ISSN 1027-5495. Functional Materials, 25, No.4 (2018), p. 809-817.
doi:https://doi.org/10.15407/fm25.04.809

Research on ultrasonic vibration assisted repair technology of high temperature and high pressure parts

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Received November 9, 2018

This paper studies the ultrasonic vibration assisted lifting laser cladding technology. Firstly, the simulation model of ultrasonic vibration-enhanced Ni60 self-fluxing alloy powder coated with 45 steel substrate is established, and the variation law of temperature field and temperature gradient in ultrasonic vibration strengthening process are analyzed by using Ansys finite element analysis software. After that, the microstructure, micro-hardness and surface roughness of the cladding layer are compared with that of the cladding test blocks with and without ultrasonic vibration. The results show that as the ultrasonic frequency increases or the scanning speed decreases, the temperature increases everywhere along the Z-axis, and the temperature gradient from the cladding layer to the interface area decreases. Compared to the cladding layer without ultrasonic vibration, the microstructure of the cladding layer obtained by applying ultrasonic vibration is finer and denser due to the effect of ultrasonic cavitation, and the microhardness is increased by 1.37 times and the surface roughness is reduced by 36.6%.
Keywords: laser cladding, high temperature and high pressure, ultrasonic vibration, process research.

В работе рассматривается технология лазерной облицовки с помощью ультразвуковой вибрации. Установлена имитационная модель покрытия, полученного самопотоком легированного порошка Ni60 45 стальной подложки. Используя программное обеспечение для анализа конечных элементов Ansys, анализируется изменение температурного поля и температурного градиента в процессе упрочнения ультразвуковыми колебаниями. Микроструктура, микротвердость и шероховатость поверхности облицовочного слоя сравниваются с микроструктурой и оболочкой тестовых блоков после ультразвуковой вибрации и до нее. Результаты показывают, что по мере увеличения частоты ультразвука или скорости сканирования температура образца увеличивается повсюду вдоль оси Z, а градиент температуры от слоя оболочки до площади раздела уменьшается. По сравнению с плакирующим слоем без ультразвуковой вибрации микроструктура слоя оболочки, полученная при приложении ультразвуковой вибрации, является более тонкой и плотной из-за влияния ультразвуковой кавитации, а микротвердость увеличивается в 1,37 раза, шероховатость поверхности снижается на 36,6%.

Дослідження впливу ультразвукової вібрації на властивості лазерного облицювання високотемпературних і високонапірних деталей. *Che Lei, Sun Wenlei, Zhang Guan, Han Jiaxin*

У роботі розглядається технологія лазерної облицювання за допомогою ультразвукової вібрації. Встановлено імітаційну модель покриття, отриманого самопотоком легованого порошку Ni60 45 сталевої підкладки. Використовуючи програмне забезпечення для аналізу кінцевих елементів Ansys, аналізується зміна температурного поля і температурного градієнта у процесі зміцнення ультразвуковими коливаннями. Мікроструктура, мікротвердість і шорсткість поверхні облицювального шару порівнюються з мікроструктурою і оболонкою тестових блоків після ультразвукової вібрації і до неї. Результати показують, що зі збільшенням частоти ультразвуку або швидкості сканування температура зразка збільшується усюди вздовж осі Z, а градієнт температури від шару оболонки до площі розділу зменшується. У порівнянні з плакируючим шаром без ультразвукової вібрації мікроструктура шару оболонки, отримана при додаванні ультразвукової вібрації, є більш тонкою і щільною через вплив ультразвукової кавітації, а мікротвердість збільшуться у 1,37 рази, шорсткість поверхні знижуться на 36,6%.

