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Microstructure and properties of Cr12MoV die steel by laser quenching with different power

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Abstract: In this paper, laser quenching on the surface of Cr12MoV cold-work die steel was carried out by CO₂ laser. The laser scanning speed was 800mm/min, and the laser powers were 1200W, 1400W, 1600W and 1800W respectively. Thickness, microstructure, hardness, XRD, friction and wear properties of the quenched layer were investigated after laser quenching with different power. The results show that the thickness and martensite content in quenched layer increase gradually with the increase of laser power. The hardness of quenched layers have an increase firstly and a later decrease along with laser power. When the laser power is 1600W, the maximum hardness is 662.9HV. When the power is 1800W, microfusion appears on the surface, and the hardness of the quenching layer decreases. The wear volume of the sample first rises and then falls along with laser power. The minimum wear volume is 0.09mm³ at 1600W, and the wear volume is reduced by 92% of the original sample. Therefore, scanning speed of 800mm/min and laser power of 1600W can get the best microstructure and properties.

1. Introduction

Cr12MoV steel is a widely used cold-work die steel with good hardenability and wear resistance. It is mainly used to manufacture cold-work die with large size, complex shape and large load^[1]. Wear failure is a common failure mode of Cr12MoV cold-work die steel^[2,3], which can reduce the life of die steel. There are many methods to strengthen Cr12MoV steel, such as surface nitriding, carburizing, carbonitriding, plasma spraying^[4-7]. However, these technologies have problems such as complicated processes, low efficiency, and high energy consumption. Surface laser quenching has many advantages such as high work efficiency, no pollution, low cost, small thermal deformation. It solves many problems that cannot be solved by traditional techniques^[8-10]. It has been widely studied and applied in recent years. In this paper, the laser scanning speed of CO₂ laser was 800mm/min. The Cr12MoV steel was quenched by different laser powers in order to analyze the microstructure, hardness and wear. Therefore, the best laser quenching power was obtained. It provides a scientific basis for the optimization and application of laser quenching technology on Cr12MoV steel surface.

2. Experimental materials and methods

The experimental material is Cr12MoV steel plate, and the chemical composition is shown in Table 1. The sample size is 50×30×20mm. Before the experiment, the surface of the sample is polished with emery paper, and then washed with acetone. The carbon ink and carbon powder mixture are used as the light absorption. The coating is used to increase the absorption rate of laser energy, and the thickness is about 0.05 mm.



Table 1. Chemical composition of Cr12MoV die steel

Chemical element	C	Si	Mn	P	S	Cr	V	Ni
Mass fraction(%)	1.51	0.03	0.3	0.024	0.002	11.69	0.23	0.1

Surface quenching was carried out by a 2000W CO₂ laser. The defocusing was 35 mm and the spot diameter was 3 mm. The scanning speed of the laser line was 800mm/min, and the powers were 1200W, 1400W, 1600W and 1800W respectively. After quenching, the samples were cut, ground and buffed, and then etched with 5% nitric acid for 5min. The cross-sectional structure was observed by metallographic microscope, and the change of internal structure was analyzed. The phase composition was analyzed by TD-3500X XRD. The hardness was measured by HXD-1000TMC/LCD, and then section hardness was analyzed. The wear test of quenched surface was carried out by MGW-02 wear tester. The wear state was analyzed according to the friction coefficient and surface morphology, and the wear volume^[3] was calculated by equation (1) to determine the wear resistance with different processes.

$$V = \frac{1}{2} R^2 L \left[2 \arcsin\left(\frac{B}{2R}\right) - \sin 2 \arcsin\left(\frac{B}{2R}\right) \right] \quad (1)$$

where V is wear volume; R is radius of the grinding ball; L is length of the wear scar, and B is width of the wear scar.

3. Results and discussion

3.1. Microstructure

Figure 1 shows the macroscopic morphology of the laser quenched layer at different powers. The magnification is 50 times. As the laser power increases, the heat of the surface and the width of the laser quenching layer increases gradually. The width of the quenching layer is shown in Table 2. The thickness of the quenching layer is only 0.03mm when the laser power is 1200W, which is thinnest. The thickness of the quenching layer increases greatly when the power increases from 1200W to 1400W. When the power is 1400W, 1600W and 1800W, the thickness of the quenching layer gradually increases. However, the increase is not obvious. As the laser power increases, the heat accumulated on the surface increases gradually. Therefore, when the laser power increases to a certain extent, the increase in width of laser quench layer is not obvious. When the laser power is 1800W, the surface of steel has the surface melting, and the width of quenched layer reaches a maximum.

