Numerical Simulation and Microstructure and Properties of 45 Steel by Scanning Electron Beam Bevel Polishing

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Abstract. In order to obtain metal products with good surface quality, it is necessary to develop an efficient bevel polishing method. Therefore, this article uses continuous scanning electron beam polishing. The surface of the material undergoes rapid melting and solidification and generates a dynamic temperature field. The polishing treatment improves the microstructure of the surface layer of the quenched and tempered 45 steel, and significantly increases the microhardness of the surface layer. The hardness after treatment can reach up to 747.6 Hv, which is about 2.4 times higher than the matrix; the structure after hardening is transformed from the mixed phase of coarse acicular martensite and lath martensite to hidden acicular martensite and retained austenite a mixed phase thereof. In addition, after bevels with different inclination angles are subjected to electron beam surface polishing modification treatments with different scanning speeds, under the same parameters, as the inclination angle increases, the hardness value at the same position decreases.

1. Introduction
Polishing is often the most critical step in precision manufacturing[1]. This process will play an important role in improving the service life and surface quality of the material. However, manual polishing or mechanical polishing can achieve surface polishing, but it is only suitable for simple curved surfaces[2-3]. Therefore, in order to obtain metal products with good surface quality, it is necessary to develop an efficient bevel polishing method. In the process of polishing with continuous scanning electron beam, the surface of the material is removed and occurs in a very thin metal layer[4]. The surface of the material undergoes rapid melting and solidification and generates a dynamic temperature field to achieve the desired surface polishing effect. 45 steel is prone to wear failure and fatigue failure in the actual application of molds. Therefore, it is necessary to polish the mold products to improve their surface properties.

In this paper, 45 steel scanning electron beam bevel polishing is used to analyze the mechanism of electron beam bevel polishing, the relationship between the changing law of surface roughness and the inclination angle. Experimental study of the effect of electron beam polishing on the microstructure and microhardness of 45 steel surface with different inclination angles.
2. Experimental materials and methods
In this experiment, the sample material is a commonly used hot-rolled and air-cooled 45 steel bar. During the test, 840 °C × 0.5 h (water cooling) + 600 °C × 1 h (air cooling) tempering treatment. The experimental equipment used in this research is HDZ-6F high-pressure CNC vacuum electron beam welding machine[5]. The process of polishing the inclined surface of the scanning electron beam is shown in Fig.1. The electron beam surface polishing parameters are acceleration voltage 60KV, beam current 6mA, scanning radius 8mm, scanning frequency 300Hz, focusing current 380mA, scanning speed respectively 2.5, 3, 3.5and 4.0mm/s. Mount the 0°, 5°, 10°and 5° inclined specimens on a specific fixture. TR-200 roughness meter characterizes roughness, FEG 450 Microscope Characterization of Microstructure and HVS-1000 Vickers hardness tester to characterize microhardness.

3. Numerical simulation of electron beam bevel polishing
3.1. Analysis of numerical simulation calculation results
It can be seen from the Fig.2 that the circle formed by scanning under the action of the deflection yoke is continuously superimposed, and the circle formed by the previous scan is used for preheating the circle formed by the subsequent scan. With the continuous change of time, the surface temperature is finally in a dynamic equilibrium. The front half of the elliptical ring is mainly used for preheating the second half, and the second half of the elliptical ring is mainly used for melting modification. Under the combined action of gravity and indicating tension, the molten metal quickly flows to low-lying areas to improve the material's performance. Surface roughness and mechanical properties. This also just proves that the process of electron beam polishing is the principle of rapid heating and rapid cooling.
Fig. 2. Scanning electron beam polishing surface temperature field distribution cloud map

4. Experimental results and organization performance analysis

4.1. The effect of scanning speed on the surface roughness of 45 steel inclined planes with different inclination angles

Fig. 3 When the scanning speed is 2.5 mm/s, the surface roughness of the modified material increases with the increase of the inclination angle of the inclined plane. The slower the scanning speed, the more concentrated energy and the increase of the molten layer. The molten metal is subject to gravity and surface tension, which aggravates the increase in surface roughness [6]. On the contrary, when the scanning speed is 3 mm/s~3.5 mm/s, with the increase of the inclination angle, the surface roughness of the processed sample material decreases compared with the original surface. When the surface of the material is inclined at 15°, the surface roughness reaches 0.899 μm.