1. Introduction

Pore and crack defects are still the main problems in the additive repair technology, because that laser power is large, the depth of molten pool is deep, and the characteristics of the rapid heating and cooling also make the molten pool of metal solidification quickly, away from the equilibrium state, the cladding layer between the cladding layer and substrate materials and internal creates, has a high temperature gradient and cladding material and the thermal expansion coefficient between the substrate material is different, in the bonding zone will produce a larger residual stress, crack extremely easily, cause waste. Ultrasonic degassing, dispel oxide film, fine grains and homogeneous structure composition and reduce stress function, the workpiece has no damage, and the safe and reliable [1-3], so at the same time of laser cladding on the substrate and molten pool melt applying ultrasonic vibration compared with not applying laser cladding method, ultrasonic vibration can improve the performance of cladding layer of cladding layer cracking effect is better.

At present, researchers have done a lot of research on the technical parameters of laser cladding. Ramirez A. et al. [4] have shown that high intensity ultrasonic treatment can significantly refine the microstructure of magnesium alloys. Fan Yangyang et al. [5] will be introduced to the ultrasonic vibration in the form of mechanical coupling of 304 stainless steel TIG welding process, the plate welding experimental results show that after applying ultrasonic welding penetration increased, deep wide ratio increases, microstructure refinement, fusion zone structure homogenization. Xu et al. [6] used ultrasonic vibration to effectively remove the pores in liquid A356 aluminum alloy, and found that the smaller the amount of liquid metal, the higher the removal rate of pores by ultrasonic. Tian Yuxin et al. [7] of ultrasonic compound TIG arc weld width and depth of molten under study found that ultrasonic composite TIG welding can increase welding penetration, and improve the weld surface, reduce the workpiece deformation and heat affected zone, and to improve the quality of the welded joint. Although the researchers on the study of ultrasonic vibration for a variety of ways, and made a lot of significant research results, but has some reports mostly stay in the study of casting, welding and other traditional techniques, such as have not too much involved in laser cladding material repair technology research, especially ultrasonic vibration influence on the laser cladding temperature field and temperature gradient, as well as to the cladding layer on the surface roughness, microstructure and microhardness of reported less.

Based on 45 steel substrate as the research object, this paper established the ultrasonic vibration strengthening cladding substrate material Ni60 self-fluxing alloy powder in the simulation model of Ansys finite element analysis software is used in the process of ultrasonic vibration is analyzed to strengthen the change rule of temperature field and temperature gradient, and through the test to get the cladding block of the microstructure, microhardness and surface roughness of the comparative analysis.

2. Ultrasonic vibration assisted repair process test method

The laser cladding powder material is a Ni60 self-fluxing alloy powder with a powder diameter of (100 to 150)μm. The base material is 45 steel. Before the test, the powder is placed in the oven to high temperature of 150 °C, and lasts for 2 h, in order to achieve the purpose of drying the moisture. The matrix material is ground with sandpaper, then cleaned with acetone to remove the oxidation layer and oil, and then dried.

For research, we used testing equipment from a company in the United States to produce 4 kW of fiber laser systems, continuous gas CO_2 laser for processing and ultrasonic vibrating plate. When the ultrasonic vibration plate starts to work, ultrasonic waves are transmitted from bottom up to the molten pool through the matrix material. Before the test, the ultrasonic vibration plate was first opened, followed by laser cladding synchronous powder delivery after 1 min. After the laser cladding test, the ultrasonic vibration plate was closed 2 min later.

Laser cladding technology parameters used in the test are laser power is 1400W, spot diameter is 2 mm, scanning speed is 3 mm/s, feed rate is 22 g/min , defocus amount is 16 mm, powder feeding gas flow is 200L/h. In order to reduce evaporation and oxidation of the surface material during the cladding process, argon is used to protect the bath. The height and width of the prepared single cladding layer are 1.5 mm and 3 mm.

3. Simulation analysis of temperature field and temperature gradient of laser cladding with ultrasonic vibration

3.1 Establishment of finite element model for ultrasonic vibration laser cladding temperature field and temperature gradient

(a) Because the ultrasonic vibration plate is connected to the bottom surface of the matrix material, the ultrasonic vibration boundary condition is approximately treated by combining dynamic boundary condition and ultrasonic vibration energy conversion [8,9].

$$P = 2\pi f\rho cA\cdot\cos(2\pi ft), \quad (1)$$

where f is the ultrasonic frequency, Hz. A is the ultrasonic amplitude, m; ρ is the density of matrix material, kg/m^3; c is the transmission speed of ultrasound, m/s; t is the time of ultrasonic vibration action, s.

