LASER ALLOYING ON CHROMIUM-COATED SURFACE OF NODULAR CAST IRON[①]

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ABSTRACT Laser-alloying technique was used to modify the mechanical properties of the chromium-coated surface of nodular cast iron. It was shown that the laser-modifying layer consists of tiny eutectic ledeburite, chromium carbide Cr_7C_3 and $(CrFe)_7C_3$, which can strengthen the wear resistance, by scanning electron microscopy(SEM), X-ray diffraction(XRD) and energy dispersive spectrometry (EDS). The crystallized area and the bright white layer area coexist in the modified layer. The microhardness of the bright white layer area of modified layer reaches HV 927(or HRC 68), while that of the matrix is HV 221.

Key words nodular cast iron chromium-coating laser alloying surface modification wear resistance

1 INTRODUCTION

Laser alloying treatment makes laser beam heat, and melt or solidify metal surface quickly by heating conduction in its own body. Due to the intensively chemical and metallurgical interaction in the high temperature melting, the alloying layer with high hardness, high wear resistance and high corrosion resistance can be obtained, and the mechanical properties of the melted surface can be improved greatly[1-7]. The great progresses have been made in treating the iron and steel materials to obtain alloying layer with high hardness, wear resistance and corrosion resistance by means of laser alloying[8-11]. Nodular cast iron is one of the most important materials widely used in engineering. However, compared with high-carbon steel, there are some restrictions in the application of nodular cast iron because of its lower hardness and strength. In order to increase the surface hardness and wear resistance of nodular iron, some surface strengthening techniques, such as chromium-plating and chromizing, have been used. However, the plating and chromizing layers are thin and the combining strength between the plating or chromizing layer and matrix is low. In this work, the laser alloying on the chromium-coated layer of nodular cast iron was investigated and the better mechanical properties, such as high hardness and corrosion resistance, were obtained.

2 EXPERIMENTAL

The experimental material was the nodular cast iron whose matrix is ferrite, its chemical compositions (%) are: C 3.3~3.6, Si 2.4~3.0, Mn< 0.3, P< 0.07, S< 0.02, Cu 0.62 ~ 0.77. The specimen size was 100mm × 50mm × 10mm. The specimen surface was coated with chromium of 0.08 mm deep by conventional chromium-plating method. After treated by laser alloying, the specimens were cut into size of 30 mm × 7 mm × 8 mm and 10 mm × 7 mm × 8 mm, for observing microstructure and inspecting properties.

The JRJ-II 2kW CO_2 Laser and its automatic processing system were used to carry out the laser-alloying treatment on the chromium-coated surface of nodular cast iron. The technological parameters of the laser alloying treatment were: laser power $P = 1200$ W, focal distance $L = 0$ (beam diameter $D = 1.5 \sim 2$ mm), laser

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scanning velocity $v = 0.2\,m/min$.

Model S-570 scanning electron microscopy (SEM) and PV9900 energy-dispersion spectrometer were used to observe the microstructure of the modifying layer and to analyze the compositions. Rigaku-3015 X-ray diffraction meter was used to examine the phase structure of the laser-modifying layer. The SIMAZUD-M microhardness tester was also used to measure the microhardness on the modifying layer. The loading time was 15 s, and loading value was 0.5 N.

3 RESULT AND DISCUSSION

3.1 Microstructure of laser-modified layer

Fig. 1 shows the SEM micrograph of specimen cross section cut in the direction which is vertical to the laser scanning. Because of the intensively chemical and metallurgical interaction between the chromium atoms and the high temperature alloy solution on the melting surface, there are obvious gradient changes of the microstructures from the melting bath bottom to its top surface in the modifying layer after the remelted surface has been cooled or condensed rapidly. There are three structural areas from the matrix to the surface. The internal part is the matrix whose microstructure is composed of ferrite and nodular graphite. The bottom of melting bath is the crystallized area. The top of melting bath is the bright-white layer area of carbide.

Fig. 1 SEM micrograph of laser-alloying modification layer of chromium-coated nodular cast iron

Fig. 2 shows the SEM micrograph of the crystallized area at the melting-bath bottom. There is eutectic ledeburite in the crystallized area after the remelted surface has been condensed and crystallized.

Fig. 3 shows the SEM micrograph of the bright-white layer area at the melting bath top. There are tiny non-uniform nucleated particles which have been condensed in the bright-white layer because of fast cooling.

