrate is 30mm × 60mm × 10 mm. According to the actual situation, V-groove with width of 3mm and depth of 1.5mm is set on the surface of the substrate. The cladding path is set as two layers and three layers, each layer is 30mm long. The mesh is divided into hexahedrons, and the repair path of laser moving along the z-axis direction is shown in Fig. 2 (a).

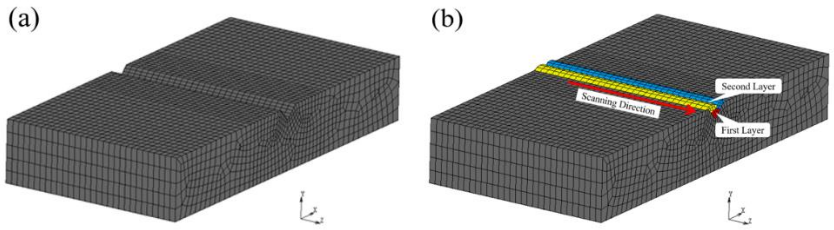

Fig 2. (a) Inactive geometric model and mesh generation; (b) laser cladding path

The finite element analysis of coaxial powder feeding laser cladding process is carried out by using the birth death element method. The physical property parameters of 3Cr2NiMo steel and Ni/WC powder are calculated by JMatPro. The density, heat flux and specific heat capacity of the two materials with temperature change are shown in Fig. 3 (a) (b) respectively.

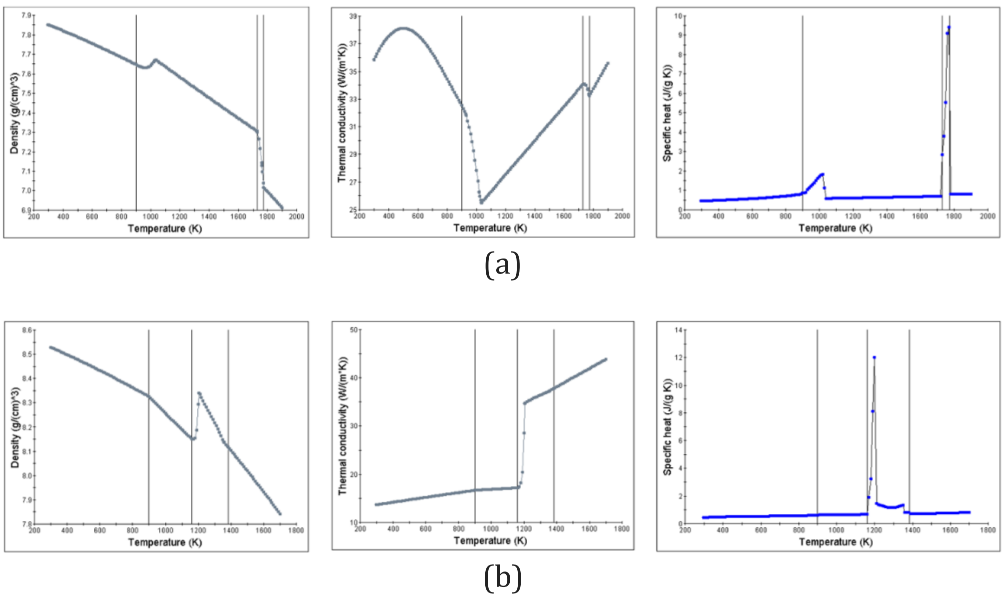

Fig 3. Physical properties of (a) 3Cr2NiMo steel and (b) Ni / WC powder

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The finite element model is simplified: ignoring the flow of the molten pool and other factors, only the heat convection between the substrate material, the cladding material and the air, the substrate and the bottom support material, and the heat radiation on the surface of the substrate are considered. The initial temperature of the workpiece is set at 20 ℃. Using a moving Gaussian heat source, the functions is as follows:

$$I(r) = \eta I_0 \exp\left[-\left(\frac{\sqrt{2}}{r_l}\right)^2 r^2\right] \tag{1}$$

$$r = \sqrt{x^2 + (z - vt)^2} \tag{2}$$

$$I_0 = \frac{2}{\pi r_l^2} P_l \tag{3}$$

Where, I_0 is heat source density (w/m^2); η is laser absorption rate; r is distance between calculation point and spot center (mm); r_l is laser heat source radius (mm); v is laser scanning speed (mm/s); t is interaction time (s); P_l is laser power (W).