The heat generated by ultrasonic vibration absorbed by melt is

$$Q = 4at\rho c(\pi fA)^2, \quad (2)$$

where a is the ultrasonic absorption coefficient.

The heat flux produced by ultrasonic vibration on the system is

$$q = \frac{Q}{S}, \quad (3)$$

where S is the area under ultrasonic action, m^2.

(b) Energy absorbed by the melt in the molten pool from ultrasonic vibration [10].

The inner energy of the molten pool can be the sum of the internal energy of the molecules, so the internal energy of each molecule can be obtained by the following formula:

$$u = u_{tr} + u_{rot} + \sum_v u_v, \quad (4)$$

where u_{tr} is the translational kinetic energy; u_{rot} is the rotational internal energy; u_{v} is the vibration energy of each component of the fluid.

The average energy per unit mass in the molten pool is:

$$u_v = (n)\frac{n_v}{n}f_{v1}kT_v^2, \quad (5)$$

where n is the number of all molecules per unit mass in the molten pool; n_{v} is the number of molecules with vibration per unit mass in the molten pool; $f_{v1} = n_v$ is the ratio of the first order excitation; $\frac{1}{2}kT_v^2$ is the average energy of the degree of freedom of the excited v class of molecules; k is Boltzmann constant; T_{v} is the temperature of the vibrating molecule.

The molten pool is affected by ultrasonic vibration, and the characteristic time τ_v of equilibrium is satisfied:

$$\frac{dT_v}{dt} = \frac{1}{\tau_v}(T - T_v). \quad (6)$$

By introducing the influence of viscosity and heat conduction into the basic hydrodynamic equation, the following equation can be obtained:

$$k = \frac{\omega}{c_0} - j\alpha_{cl} - \frac{2}{\lambda}\sum_v (\alpha_v\lambda)_{\max}\frac{j\omega\tau_v}{1 + j\omega\tau_v}, \quad (7)$$

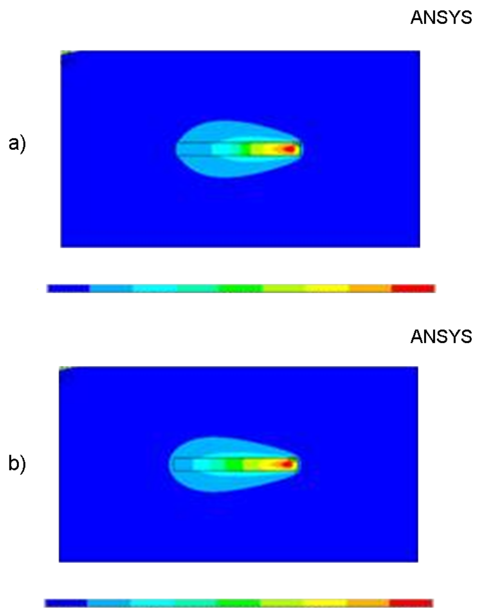

Fig. 1. Temperature field distribution cloud maps of the test blocks with (b) and without (a) ultrasonic vibration.

where $\frac{\omega}{c_0}$ is the number of waves or propagation coefficient without attenuation; α_{cl} is the classical attenuation coefficient; α_υ is the relaxation attenuation coefficient of type υ molecular vibration mode; λ is the wavelength of unattenuated sound waves. $(\alpha_\upsilon\lambda)_{\max}$ is the maximum value of $\alpha_\upsilon\lambda$, when $\omega\tau = 1$, it is $\sqrt{\frac{\pi}{2}(\upsilon-1)\frac{c_w}{c_p}}$, τ_υ is relaxation time, $\tau_\upsilon = \frac{c_w}{n_\upsilon k\beta_\upsilon N_{c\upsilon}}$ and β_υ is constant, $N_{c\upsilon}$ is collision number per unit time of class υ molecules, $c_w = \frac{n_\upsilon}{n}R\left(\frac{T_\upsilon^*}{T_\upsilon}\right)^2\exp\left(-\frac{T_\upsilon^*}{T}\right)$.

