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STUDY ON LASER SURFACE QUENCHING STRUCTURE AND HARDNESS OF C45 STEEL

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The changes of hardening depth and surface hardness of C45 steel after laser surface quenching were studied. Firstly, the Nd: YAG laser and CO2 laser were used to realize the surface quenching. High power CO2 laser quenching C45 steel, variable process parameters include power, scanning speed and defocusing distance. Then, the Nd:YAG laser was used to quench the samples through orthogonal experiments, and the optimized process parameters were obtained, and the surface hardness was obviously improved. Finally, by comparing the quenching C45 steel of CO2 laser, the influence curve of process parameters on surface hardness was found, and the optimal process parameters were obtained.

Keywords: C45 steel, laser quenching, surface, hardness, microstructure

INTRODUCTION

C45 steel is high quality carbon structural steel, and has good compre- hensive mechanical properties after mo- dulation treatment. It is widely used in motorcycles and automobiles, especially for connecting rods, bolts, gears and shafts that work under alternating loads [1]. C45 steel is subject to great friction in work, and is usually hardened to improve its hardness, wear resistance and service life. In recent years, the Nd: YAG laser and CO_2 laser are mainly used to realize the surface quenching of materials [2-3]. The effect of these two lasers on the microstructure, hardening depth and surface hardness of C45 steel after quenching was studied in this paper. After the laser quenching, the micro- structure of the hardened layer changes and the martensite becomes thinner, which greatly improves the properties of the material. Easy to process, wide app- lication, simple processing technology, no pollution, low noise, high efficiency.

EXPERIMENTAL MATERIALS AND EQUIPMENT

The experimental material is a roll- ed C45 steel cut into a 100 × 25 × 10 mm matrix by wire cutting. The experi- mental equipment is HGL-6000 cross flow CO_2 laser and 400 Watt Nd: YAG laser. Microstructure was observed using metallographic optical microscopy and scanning electron microscopy. The sur- face roughness meter is jB-5C contour roughness meter. Hardness is measured by microhardness tester. After the matrix is quenched, the cross section of the ma- trix is cut out, and then ground and polished by the metallographic inlay ma- chine.

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EXPERIMENTS

The experiment uses the laser sing- le channel to scan the sample. The tech- nological parameters of CO_2 laser are power, scanning speed and defocus. It is shown in Table 1. The technological parameters of Nd:YAG laser are input current, pulse width and pulse frequency. It is shown in Table 2.

The sample preparation of CO_2 laser is shown in Figure1.

The sample preparation of Nd:YAG laser is shown in Figure 2.