3.2. Finite Element Analysis Results

Based on the esTable. lished geometric model, three sets of heat source parameters are used to simulate the transient temperature field and stress field during the cladding process with the laser power as the variable. See Table. 4 for the specific parameters.

Table. 4. Transient numerical simulation of laser heat source parameters

Number	the first laser power	the first scanning speed	the second laser power	the second scanning speed
1	1.5kW	5mm/s	1.8kW	5mm/s
2	1.5kW	5mm/s	1.5kW	5mm/s
3	1.5kW	5mm/s	1.5kW	8mm/s

After the simulation, the temperature distribution cloud diagram of XY plane in the middle of the geometric model during each processing is cut as shown in Fig. 4.

According to Fig. 4(a) and (b), when the laser scanning speed was constant, as the laser power increases from 1.0kw to 1.2kW, the heat input on the surface of the substrate increases, the range of heat influence was not changed much, and the heat temperature in the cladding area increased significantly. As shown in Fig.4 (b) and (c), after the laser power continues, the heat input in the repair area further increases, and the temperature also increased with the increase of the heat input, but the amplitude slowed down, and the heat effected on the substrate increases.

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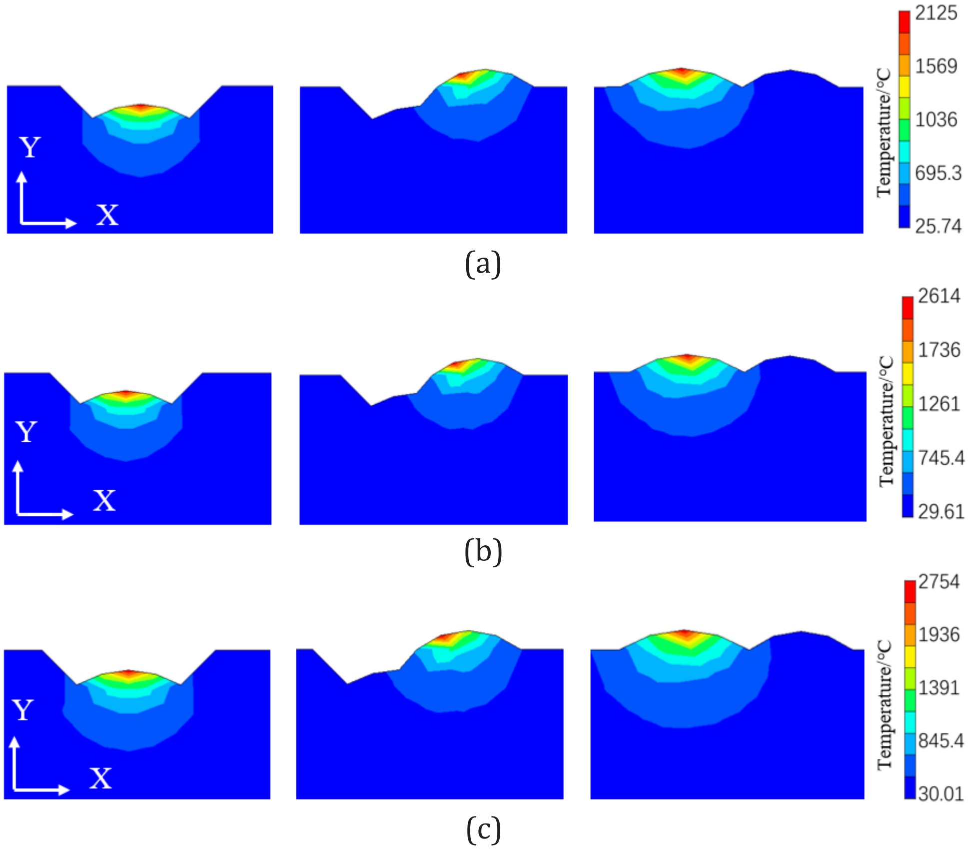