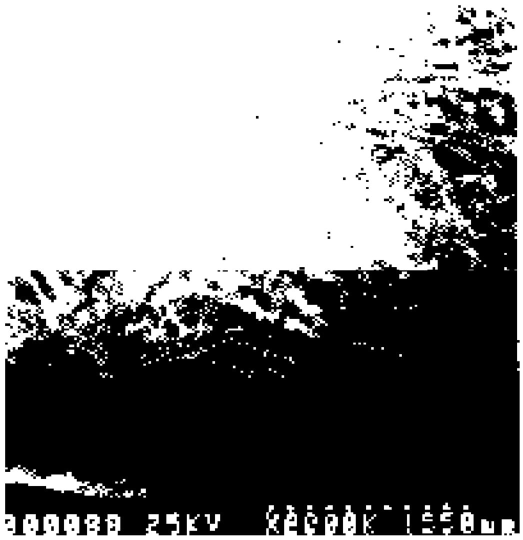

Fig. 2 SEM micrograph of crystallized area of melting bath bottom

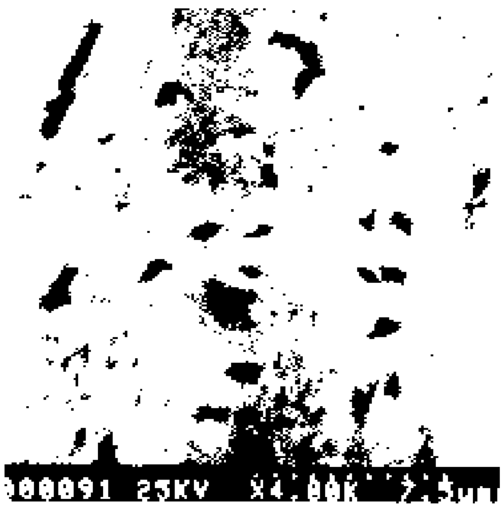

Fig. 3 SEM micrograph of bright-white layer of melting bath top

Fig. 1 shows that during the laser alloying, the graphite numbers in the matrix of nodular cast iron reduce obviously, the graphite is smashed into tiny bits and solved in the ferrite. Thus, the affluent carbon sources are provided for the intensively chemical and metallurgical interaction in the procedure of laser alloying.

From Fig. 1 and Fig. 2, the eutectic ledeburite initially grows from incomplete crystal side at the melting bath bottom when the melting bath is condensed rapidly, and then expands towards the melting area in the thermal-current direction which is vertical to the melting-bath bottom line, finally grows in the extensive way. When the extensive growth reaches certain extents, because melting bath is cooled down rapidly at the speed of $10^3 \sim 10^4$ K/s[11-13], the temperature in the melting bath becomes lower quickly. The atomic diffusion and its movement required for crystal growth are carried out difficultly. In this way, the extensive growth is discontinued abruptly and then the bright-white layer area or non-crystallized area forms[5].

3.2 Chemical composition and phase structure of modifying layer

The chemical composition in bright-white layer area is shown in Table 1. EDS patterns of the bright-white layer inspected by PV9900 EDS are shown in Fig. 4.

From Table 1, the chromium element is diffused gradually towards the inside matrix and formed itself into chromium carbides and chromium-alloy carbides, which make remelted layer modified and obtain high hardness.

Table 1 Main chemical composition of different position in bright-white layer(%)

Tested position	Chromium	Silicon	Ferrite
Top	29.180	0.979	69.850
Middle	19.675	1.121	79.204
Bottom	14.308	1.240	84.452

Fig. 5 shows the X-ray diffraction pattern of laser-alloying on the top. There are alloying carbide phases including $(CrFe)_7C_3$ and Cr_7C_3 which have properties of high hardness, wear resistance and corrosion resistance on the laser remelting surface. The graphite in the nodular cast iron is smashed into tiny bites which solve in the matrix as carbon sources. Thus, the enough carbon is provided to form carbide compounds or alloy compounds together with the chromium atoms during the intensively chemical and metallurgical interaction in the high temperature alloying liquid of melting bath, and then the modifying layer with wear resistance and high hardness is obtained.