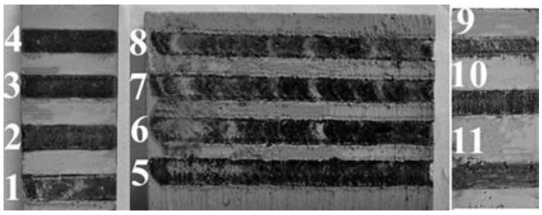


Figure 1 CO_2 laser sample

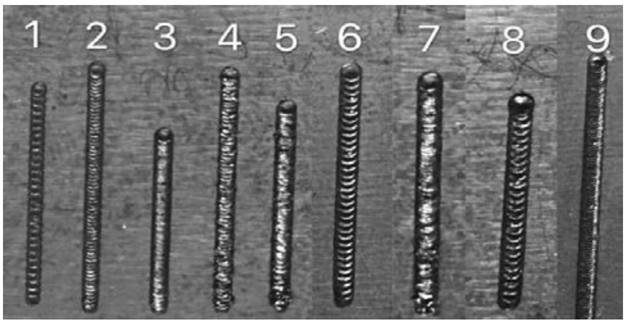


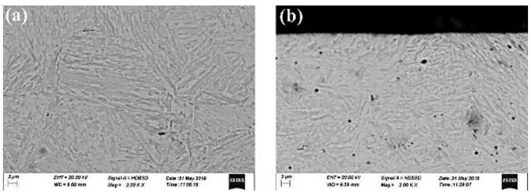
Figure 2 Nd:YAG laser sample

Table 1 **CO_2 Laser parameters**

No.	Laser power	Scanning speed	Defocus distance
1	1 600 W	300 mm/min	35 mm
2	1 600 W	600 mm/min	35 mm
3	1 600 W	900 mm/min	35 mm
4	1 600 W	1200 mm/min	35 mm
5	1 400 W	600 mm/min	35 mm
6	1 600 W	600 mm/min	35 mm
7	1 800 W	600 mm/min	35 mm
8	2 000 W	600 mm/min	35 mm
9	1 600 W	600 mm/min	5 mm
10	1 600 W	600 mm/min	35 mm
11	1 600 W	600 mm/min	50 mm

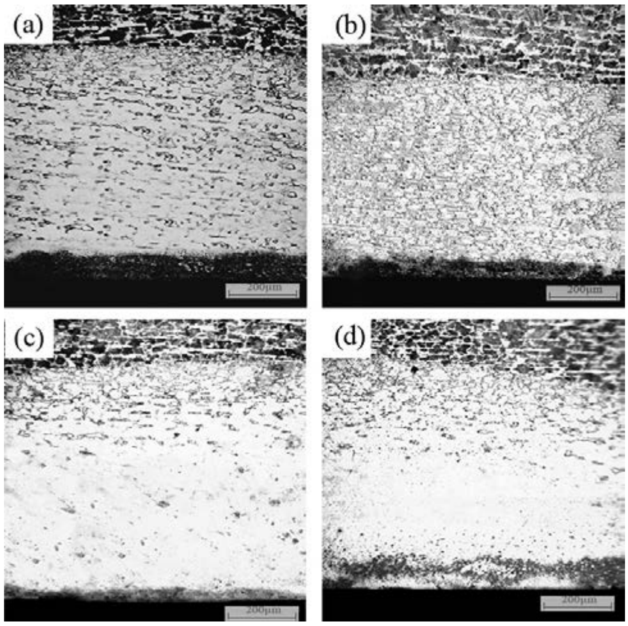
Table 2 **Nd:YAG Laser parameters**

No.	Current/A	Pulse /ms	Frequency /Hz	HRA
1	200	1	5	72,5
2	200	1,2	10	74,8
3	200	1,4	15	75,1
4	240	1	10	76
5	240	1,2	15	76
6	240	1,4	5	75,6
7	280	1	15	77,1
8	280	1,2	5	78
9	280	1,4	10	79,6



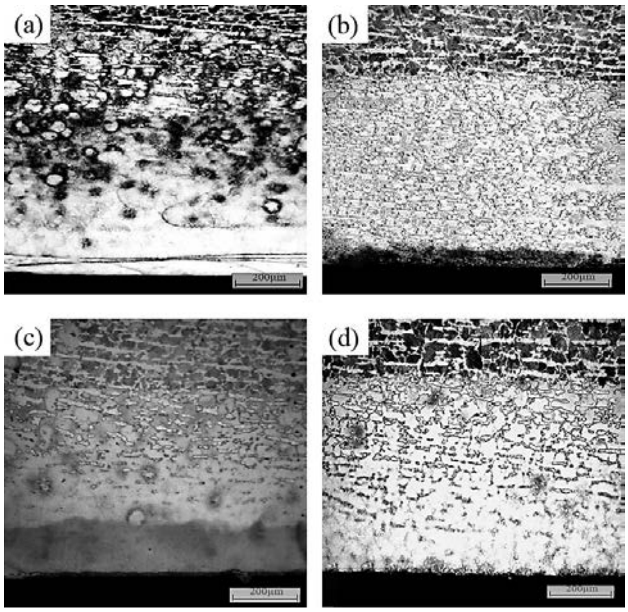
(a) Thermal effect of martensite
(b) Hardening layer of martensite structure