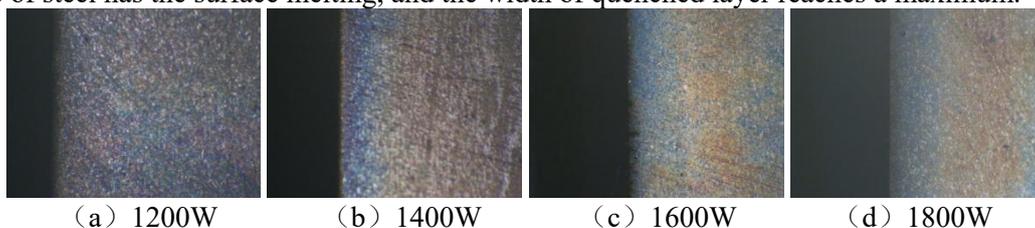


Figure 1. Macroscopic morphology of laser quenched layer at different powers.

Table 2. Laser quenching process parameters and quenching layer width of Cr12MoV steel.

	Power (w)	Speed (mm/min)	Defocus amount (mm)	Hardened layer width (mm)
Sample 1	1200	800	35	0.03
Sample 2	1400	800	35	0.2
Sample 3	1600	800	35	0.3
Sample 4	1800	800	35	0.35

Figure 2 shows the metallographic structure of the phase transformation zone, transition zone and substrate at a laser power of 1600W. As shown in figure 2(a), the heat in the phase transformation hardening zone is the most concentrated. The temperature is much higher than that of Ac₃, and a

complete austenite transformation occurs. A large amount of carbon is dissolved. When cooling rapidly, most of the austenite transforms into fine needle-shaped martensite, and the coarse carbides in the substrate are converted into fine carbides. Therefore, the microstructure is a mixture of fine needle-shaped martensite, fine carbides and retained austenite. The temperature in the transition zone is lower than that in the phase transformation hardening zone. Between A_{c1} and A_{c3} , the temperature gradient is relatively small. The action time is short, and the phase transition is insufficient. Austenitization is not completed. Cooling rate is relatively slow. A small amount of martensite structure is gained, and carbide size is larger than the phase transformation zone. The microstructure is fine pearlite, carbide and a small amount of martensite, as shown in figure 2(b). Figure 2(c) is a microstructure of a Cr12MoV steel substrate consisting of pearlite and a large amount of carbide.

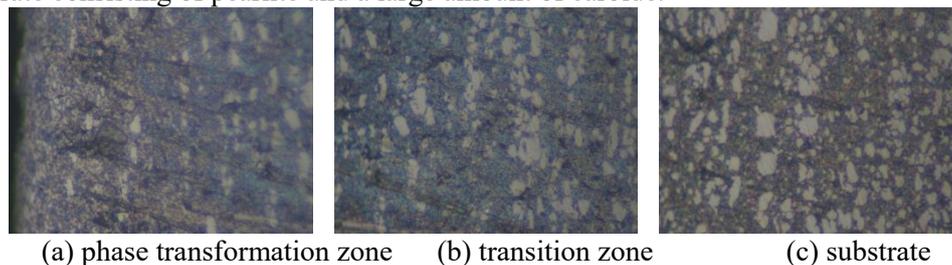


Figure 2. Metallographic structure of phase transformation zone, transition zone and substrate at 1600w.

Figure 3 shows the metallographic structure of the near surface layer with different laser powers. With the increase of laser power, the martensite content increases gradually, but the carbide size decreases gradually. The surface heat is relatively small when the laser power is 1200W. Therefore, temperature is low, and only a part of the surface layer is austenitized as shown in figure 3(a). A small amount of martensite is formed after rapid cooling, and the carbide has a relatively large size. The thickness of the quenched layer in figure 3(b) is more than that in figure 3(a), and the carbide size is less. In figure 3(c), as laser power increases, the amount of martensite increases and the carbide size is finer. However, when the laser power is 1800W, the surface of the sample is overheated and melted. So the martensite and carbide become bigger.