The relaxation term can be simplified as

$$\alpha_\upsilon = \frac{2}{\lambda}(\alpha_\upsilon\lambda)_{\max}\frac{j\omega\tau_\upsilon}{1+j\omega\tau_\upsilon} = \tag{8}$$

$$= \frac{2}{\lambda}(\alpha_\upsilon\lambda)_{\max}\frac{j\omega\tau_\upsilon(1-j\omega\tau_\upsilon)}{1+(\omega\tau)^2} =$$

$$= \frac{2}{\lambda}(\alpha_\upsilon)_{\max}\left(\frac{j}{\frac{\omega}{\omega_\upsilon}+\frac{\omega_\upsilon}{\omega}} + \frac{\omega\tau_\upsilon}{\frac{\omega}{\omega_\upsilon}+\frac{\omega_\upsilon}{\omega}}\right)$$

where $\omega_\upsilon = \frac{1}{\tau_\upsilon}$, $\frac{\omega_\upsilon}{2\pi}$ is the relaxation frequency.

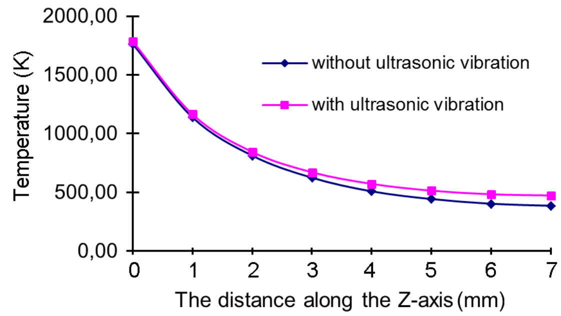

Fig. 2. Temperature curves along the Z-axis between ultrasonic vibration and non-ultrasonic vibration.

3.2 Analysis of ultrasonic vibration laser cladding temperature field simulation results

3.2.1 Comparison of laser cladding temperature field between ultrasonic vibration and non-ultrasonic vibration

Fig. 1 shows that the temperature field distribution cloud diagram of laser cladding with and without ultrasonic vibration. As shown in Fig. 1, whether applying ultrasonic vibration, or in other process under the same conditions of laser cladding temperature field distribution are shown as approximate elliptic, but applying ultrasonic vibration of laser cladding temperature variation is relatively soft, the temperature gradient of the smaller range is big, overall, the distribution of temperature field is more uniform. After ultrasonic vibration was applied, the minimum temperature of the matrix increased from 292.08K without ultrasonic vibration to 421.359K. Meanwhile, the maximum temperature of the melt in the cladding pool increased from 1601.95K without ultrasonic vibration to 1652.76K, but the degree of temperature increase was smaller than that of the substrate. The reason is that after applying ultrasonic vibration, the vibration energy, consistently with the laser energy absorption of melt pool and matrix, and into the melt and the matrix of the internal energy, so the molten pool was increasing the temperature of the melt and the matrix, at the same time, the ultrasonic vibration energy increased with the increase of propagation distance attenuation, combined with ultrasonic vibration of molten pool melt have similar to the mixing effect, has a cooling effect, so the molten pool melt temperature increases are smaller than the substrate.

Fig. 2 shows that the temperature change along the Z-axis under the condition

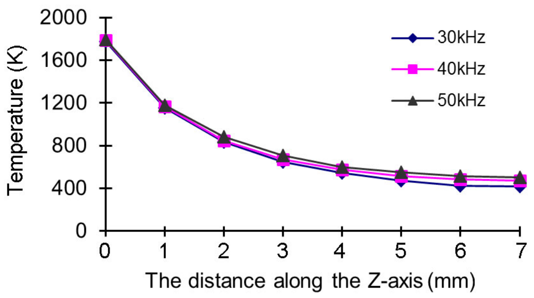

Fig. 3. Temperature curves of ultrasonic frequency in the direction of Z-axis.