Figure 3 Electron microscopy of martensite



(a) 300 mm/min (b) 600 mm/min
(c) 900 mm/min (d) 1 200 mm/min

Figure 4 Tissue changes at different scanning speeds



(a) 1 400 W (b) 1 600 W (c) 1 800 W (d) 2 000 W

Figure 5 Tissue variation of different power

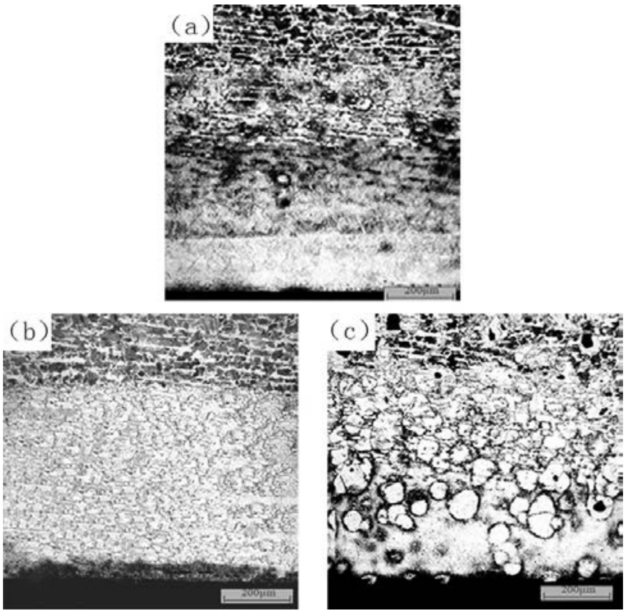
QUENCHING STRUCTURE AND HARDENING LAYER

Observed with electron microscopy, 2000 X martensite structure, as shown in In the Figure 3, the martensite structure can be clearly seen as spicules. It is obvious that the martensite structure near the hardened layer is more fine- grained than that near the heat-affected area, and the laser quenching is more fine-grained than the normal quenching.

Microstructure changes after laser quenching were observed by metallo- graphic optical microscope, as shown in Figure 4.

In Figure 4, from the microscopic observation, the changes of the material structure after laser scanning can be roughly divided into three regions: the hardening layer, the heat-affected region and the matrix. From the surface to the matrix, with the increase of the depth of the hardening layer, the size and shape of martensite also changed significantly, and the thicker martensite tissue was formed near the heat-affected zone, while the hardened layer was the aci- cular martensite tissue. The depth and width of the hardened layer decrease with the increase of scanning speed. On the metallographic microscope, a silvery white hardened layer can be clearly seen. When the scanning speed is 300 mm/min , the austenite transformation is affected due to the relatively high energy, and the tissue is destroyed. When the scanning speed is 600 mm/min, the austenite transformation is better, and the martensite grain is fine and uniform, then it is the best value. When the scanning speed was 900 mm/min, the martensite tissue was fine and uniform. When the scanning speed is 1200 mm/min, the depth of the hardened layer drops by one time and the width increases by one time.

In Figure 5, the microstructure of the hardened layer was observed by metallographic microscope, and it was



(a) 5 mm (b) 35 mm (c) 50 mm

Figure 6 Tissue changes at different defocusing distances

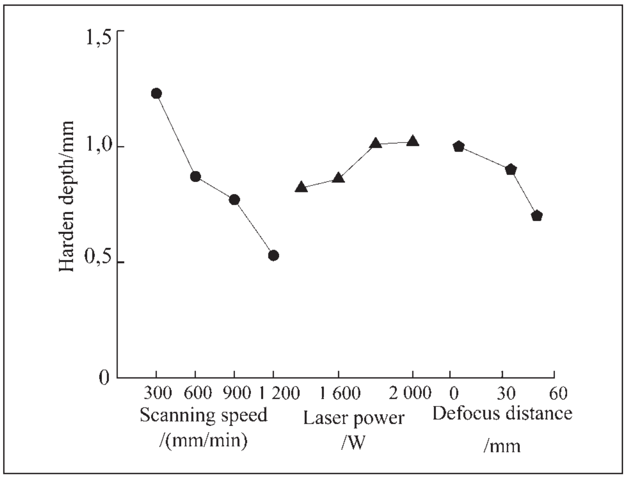


Figure 7 Hardening depth of different parameters

found that under the four laser power parameters, the metal surface underwent phase transformation to form a certain depth of the hardened layer, and the hardened layer area was fine needle-like martensite tissue.