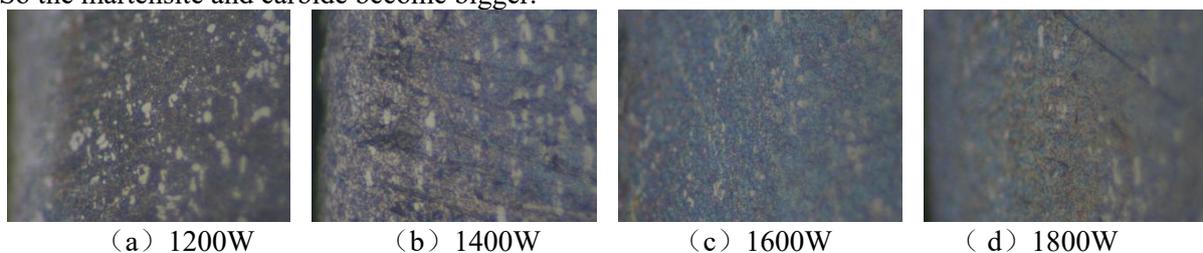


Figure 3. Metallographic structure of the near surface layer at different laser powers.

3.2. XRD

Figure 4 is a XRD pattern of the surface of the Cr12MoV laser quenched sample with laser power 1600W. It can be seen from the X-ray diffraction pattern that the martensite phase and carbide are formed on the surface of the sample, which is the same as the results of metallographic analysis.

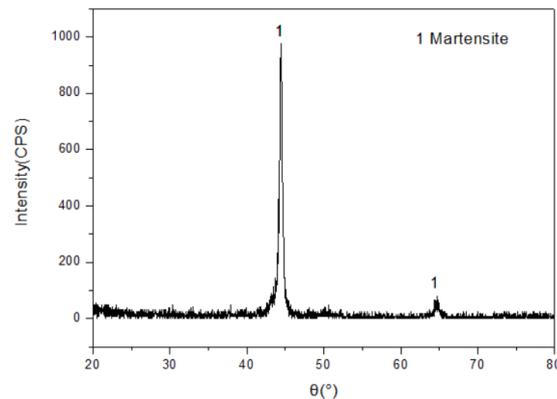


Figure 4. Surface XRD pattern of laser quenched sample.

3.3. Hardness

Figure 5 is the cross-sectional hardness of different laser power from 1200W to 1600W. With the increase of laser power, the maximum hardness increases gradually, which has an upward trend. The maximum hardness is 665.7HV at laser power 1600W, which is about 2.5 times to that of substrate. When the laser power rises to 1800W, the maximum hardness drops to 620.7HV. The reason is that the higher laser power causes surface melting on the surface. Therefore, the surface and near surface hardness is down.

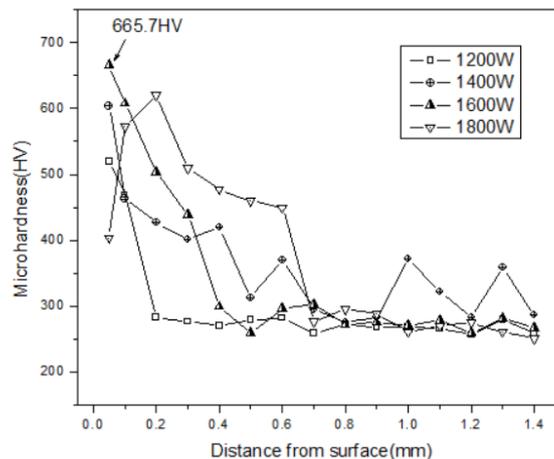


Figure 5. Section hardness of the sample under different laser power.