Fig 4. Temperature field of different laser power: (a) 1000W; (b) 1200W; (c) 1500W

As the transition area between the substrate and the cladding coating, the heat affected zone is directly related to the mechanical properties of the substrate in the whole repair area. Laser power can effectively control the heat input of the substrate in the process of cladding and determine the size of the heat affected zone, which is the main control factor of the heat affected zone. Simultaneously, in the process of laser cladding, the heating and cooling speed is very fast. If the laser power is too low, the solidification time of the molten pool is shortened, and the gas produced in the process of laser cladding cannot escape in time, it will remain in the cladding coating and form pores. On the contrary, if the laser power is too high, the heat input to the cladding coating and the substrate will increase, the temperature gradient in the repair area will increase, and the heat affected area will increase big. The above factors will directly affect the properties of the cladding coating. Therefore, in the process of making cladding process, the laser power needs to select the appropriate parameters. Therefore, 1.2kW is suiTable.

4. ANALYSIS OF TEST RESULT OF CLADDING PROCESS

4.1. Pattern of Cladding Coating and Microstructure of Substrate

According to the results of finite element analysis, the second group of parameters was used to carry out the laser cladding process test, filling the V-groove on the die steel surface, and the other process parameters are the same as Table. 3. As shown in Fig.5 (a), cut the sample with the size of 10 mm × 10 mm × 15 mm along the line perpendicular to the laser scanning direction, and polish, polish and clean it to get the sample as shown in Fig.5 (b).

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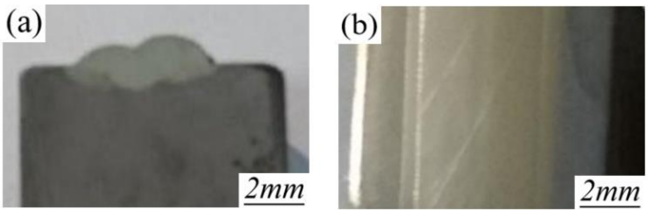

Fig 5. Cladding coating style: (a) longitudinal section; (b) cross section after grinding

The microstructure of substrate and cladding coating is shown in Fig. 6. (a) (b) the microstructure of the longitudinal section and the cross section of the HAZ. During the laser cladding process, the molten pool of the cladding coating formed rapidly cools and solidifies, and transfers heat to the substrate, so that the temperature of the HAZ exceeds its transformation temperature, forming strip like martensite. The gray white part around the martensite is retained austenite. (c) (d) it is the tempered martensite with better toughness in the substrate.

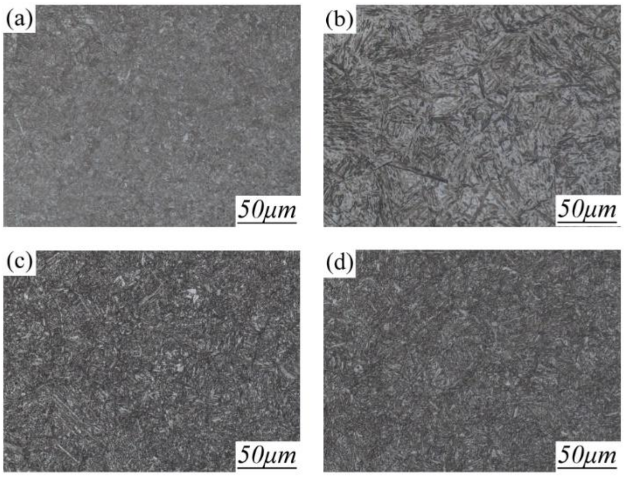

Fig 6. Microstructure of substrate

4.2. Microstructure and Composition Analysis of Cladding Coating

The microstructure of the cladding coating was analyzed by XRD, as shown in Fig. 7. The main diffraction peaks are composed of γ-Ni(Fe),Fe_6W_6C, Fe_2B, WC, W_2C, Cr_7C_3,W_2B and other hard phases and complex gap compounds were formed during the process of cladding.