Fig. 3. The effect of different scanning speeds on the surface roughness of the inclined surface polishing with different inclination angles
4.2. The effect of scanning speed on the structure of hardened layer of 45 steel with different inclination angles

The results Fig.4 shows: The microstructure of the modified layer is a mixed phase of acicular martensite and lath martensite. In addition, as the tilt angle increases in the scanning speed range of 2.5mm/s~4mm/s, the electron beam is in a defocused state, the unevenness of the electron beam energy increases, and the electron beam energy acting on the surface decreases. The less heat absorbed by the sample surface and the less energy transferred to the matrix, the polished modified layer will gradually decrease[7]. After the matrix is rapidly cooled, the crystal grains will not have time to grow. After hardening, the structure will change from coarse needle-shaped Martens. The mixed phase of body and lath martensite is transformed into a mixed phase of cryptoacicular martensite and retained austenite.

![Image of microstructures](image)

Fig.4. The effect of scanning speed of 2.5mm/s~4mm/s on the microstructure of 45 steel inclined planes with different inclination angles

4.3. The effect of scanning speed on the hardness of 45 steel hardened layer on inclined plane with different inclination angles

It can be seen from the fig.5 that after the inclined planes with different inclination angles are polished and modified by the electron beam surface at different scanning speeds, the hardness value of the same position decreases with the increase of the inclination angle under the same [8]. When the sample is flat, the maximum hardness value is 846.7Hv, which is approximately 2.73 times that of the substrate. When the sample tilt angle is 15°, the maximum hardness value is 747.6Hv, which is approximately 2.4 times that of the substrate. The reason is that the slower the scanning speed, the more energy absorbed by the surface of the sample, and the thickness of the molten layer increases. At this time, the surface is inclined. The gravity and surface tension of the molten metal aggravate the solidification of the molten layer. Non-uniformity and rapid cooling lead to the formation of coarse acicular martensite, and the hardness is correspondingly reduced.
5. Conclusions

Numerical simulation of scanning electron beam inclined surface polishing reveals that the characteristics of electron beam inclined surface polishing are rapid heating and rapid cooling.

Scanning electron beam polishing can change the microstructure of the surface layer of the quenched and tempered 45 steel, and significantly improve the microhardness of the surface layer. After hardening, the structure transforms from a mixed phase of coarse acicular martensite and lath martensite to a mixed phase of cryptoacicular martensite and retained austenite.

After the slopes with different tilt angles are polished and modified by the electron beam surface at different scanning speeds, the hardness value of the same position decreases with the increase of the tilt angle under the same parameter.

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References

[1] H. Xiao, Y. Dai, J. Duan, Y. Tian, J. Li, Material removal and surface evolution of single crystal silicon during ion beam polishing, APPL. SURF. SCI., (2021) 148954.

[2] Y. Fu, J. Hu, X. Shen, Y. Wang, W. Zhao, Surface hardening of 30CrMnSiA steel using continuous electron beam, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 410(2017) 207-214.

[3] A. Okada, Y. Okamoto, Y. Uno, K. Uemura, Improvement of surface characteristics for long life of metal molds by large-area EB irradiation, J. MATER. PROCESS. TECH., 214(2014) 1740-1748.

[4] S. Amini, A. Bagheri, R. Teimouri, Ultrasonic-assisted ball burnishing of aluminum 6061 and AISI 1045 steel, MATER. MANUF. PROCESS., 33(2018) 1250-1259.

[5] T. Deng, J. Li, Z. Zheng, Fundamental aspects and recent developments in metal surface polishing with energy beam irradiation, INT. J. MACH. TOOL. MANU., 148(2020) 103472.

[6] R. Wang, H. Cui, J. Huang, H. Jiang, Effect of the continuous electron beam process treatment in
the surface modification of T10 steel, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 436(2018) 29-34.

[7] J. Lu, D. Wei, R. Wang, X. Sui, J. Yin, Surface polishing and modification of 3Cr2Mo mold steel by electron beam irradiation, VACUUM, 143(2017) 283-287.

[8] V.Y. Skeeba, V.V. Ivancivsky, N.V. Martyushev, D.V. Lobanov, A.K. Zhigulev, Numerical Simulation of Temperature Field in Steel under Action of Electron Beam Heating Source, Key Engineering Materials, 712(2016) 105-111.