In Figure 6, the sample tissues with a distance of 35 mm from defocusing is the best. It can be clearly seen that after quenching, it is divided into three re- gions, namely, the hardening layer, the heat-affected region and the matrix. Organization of the hardening layer of fine acicular martensite and a few resi- dual austenite organizations, organiza- tions are more uniform, hardening layer is deep, heat affected zone near the grain is bulky, away from the focal distance of 5 mm, because of the close, laser instantaneous temperature is exorbitant, quenching layer by laser energy is too large to produce oxide, and grain is bulky. However, for the sample struc- ture with a distance of 50 mm from fo- cus, due to a relatively long distance from focus, the energy during quenching is small, and the temperature is not enough to change the internal structure almost.

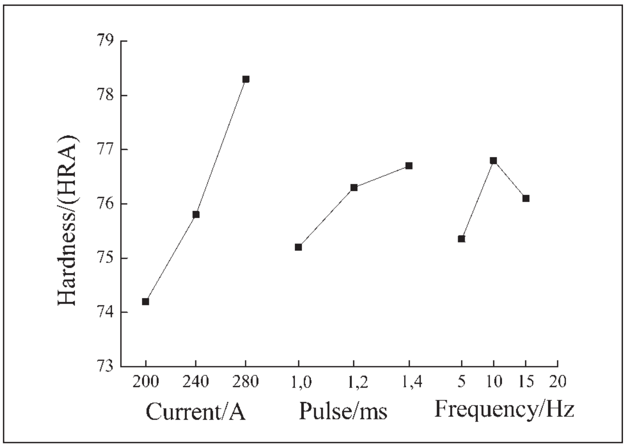


Figure 8 Curve effect diagram

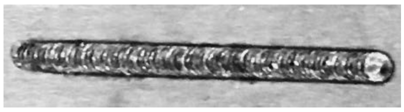


Figure 9 Optimization of sample

In Figure 7, the depth of hardened layer decreases with the increase of scanning speed and defocusing amount, but increases with the increase of laser power.

SURFACE HARDNESS

The data in Table 2 were intuitively ana- lyzed by orthogonal method, and the curve effect diagram was drawn, as shown in Figure 8.

The maximum hardness parameter cur- rent 280 A, pulse width 1,4 ms and fre- quency 10 Hz was selected from Figure 8. Verification experiments were con- ducted to obtain sample surface hardness HRA 81,5 is shown in Figure 9.

Vickers hardness tester was used to measure the surface hardness of sample in scale 1, as shown in Figure 10.

It can be concluded from Figure 10 that the sample surface hardness and CO_2 laser parameters show a normal distribution. When scanning speed in- creaseing, a laser beam to stay on the surface of the sample, shorter time, less energy is, the process of energy is larger, higher temperature, easy to become bulky, austenite grain size in the mar- tensite after transformation, martensite structure also becomes bulky, and or- ganization is not uniform, so the surface hardness value is small. When the scan- ning speed is higher than 600 mm/min, the surface energy is insufficient and the laser beam stays on the surface of the sample for less time. As a result, the sur- face energy drops and the temperature drops, so that austenite cannot be com- pletely transformed into martensite tissue. Therefore, the surface hardness gra- dually decreases, and with the increase of scanning speed, vickers hardness first rises and then drops. When the power gradually increases, the surface hardness first increases and then decreases. When the power reaches 1600 W, the surface

