Examination and Research of the Surface Topography of Ultrasonic Vibration Honing Nd-Fe-B

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Abstract – The mechanism of ultrasonic vibration honing Nd-Fe-B has been briefly elaborated after the introduction of the strategic significance of processing Nd-Fe-B. Based on the formation principle of Scanning Electronic Microscope (SEM), and at the examination with the aid of SEM to the ultrasonic vibration honing Nd-Fe-B material′s superficial microscopic topography, the paper discusses the new processing mechanism according to the SEM examination picture. The research indicates that as a result of supersonic high frequency vibration, the path of the abrasion extends at the same time, and the supersonic cavitation effect forms the intense shock-wave, impacting Nd-Fe-B material's internal surface, providing the supersonic energy for the superficial abrasive dust′s elimination, which directly explain that the honing processing efficiency is enhanced, and the processing surface roughness is high.

Key words* – *SEM*; *ultrasonic processing*; *honing*; *Nd-Fe-B*; *ultrasonic cavitation

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1 Introduction

With the rapid development of materials, difficult processing materials are becoming more and more extensive, which causes a new type of special processing methods, that is the technology of ultrasonic vibration. This special processing technique can cut ductile materials and super-hard materials, and improve processing efficiency and product quality. Nd-Fe-B material has the characteristics of high hardness, brittleness and poor thermal stability. But at the moment, the processing technology of Nd-Fe-B has lagged behind, let alone put forword a way of finishing machining Nd-Fe-B material.

The content of this paper is combining ultrasonic vibration technology theory and practice, using the advantages of ultrasonic vibration honing to machining the Nd-Fe-B material, which offers an efficient, high-quality and low-cost method.

2 Material performance and operating principle

2.1 Brief introduction of Nd-Fe-B

The Nd-Fe-B permanent-magnet material takes $Nd_2Fe_{14}B$ as a substrate, the volume fraction of which is approximately 85% ～ 97%. The rare-earth element is about 30% in the permanent-magnet material. The intermetallic compound of the $Nd_2Fe_{14}B$ has the complex crystal structure and few slipping department, therefore the room temperature mechanical properties are bad. Under the room temperature conditions, the $Nd_2Fe_{14}B$ monocrystal′s magnetostriction coefficient is aeolotropic. When polycrystal is formed from high-temperature cooling to room temperature, the crystal will bring a big internal stress, therefore the Nd-Fe-B material′s heat-resistant striking can be very bad, which causes the polytropism material room temperature mechanical properties to be bad, and the bending strength will be 300～350 MPa, the breaking strength will be 220～350 MPa, brittleness will be big[1-2].

2.2 Ultrasonic vibration honing's operation principle

The principle of the honing device is: the electric oscillations produced by generator changes into longitudinal mechanical vibration through the transducer, the amplitude pole amplifies the vibration and spreads it to vibration discs, the flexible pole transmits it to the oilstone seat, which drives the oilstone to do longitudinal vibration[3-4] (shows in Fig.1).

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2.3 Basic principle of SEM

SEM is a microcosmically observed means between transmission electron microscope and optical microscope, which can image directly by the surface of the material. After the electron beams bombard the sample, the atomic nucleus interact with the extra nuclear electrons and produce secondary electrons, back-scattering and X-rays and other physical information.

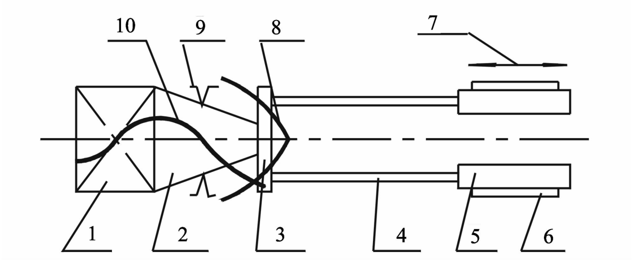


Fig. 1 Ultrasonic vibration honing principle: 1 is transducer, 2 is amplitude pole, 3 is disc, 4 is flexible pole, 5 is oilstone seat, 6 is oilstone, 7 is oilstone's longitudinal vibration, 8 is disc's transverse wave pattern, 9 is node, 10 is transducer and amplitude pole's longitudinal wave pattern