3.3 Hardness of modified layer

Fig. 6 shows the microhardness distribution in the laser-alloying modified layer. Because the chemical compositions and microstructures of the

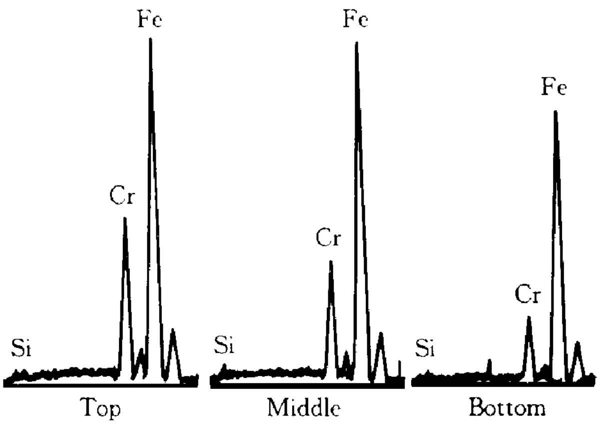

Fig. 4 EDS pattern of bright-white layer of melting bath top

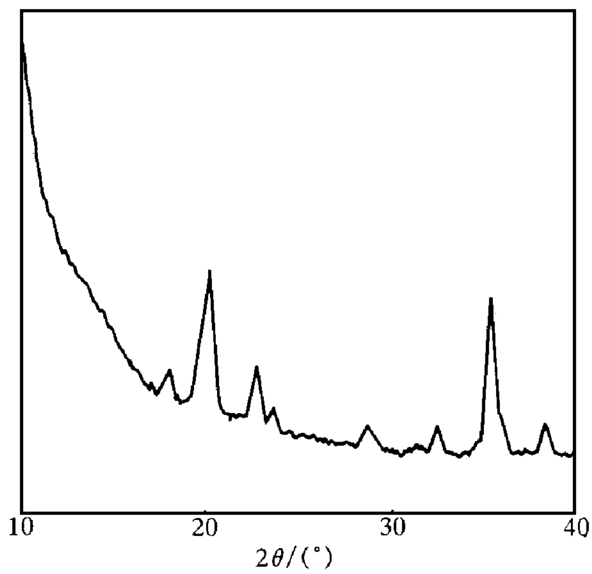

Fig. 5 X-ray diffraction pattern of laser-alloying modified layer

modifying layer have the characteristics of the gradual-gradient changes, the microhardness from the bottom to the top in melting bath increases in the gradient way. The matrix hardness of nodular cast iron is HV 221 and the microhardness of the modifying layer ranges from HV 549 to HV 927. The hardening depth is 1.024 mm. The characteristics of gradient-range microhardness is determined by fast-speed condensing process of laser alloying when the metal on the melting-bath surface condenses, the condensing boundaries expand gradually from the top to the bottom in the melting bath. The nearer they reach the surface, the longer time the chemical and metallurgical interaction takes, the more compounds Cr_7C_3 are formed by direct chemical reaction since the chromium atoms is solved in the alloying liquid of melting bath. Meanwhile, more and more alloying-carbides $(CrFe)_7C_3$ are obtained in the surface after the laser-scanning surface has condensed quickly.

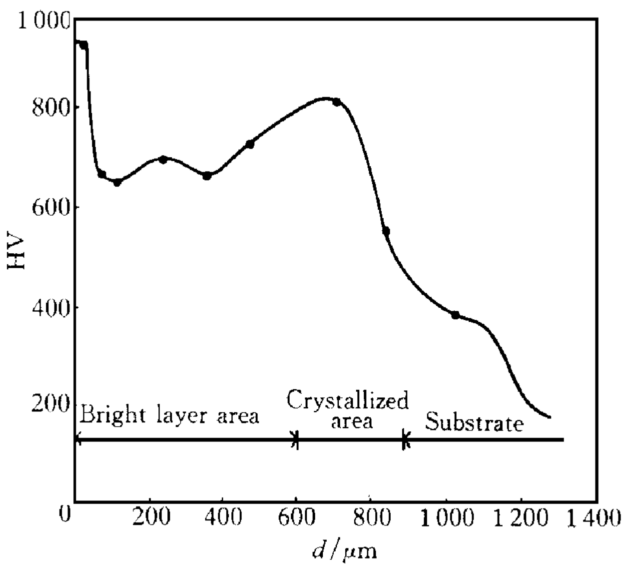

Fig. 6 Hardness profile across the laser-alloying modified layer

4 CONCLUSIONS

(1) After the chromium-coated surface of nodular cast iron is modified by laser alloying, there are tiny eutectic ledeburite, carbides Cr_7C_3 and alloy carbides $(CrFe)_7C_3$ in the modifying layer which has high hardness, wear resistance and corrosion resistance.

(2) The microhardness of the chromium-coated modification layer of nodular cast iron strengthened by laser alloying is HV 927 (HRC68).

(3) There exist the crystallized area and the bright-white layer area or carbide layer in the surface-modifying layer of chromium-coated nodular cast iron.

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