3.4. Wear

Figure 6 shows the wear scar morphology of different samples. A1, A2, A3 and A4 are furrows in the wear scars. When the laser power is 1200W, 1400W and 1800W, the number and width of furrows are larger. There is spalling in the furrows, which is the type of adhesive wear. When the laser power is 1600W, the width and number of furrows are significantly reduced. Because there are a large number of fine martensite grains and refined carbides without obvious spalling, it is close to abrasive wear. As shown in table 3, the laser power increases, the width value of wear scar gradually decreases between 1200W and 1600W. The width of original sample's wear scar is 1.98 mm. At 1600W, the width of wear scar is 0.93mm. According to equation (1), the calculated wear volumes are 1.14mm³ and 0.09mm³ respectively. The wear volume reduces about 1.05mm³ (92%) compared with the original sample, which improves the wear resistance of Cr12MoV greatly. The reason is that the fine martensite and the refined carbide improve the surface hardness and wear resistance. In addition, when the laser power is 1800W, the wear volume suddenly increases. The reason is that the surface melting

reduces the hardness and wear resistance. In summary, it has better wear resistance when the laser power is 1600W.

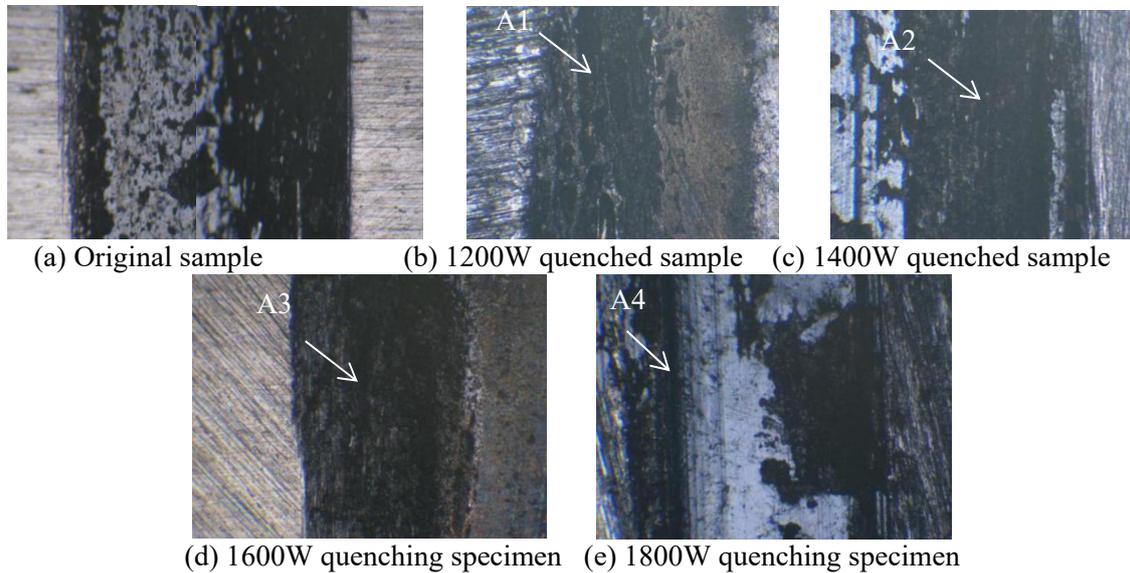


Figure 6. Wear profile of different samples (50 times).

Table 3. Wear width and volume.

	Original sample	1200W	1400W	1600W	1800W
Width (mm)	1.98	1.76	0.99	0.93	1.04
Volume (mm ³)	1.14	0.78	0.12	0.09	0.15

4. Conclusion

(1) After laser quenching, the sample is divided into phase transformation zone, transition zone and substrate. The quenched layer microstructure is mainly composed of martensite and fine carbide. As the laser power increases, the thickness and martensite content of the quenched layer increase gradually. The surface of steel has surface melting when power is 1800W. The hardness of quenched layers has an increase firstly and a later decrease along with laser power. When the laser power is 1600W, the hardness reaches the maximum value 665.7HV. It is about 2.5 times to the hardness of substrate. When laser power is 1800W, the hardness begins to decrease.

(2) The wear test of Cr12MoV steel after laser quenching is carried out, and there are some furrows on the surface. The width and number of furrows first rise and then fall along with laser power, and it has the smallest width of wear scar at 1600W. The wear width and volume are 0.93mm and 0.09mm³ respectively. The wear volume is reduced by 92% of the original sample. The results show that the antiwear performance of die steel can be improved through laser quenching on the surface of Cr12MoV steel. When laser scanning speed is 800mm/min and power is 1600W, Cr12MoV steel quenched with CO₂ laser has the best properties.

Acknowledgements

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