The secondary electrons are the extra nuclear electrons after the incident electrons are bombarded. Because the binding energy is very small between atomic nucleus and the outer valence electrons, when the extra nuclear electrons of the atom obtain greater energy corresponded with the binding energy from the incident electron, it may become a free electron breaking away from the atom. Generally, the basic principle of SEM is: automatic electron gun→anode→gather-light mirror→gather-light mirror grating→gather-light mirror→field lens grating→scanning beam→lens→sample→secondary electron detector→imaging.

3 Examination and research the surface topography

3.1 Laboratory instrument

The power ultrasonic vibration honing processing Nd-Fe-B material experiment is carried out on the MBA4215 semiautomatic vertical honing machine, in the North University of China's project experiment center. The experimental conditions and instruments are shown in Tab.1.

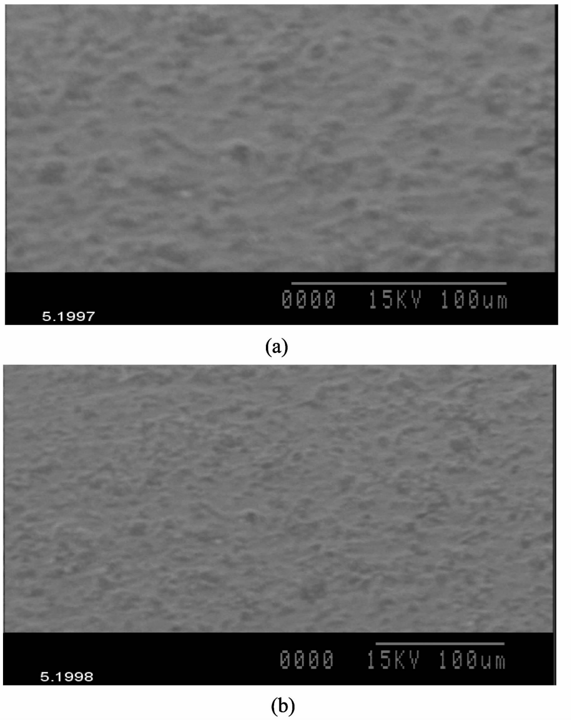
3.2 Processing parameters and the examination of the surface topography

In the experiment, work-piece material is Nd-Fe-B, the cooling liquid is the new home-made grinding fluid, the ultrasonic vibration frequency is $f = 18.6$ kHz, the amplitude is $10 \sim 15$ μm. The inside diameter of the work-piece to be processed is $d = 47$ mm.

Tab. 1 Experimental condition and instrument

Machine	MBA4215 semiautomatic vertical honing machine
Honing head	Home-made ultrasonic vibration honing installment
Honing style	Reciprocation rotation and radial feed
Oilstone	CBN, granularity: $120^{\#}$, $150^{\#}$; binder: Q; consistency: 100%
Oilstone's distribution	3(Symmetrical equispaced), 6×6×100(mm)
Finishing grinding wheel	Silicon carbide grinding wheel, $80^{\#}$, Resin binder, φ102×20×φ32(mm)
Finishing condition	Finishing machine: MQ1320, speed: 35 m/s Work table reciprocation speed: 800 mm/min
Work piece material	Nd-Fe-B
Work piece type	$d \times D \times L$: φ47×φ165×275 mm
Ultrasonic generator	750 W, 18.6 kHz, Amplitude = 10～15 μm
Honing parameter	Swiveling speed: 80 r/min, 112 r/min, 125 r/min, 200 r/min, 315 r/min; Reciprocation speed: 3～23 m/min; Honing depth: 1～6 μm
Cooling liquid	The new home-made grinding fluid
experimental instrument	SEM

The processing technological parameter is as follows: The grinding depth is 0.05 mm, the spindle's speed is 225 r/min, the honing head's reciprocation speed is 30 mm/s. With the examination of SEM, the surface topography is shown in Fig.2(a).