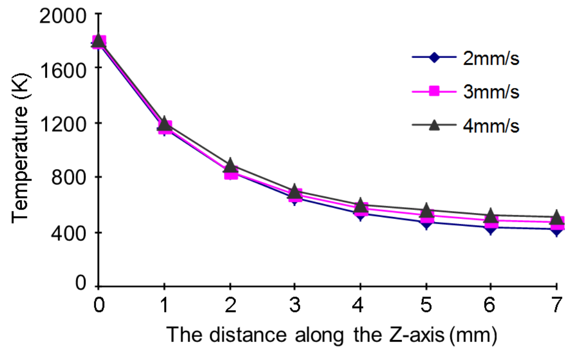

Fig. 4. Temperature curves of the scanning speed on the direction Z-axis.

of applying ultrasonic vibration and not applying ultrasonic vibration. From the cladding layer surface to within 1 mm of the surface of cladding layer, applying ultrasonic vibration of the temperature of the laser cladding temperature and not twisting vibration downtrend basically consistent, this is because the surface cladding layer, the influence of the laser energy dominant, and the influence of ultrasonic vibration heat effect because of the propagation distance attenuation to the impact can be ignored. With the increase of distance from the surface cladding layer, the temperature under the action of ultrasonic reduced more slowly, finally applying ultrasonic vibration and applying ultrasonic vibration of the laser cladding temperature are stable, but applying ultrasonic temperature a little higher. The reason is that the laser energy is continuously transmitted to the matrix through heat conduction. At this time, the energy of the matrix is mainly the synthesis of laser energy and ultrasonic vibration thermal effect. However, with the increase of space from the surface cladding layer, the laser energy decreases on the heat conduction of heat affected zone, the matrix effect, however, applying ultrasonic vibration of the heating effect of the laser cladding with ultrasonic vibration generated, so the temperature drop a softer. In the lower part of the matrix, the laser energy of the heat transfer effect can be ignored, the heating effect of ultrasonic vibration dominate, so applying ultrasonic vibration of the laser cladding of applying ultrasonic vibration and temperature are stable, but ultrasonic cladding temperature a little higher.

3.2.2 Effect of ultrasonic frequency on temperature field

Fig. 3 shows that the effect of ultrasonic frequency on the temperature field on the Z-axis. As can be seen from the Fig. 3, as the ultrasonic frequency increases, the temperature on the Z-axis direction increases. When the ultrasonic frequency increased from 30 kHz to 50 kHz, the temperature at 7 mm from 414.32 K to 501.55 K along the Z-axis increased from 414.32 K to 87.23 K. The maximum temperature of the molten pool in the cladding layer increased from 1774.1 K to 1795.9 K, only increasing by 21.8 K. Investigate its reason is that the bigger the base at the bottom of the ultrasonic frequency, ultrasonic vibration effect is significant, and melt into a matrix, the greater the internal energy of the ultrasonic vibration energy all along the Z-axis direction everywhere temperature is increased, however, with the increase of ultrasonic vibration frequency will lead to the molten pool is similar to the effect of stirring melt also more and more intense, accelerate the cooling of the molten pool melt, so bath melt under the influence of ultrasonic frequency as substrate.

3.2.3 Effect of scanning speed on temperature field

Fig. 4 shows that the effect of laser cladding scanning speed on the temperature field in the direction of Z-axis. As can be seen from the figure, as the scanning speed increases, the temperature on the Z-axis decreases as a whole. When the scanning speed increased from 2 mm/s to 4 mm/s, the temperature at 7 mm from the cladding surface along the Z-axis decreased from 507.77 K to 425.48 K, decreasing by 82.29 K. The maximum temperature of the molten pool in the cladding layer decreased from 1805.5 K to 1775.7 K, only 29.8 K. Investigate its reason is that with the increase of scanning speed, not only make the stay in laser cladding layer on the surface of the powder time reduced, reducing the melt pool for the absorption of laser energy, but also shortens the ultrasonic vibration acting on

