Effect of Laser scanning speed on Wear Behavior of 45# Steel against Plant Abrasive

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Abstract. In this paper, the author studied the effect of laser quenching scan time on the wear resistance of 45# steel against plant abrasive by using alfalfa meal as a typical plant abrasive. The results showed that under the experimental conditions, the maximum surface hardness of the material can reach 735HV, and the maximum hardness of the material is between 0.5 and 0.8 mm from the surface; the wear resistance of 45# steel after laser quenching is much higher than that without laser; the higher hardness of the treated specimen, the better wear resistance; in comparison with the untreated specimen, the plow depth of the surface of the specimen after laser treatment is significantly shallower and narrower, and the degree of fatigue wear is also significantly smaller than untreated specimen.

1. Introduction
The wear of plant abrasive to metal materials is soft abrasive wear, widely existing in the agricultural machinery, agricultural product processing, food processing and other industries, such as the abrasion of the combined harvester header, the abrasion of key components of agricultural machinery and granulators, the abrasion of key components of milling machines and oil press. It is one of the main reasons for affecting the service life of related machinery. Therefore, to study the abrasive wear mechanism of plant materials to metal surfaces is of great significance for selecting metal materials and heat treatment processes, and improving mechanical equipment design and lubrication methods.

The wear of mechanical parts mostly occurs on the surface, so surface technology can be used to improve the wear resistance of the material surface [1]. Laser surface treatment is the technology that uses the interaction between a high-energy laser and the surface of a material to change the structure, physical properties and stress state of the surface of the material to improve the surface properties of the material, increase the service life of parts and expand the application of the material [2].

Ling Gang conducted laser phase transformation and laser fusion treatment on 65Mn steel which is used in agricultural machinery, analyzed the effect of different laser process parameters on microstructure and micro-hardness. The results showed that wear resistance was significantly improved compared with conventional quenching and tempering treatment [3]. In Hua Yin-qun made a
comparative analysis of its surface hardness and wear resistance by conducting laser quenching + laser impact strengthening treatment on QT8002, and found that the hardness after composite strengthening treatment increased by 1.8% compared with the hardness of pure laser quenching treatment and the wear resistance increased 3 times or doubled than that of soft nitriding and pure laser quenching respectively [4].

Chen Zhuo-jun investigated the effect of laser strengthening process parameters to the micro-hardness of 65Mn and 9SiCr rotary tiller blades through soil abrasion test. The surface hardness and the amount of wear were used as test indicators to obtain the best process parameters of the laser strengthening treatment of rotary tiller blades. The results showed that the surface wear resistance is significantly improved compared with that of general quenching [5-7].

In this work, the wear performance of 45# steel was tested by using the wear test machine. The relationship between 45# steel wear rate, microstructure, wear surface morphology and mechanical properties was studied, and the best heat treatment process for abrasive wear was determined.

2. Experimental Materials and Methods

2.1. Sample preparation

For the purposes of the wear tests, the 45# steel was cut into 57mm×25.5mm×6mm samples. Tab.1 is the heat treatment processes of samples.

The abrasive was Gannon III alfalfa, dried for 8h by the method of hot air connecting, milled with 6mm each. The mass percentage of crude protein was 17.39%, moisture 7.65%, crude fiber 25.06%, and crude ash 8.98%.

2.2. Test equipment and method

The experimental tests were carried out on the MLS-225 wet-sand-rubber-wheel abrasion test machine, with the room temperature controlled at 20°C–25°C. The rubber wheel was rotated with a velocity of 200r/min and the load on the sample was 250N, each 10000r is 1 grinding pass, a total of 5 grinding passes, and the plant abrasive is tested Abrasion test of 45# steel with different laser quenching processes. The selected laser power is 2200W, the spot diameter is 2mm, and the 45# steel laser quenching test pieces are prepared with scanning speeds of 15mm/s, 20mm/s, 25mm/s, and 30mm/s. All samples were immersed in acetone solution for ultrasonic cleaning before and after the wear test, and weighed by using an analytical balance with an accuracy of 0.1 mg. The difference between the mass before and after the war was the weight of the wear loss, which was converted into the wear volume to obtain its wear rate and wear coefficient. Three tests were carried out under each test condition, and the average value was taken. To analyze the surface morphology, the metal samples were observed with JSM-5600LV scanning electron microscope (SEM), analyzing the wear mechanism of plant abrasives on 45# steel under different laser quenching processes, and discussing the mechanism of laser quenching to improve the wear resistance of 45# steel against plant abrasives.