(a)

(b)

Fig. 2 The surface topography of processing Nd-Fe-B

The processing technological parameter is as follows: The grinding depth is 0.05 mm, the spindle's speed is 225 r/min, the honing head's reciprocation speed is 15 mm/s. With the examination of SEM, the surface topography is shown in Fig.2(b).

3.3 Analysis of the ultrasonic vibration honing mechanism

1) Abrasive path analysis

The analysis of the surface topography of processing Nd-Fe-B in Fig. 2 show that, when ultrasonic vibration honing, each equal-spaced abrasion's path has been influenced under the high frequency vibration, which is different form normal processing. The ultrasonic vibration honing processing mechanism from the abrasion's path is analyzed.

It may be divided into three forms according to the ultrasonic wave vibration direction relative to reciprocal motion direction: longitudinal vibration, transverse vibration and torsional vibration. This testing installation supersonic resonance system is the longitudinal vibration, and the brief movement principle is shown in Fig.3. The longitudinal ultrasonic vibration honing processing belongs to one pulse cutting method. During the cutting process, each abrasion's velocity of the size and the direction is changing unceasingly. Suppose the style of vibration is the sine wave, the change of the resulting velocity is shown in Fig.4.

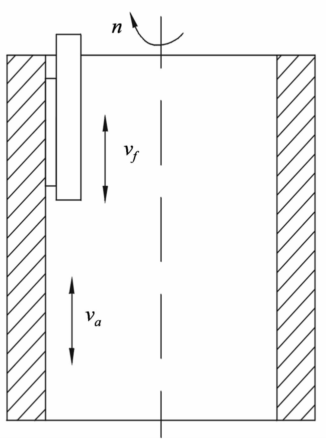


Fig.3 Longitudinal vibration

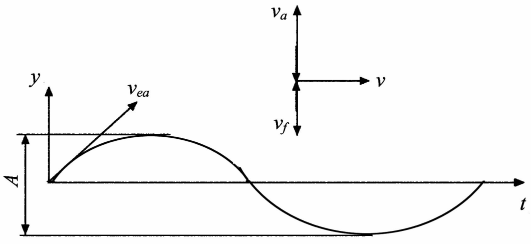


Fig.4 Changed resultng velocity

The resulting longitudinal vibration velocity is

$$v_{ea} = \sqrt{v^2 + (v_a + v_f)^2} = \sqrt{(\pi dn)^2 + (v_a + 2\pi Af\cos 2\pi ft)^2}. \quad (1)$$

In the above formula: v_{ea} is the resulting longitudinal vibration velocity, m/s; v_a is the Oilstone reciprocation velocity, $\dot{y} = v_a$, m/s; v_f is the Oilstone vibration velocity, m/s; f is the resonance frequency, Hz; t is time, s; A is the amplitude, μm; v is the honing circumferential velocity, $v = \pi dn$, m/s; d is the work-piece's inside diameter, mm; n is swiveling speed, r/min.

The resulting longitudinal vibration velocity is divided into two coordinate axes, which are the radial direction and the axial direction, then

$$\begin{cases} x = \int (\pi d n)\mathrm{d}t, \\ y = \int (v_a + 2\pi Af\cos 2\pi ft)\mathrm{d}t. \end{cases} \quad (2)$$

When $f = 18.6$ kHz, $A = 10$ μm, $d = 47$ mm, $n = 225$ r/min, $v_a = 30$ mm/s, then

$$\begin{cases} x = \int (\pi d n)\mathrm{d}t = \int 176.25\pi \mathrm{d}t, \\ y = \int (v_a + 2\pi Af\cos 2\pi ft)\mathrm{d}t = \\ \quad \int (30 + 372\pi\cos 37200\pi t)\mathrm{d}t. \end{cases} \quad (3)$$

The periodic time $T = \frac{1}{f} = \frac{1}{18\,600} \approx 5\times10^{-5}$ s, because $f = 18.6$ kHz. When $t = [0, 1.05\times10^{-4}]$, the abrasion's path under the high frequency vibration is shown in Fig.5.