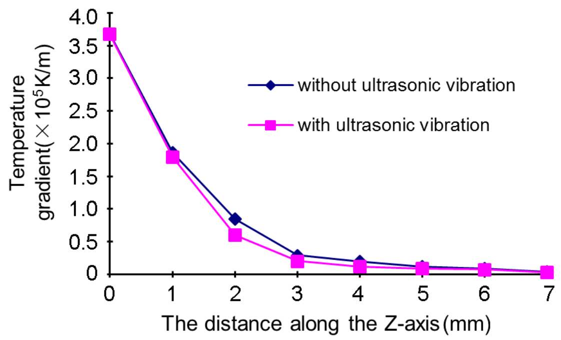

Fig. 5. Temperature gradient distribution along the Z-axis.

the substrate and molten pool of time, reduced the ultrasonic vibration energy into internal energy of substrate and the melt pool.

3.3. Analysis of ultrasonic vibration laser cladding temperature gradient simulation results

Fig. 5 shows that the temperature gradient distribution along the Z-axis. It can be seen from the figure that the temperature gradient of laser cladding with ultrasonic vibration along the Z-axis is smaller than that without ultrasonic vibration, and the two finally tend to be the same. Applying ultrasonic vibration to sum up, the laser cladding can effectively reduce the internal cladding layer and the cladding layer and substrate interface combined with the temperature gradient, reduce the inner cladding layer and the residual stress of interface bonding area, to reduce or even eliminate inner cladding layer and interface bonding area crack.

3.3.1 Effect of ultrasonic frequency on temperature gradient

Fig. 6 shows that the effect of ultrasonic frequency on the temperature gradient of cladding along the Z-axis. Along the Z-axis direction of cladding layer on the surface of 3 mm, with the increase of ultrasonic frequency, temperature gradient decreases, investigate its reason is that the bigger the ultrasonic frequency, the greater the ultrasonic energy into the matrix, the smaller the temperature gradient. From 3 mm to a deeper distance, the influence of ultrasonic frequency on temperature gradient is no longer obvious, and finally tends to be consistent.

3.3.2. Effect of scanning speed on temperature gradient

Fig. 7 shows that the relationship between laser cladding scanning speed and

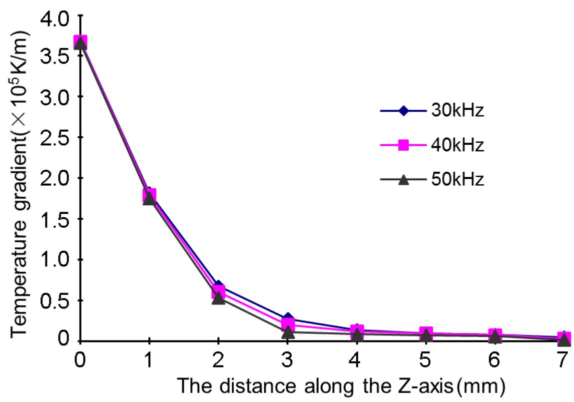

Fig. 6. Temperature gradient of the ultrasonic frequency on the direction Z-axis.

temperature gradient of cladding layer along Z-axis. Along the Z-axis direction of cladding layer on the surface of 3 mm, with the increase of scanning speed, the temperature gradient is also gradually increase, investigate its reason is that the smaller scanning speed can increase the laser on the molten pool of powder and the effect of ultrasonic vibration time, at the same time increase the energy density of the cladding layer and substrate of internal energy, but in the cladding layer 3 mm along the Z-axis direction, the interface bonding area due to the action of ultrasonic vibration is the most remarkable, the energy density of the region is the largest. Therefore, the lower the scanning speed, the lower the temperature gradient from the cladding layer to the interface area.