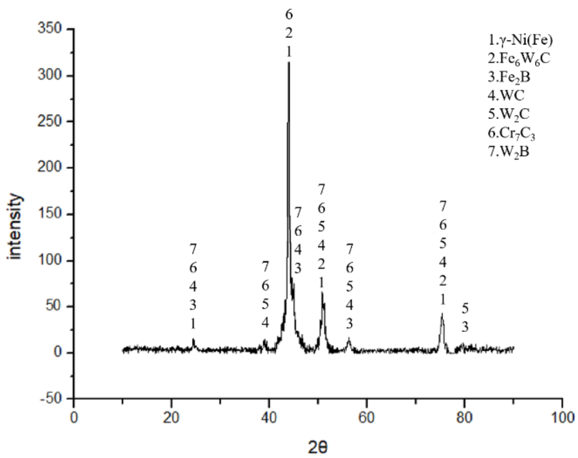

Fig 7. Result of XRD analysis

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SEM and EDS analysis of the structure composition in the middle area of the cladding layer are shown in Fig. 8, and the proportion of element composition is shown in Table.5. According to EDS results, the hard phases containing C and W elements are mainly concentrated at the grain boundary.

The results show that the proportion of C and W elements in the cladding layer plays an important role in the wear resistance and hardness of the coating. As shown in the Fig. 8, the area of grain boundary in the middle area of the prepared cladding layer is relatively uniform. According to the XRD analysis results in Figure 7, it can be inferred that the hard phases (WC, W_2C, Cr_7C_3, W_2B) containing C, W and other elements are easier to precipitate and disperse in the grains at higher temperature, effectively improving the wear resistance and hardness of the repaired parts.

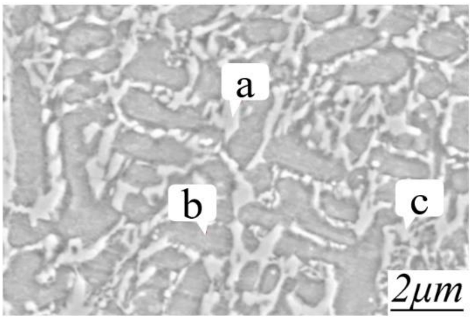

Fig 8. SEM of the middle area of the cladding layer

Table 5. EDS analysis of main elements in middle area of the cladding layer

	Measuring region	W	C	Fe	Ni	Cr	Mo	B	Si
Wt%	Crystal boundary(a)	14.2	5.3	41.81	27.32	8.32	1.65	0.24	1.16
	Crystal face(b)	5.8	3.7	43.3	30.47	10.69	1.86	2.3	1.88
	Crystal boundary(c)	18.8	6.1	40.8	23.2	9.1	1.59	0.73	0.94

5. CONCLUSION

In this paper, MSC Marc finite element analysis software is used to simulate the transient state of laser cladding V-groove multi-layer coating, and the laser power is selected as a single variable to analyze and develop the wear-resistant coating with good combination of experimental process parameters. The specific conclusions are as follows:

(1) According to the results of the finite element analysis, the laser cladding technology was establelished, and the multilayer laser cladding coating with good combination with the substrate was prepared, which had little heat effect on the substrate.

(2) The heat affected zone is high strength lath martensite, and the substrate is tempered martensite.

(3) The cladding layer is composed of γ-Ni(Fe),Fe_6W_6C, Fe_2B, WC, W_2C, Cr_7C_3,W_2B and other hard phases and complex gap compounds. The hard phases (WC, W_2C, Cr_7C_3, W_2B) of C, W and other elements are easier to precipitate and disperse in the grains at higher temperature, which effectively improves the wear resistance and hardness of the repaired parts.

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