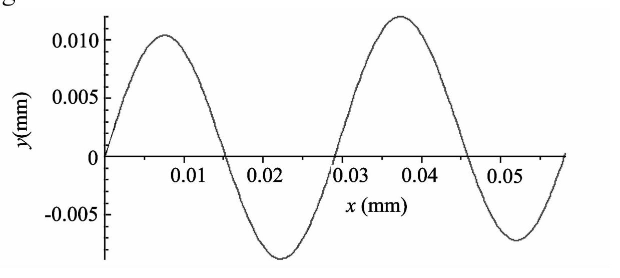


Fig.5 Abrasive path under high frequency vibration

Under identical conditions without supersonic high frequency vibration, the abrasion's path is shown in Fig.6.

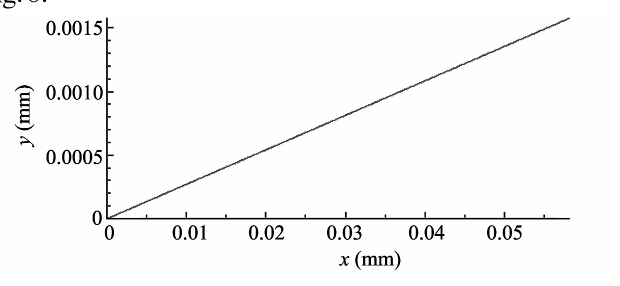


Fig.6 Abrasive path without high frequency vibration

Comparion of the abrasion's paths between Fig.5 and Fig.6, shows that when the ultrasonic vibration honing processes the Nd-Fe-B material, as a result of supersonic high frequency vibration function, the path of the abrasion extends at the same time, which raises the honing processing efficiency. Also because the longitudinal oscillation causes the abrasive speed to change unceasingly at the axial motion and impacts the work-piece's surface unceasingly, which is possible to reduce the grinding strength and increase the work-piece's precision.

2) Ultrasonic cavitation effect

The ultrasonic cavitation refers to the tiny bubbles in the liquid, which are activated under the ultrasonic waves, which are a series of dynamic processes containing the bubble core's oscillation, growth, contraction and collapse.

During the ultrasonic vibration honing machining the Nd-Fe-B material, the analyses of the ultrasonic cavitation effects are as follows: oilstones are symmetrically equal-spaced, after the high-frequency amplitude transferring through the bending vibration disc and the flexible pole to the oilstone, the oilstone will experience the longitudinal high-frequency vibration. It will produce small quantities of abrasion dust during honing, some of it which sheds under the impact of the flowing lubricating fluid. Since the lubricating fluid is effected by the ultrasonic waves, it is easy to form ultrasonic cavitation bubbles or cavities around the abrasion dust. Tie cubbles produced by the ultrasonic cavitation are short-lived, because the hole has just been generated, immediately under the pressure from the adjacent compression, and finally causes the cavity to break. At the time of breakdown, the air or steam pressure in the bubbles can reach thousands of atmospheric pressure, form strong shock waves, affect the Nd-Fe-B material's internal surface, and provide the supersonic energy for the superficial abrasion dust´s elimination, which directly increases the honing processing efficiency.

4 Conclusion

Through discussing of ultrasonic vibration honing principle of work, studying the Nd-Fe-B material´s performance, processing the work-piece´s surface microscopic appearance by SEM, analysing the high frequency grains the reasons of raising the honing processing efficiency and the surface roughness quality are clear. As a result of the supersonic high frequency vibration function, the path of the abrasion extends at the same time, and the supersonic cavitation effect forms the intense shock-wave, impacting Nd-Fe-B material's internal surface, and providing the supersonic energy for the superficial abrasion dust´s elimination. The paper discusses the grinding mechanism from the microscopic grinding path, which opens a new way to raise the grinding efficiency and solve the hard crisp Nd-Fe-B material precision processing.

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