4. Comparison analysis of microstructure, microhardness and surface roughness of cladding layer

4.1. Microstructure comparison

The cross-section metallographic specimen of laser cladding layer was prepared by linear cutting. The corrosion agent used in the preparation of the metallographic specimen is aqua regia ($HCl:HNO_3=3:1$), and the microstructure of the cladding layer of the sample was analyzed by MJ21 type orthopaedic metalloscope, as shown in Fig. 8. LEO 1430VP type scanning electron microscope was used to magnify the microstructure of the sample cladding layer by 3000 times, as shown in Fig. (9).

The Fig. 8 and Fig. 9 shows that applying ultrasonic vibration of cladding layer is not bulky columnar crystal, and presents the irregular state, after ultrasonic vibra-

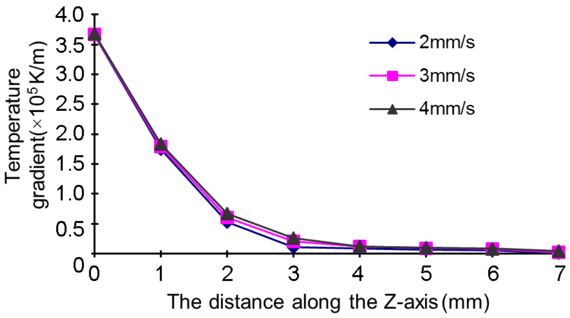

Fig. 7. Temperature gradient of the scanning speed on the direction Z-axis.

tion is applied to obtain the cladding layer microstructure morphology changes, the original columnar crystal disappeared, and significantly enhanced. Investigate its reason is that ultrasonic vibration can make the melt in the metal solidification process formation of cavitation bubble, primary crystal grew up and is the crystallization of the organization is its high temperature and high pressure shock wave produced by the break up, grow up to speed is affected, the molten pool in the original direction of columnar crystal structure also is interrupted, form fine crystal nucleus is relatively evenly spread to various parts of the cladding layer, grew up in isotropic, improve the nucleation rate of the melt, the cladding layer are refined and dense.

4.2 Microhardness comparison

Section microhardness of laser cladding layer with HXD-1000 TB digital micro hardness tester to test, test the applied load is 500 g, load duration of 10 s, respectively in each block of measuring surface along a straight line from the first layer of the cladding layer in turn to the direction of substrate material, such as measuring point spacing, spacing of 0.1 mm, a total of 19 points, measuring microhardness values as shown in Fig (10).

Fig. 10 shows that the microhardness curve of laser cladding perpendicular to the scanning path section. Applying ultrasonic vibration can be seen from the diagram, the cladding layer on the surface of 0.1 mm to 0.7 mm depth within the scope of applying ultrasonic vibration than the microhardness of the cladding layer increases obviously, applying ultrasonic vibration of laser cladding layer maximum microhardness was 998.72 HV, the same depth of not applying ultrasonic vibration of laser cladding layer microhardness value is 731.64 HV, increased 1.37 times. With the increase of measuring depth, two different cases of microhardness of the cladding layer are present decreasing trend, but applying ultrasonic vibration of cladding layer microhardness were greater than not applying ultrasonic vibration of microhardness of the cladding layer. As the measuring depth continues to increase, in the junction of the cladding layer and substrate material and the heat affected zone, applying ultrasonic vibration to get the microhardness value of the cladding layer while still greater than not applying ultrasonic vibration to get the microhardness of the cladding layer in the same depth values, but increases the size of the smaller. In the case of measuring depth is still increasing, microhardness eventually will be more and more close, tend to be the same, this is because the heat affected zone substrate material the following part, while under the influence of ultrasonic vibration, but it receives laser energy is limited, the effect of combination of these two didn't happen.