The wear rate and wear coefficient were considered as the wear test index, which were obtained by formulas (1) and (2) respectively [8].

\[
Q = \frac{V}{d} \tag{1}
\]

In formula (1), Q is the wear rate (mm³/m), V is the volume wear (mm³), and d is the sliding distance (m).

\[
k = \frac{Q}{W} \tag{2}
\]
In formula (2), k is the wear coefficient (mm$^3$/Nm), Q is the wear rate (mm$^3$/m), and W is the load applied by the wear test (N).

3. Results and Discussion

3.1. Micro hardness analysis

Fig.1 shows the micro hardness of 45# steel at different scanning speeds when the laser power is 2200W and the spot diameter is 2mm. It found that with the increase of the scanning speed, the micro hardness of the surface of the test piece gradually increases, but when the scanning speed exceeds 25mm/s, the hardness decreases greatly. When the maximum hardness is between 0.2 and 0.4m from the surface, the hardness of the hardened layer is between 498HV and 693HV, which is 1.83 to 2.56 times of the hardness of the substrate. When the scanning speed is 25mm/s, the maximum hardness is under the surface of 0.3mm, and reaches 735HV, and the depth of the laser hardened layer decreases with the increase of the scanning speed. Within the range of the selected scanning speed, the depth of the hardened layer is between 0.5 and 0.8mm.

![Figure 1. Micro hardness of 45# steel at different scanning speeds](image)

3.2. Wear performance analysis

Fig.2 shows the wear rate and wear coefficient of 45# steel at different scanning speeds. It found that the effect of scanning speed on material hardness and wear resistance is basically the same. At the same
time, it can be seen that in the early stage of wear, the difference in the degree of wear of the test pieces at different scanning speeds is very small, and the curves cross each other. When the sliding distance exceeds 3000m, the effect of the scanning speed on the wear resistance of the material gradually appears.

3.3. Metallographic analysis

Fig.3 (a) shows that the base structure of 45# steel is pearlite + ferrite. In the process of laser quenching, due to the influence of temperature gradient, the temperature of 45# steel from surface to interior also varies, resulting in a very different structure. The picture shows the overall appearance of the 45# steel metallographic structure when the laser power is 2200W, the scanning speed is 20mm/s, and the spot diameter is 2mm. It can be seen that after laser quenching, the hardened area in the depth direction can be divided into three layers, followed by the superheated area, the phase change hardened area and the transition area.

![Microstructure of 45# steel by laser quenching](image)

(a) Original microstructure of 45# steel (b) Whole microstructure of laser quenching
(c) Surface over heat transformation area (d) Transformation hardening zone (e) Transition area

**Figure 3.** Microstructure of 45# steel by laser quenching

3.4. Wear morphology analysis

![Abrasion morphology under different laser processing parameters](image)

(a) Untreated (b) 20mm/s (c) 30mm/s

**Figure 4.** Abrasion morphology under different laser processing parameters
Fig. 4 shows the wear morphology of alfalfa meal on 45# steel specimen under different laser strengthening process parameters. The fig. 4(a) indicated that the untreated 45# steel specimen has a large number of deep and wide furrows on the worn surface, with obvious ploughing phenomenon, and plastic marks on the surface. The surface depth of the laser-treated specimen is significantly shallower and narrower than that of the untreated specimen. Comparing the graphs (b) and (c), it found that when the laser power is high and the spot diameter is short, the wear morphology of the specimen has little difference with the change of scanning speed, all of them show shallow and narrow furrows.

4. Conclusion
From the experimental results, the following conclusions can be drawn.

1. With the increase of the scanning speed, the micro hardness of the surface of the test piece gradually increases, but when the scanning speed exceeds 25 mm/s, the hardness decreases greatly. In the selected scanning speed range, the depth of the hardened layer is between 0.5 and 0.8 mm.
2. After laser quenching, the hardened area in the depth direction can be divided into three layers: overheated area, phase change hardened area and transition area.
3. The anti-vegetable abrasive wear resistance of 45# steel after laser treatment is much greater than that of 45# steel without laser treatment. Within the selected scanning speed range, the higher the hardness of the material, the better its wear resistance.
4. After the plant abrasive is worn out, the surface plow depth of the laser-treated specimen is significantly shallower and narrower than that of the untreated specimen, and its fatigue wear is also significantly less than that of the untreated specimen.

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