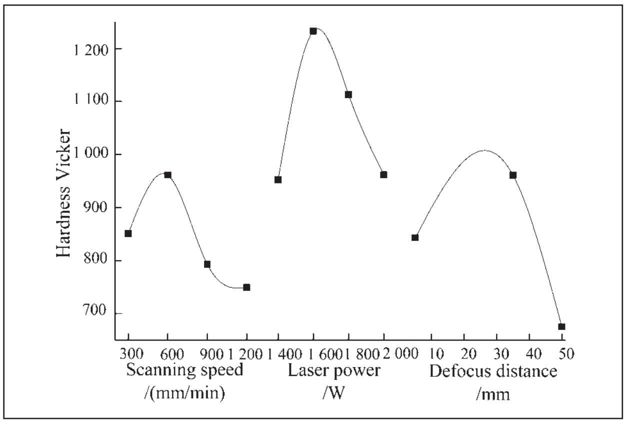


Figure 10 Surface hardness of different parameters

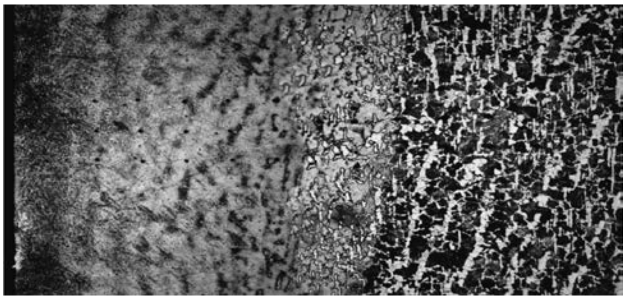


Figure 11 Microhardness distribution

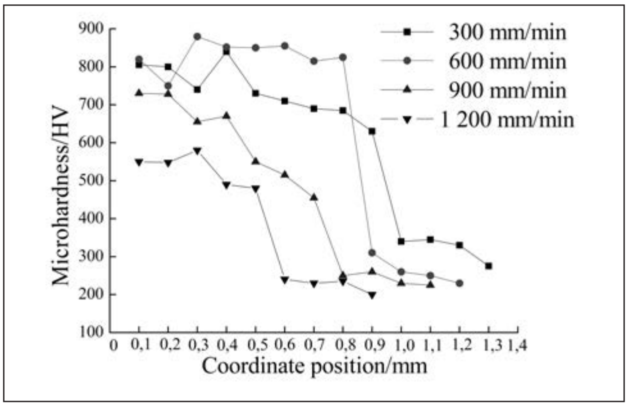


Figure 12 Effect of laser parameters on microhardness of hardened layer

hardness reaches the maximum value of HV 1 233. When the power is 1 400 W, due to the small power, the energy is not enough and the temperature is low, so that the austenite tissue has not been completely transformed into the marten- site tissue, and the successful trans- formation of martensite tissue is few, resulting in low surface hardness. When the laser power is higher than 1 600 W, the high power leads to high power density and energy per unit time, which makes the surface of the sample undergo micro-melting, so the surface hardness decreases. When the defocusing distance increases gradually, the surface hardness first increases and then decreases, and the maximum value is HV 961,2. There- fore, when the defocusing distance is 35 mm, it is the best value. When the defocusing distance is 5 mm, due to the relatively close distance from the focus, the energy and temperature per unit time are large and the metal surface is slightly melted, which reduces the hardness. When the defocusing distance is 50 mm, the defocusing distance is relatively large, and the energy exerted by the laser on the surface of the sample is reduced, which cannot achieve instantaneous quenching. Austenite cannot be converted into martensite structure, resulting in the decrease of surface hardness.

MICROHARDNESS

The cross section hardness of laser quenched samples was analyzed by microhardness tester. The microhardness distribution is shown in Figure 11.

It can be clearly seen from Figure 11 that the curve of the hardening layer is divided into three regions, namely, the hardening layer, the heat-affected region and the matrix. It can be seen from Figure 12 that the hardness distribution is also relatively clear, the hardness of the hardened layer is the hardest, the hardness of the heat-affected area shows a downward trend, until it drops to the hardness of the matrix itself.

CONCLUSIONS

Laser quenching can improve the microhardness and surface hardness of the metal. The enhanced microhardness is about 2~5 times that of the matrix, and the surface hardness is about 3~5 times that of the matrix.

Nd:YAG laser optimum process parameters: current 280 A, pulse width 1,4 ms, frequency 10 Hz. Surface hard- ness HRA 81,5. Best process parameters of CO_2 laser: scanning speed 600 mm/min, power 1 600 W, defocus 35 mm. The maximum quenching depth of CO_2 laser is 1,1 mm and the maximum surface hardness is 1 233 HV.

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Note: The responsible translator for English language is Y.X. Chen, Anshan, China