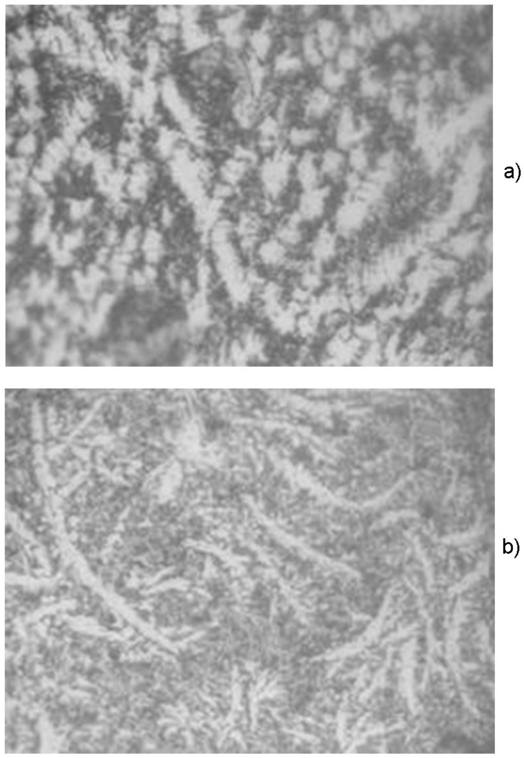

Fig. 8. Microstructure of cladding layer with ultrasonic vibration (b) and without (a) ultrasonic vibration under metalloscope.

With section 4.1 of the microstructure of laser cladding layer, you can see that the combination of the test of microhardness of the cladding material Ni60 powder and grain size meeting Hall-Petch formula of

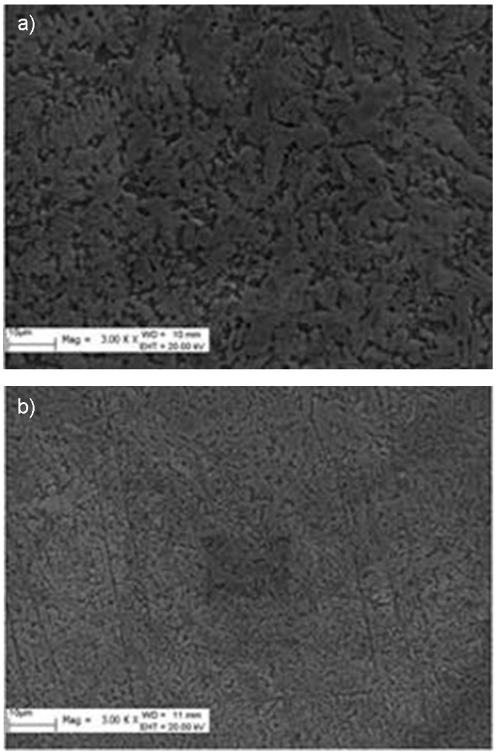

Fig. 9. Microstructure of cladding layer with ultrasonic vibration (b) and without ultrasonic vibration (a) under scanning electron microscope.

the relationship. The combination of ultrasonic vibration and laser energy resulted in different degree of refinement of cladding structure, so the microhardness of cladding layer was also increased. Metal material will form dislocation movement when plastic deformation leads to occlusion at grain boundary. In this case, a large external force must be applied to keep the metal from deforming. Cladding layer at the top of the main organization form for different direction of high density dislocation plug formation of small crystal pieces, such as to make the small crystal block shape change must exert larger external force, so the cladding layer microhardness strong plastic deformation area is the largest. The middle and bottom of the cladding layer deformation zone formed by ultrasonic vibration of isometric twigs and refine crystal, with varying degrees of grain size, grain boundaries increased than before, the area of dislocations becomes more, the more the plug product produced at the grain boundary, the resistance increase, so the strength and hardness of the cladding layer were greatly improved.

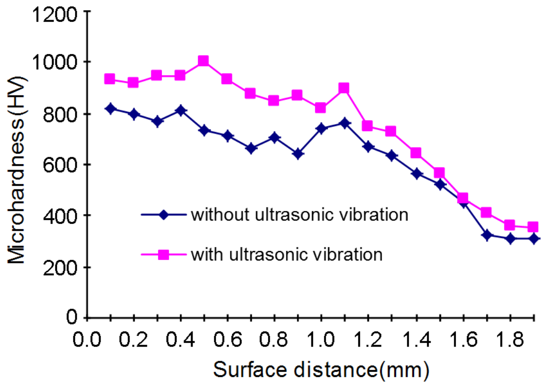

Fig. 10. Microhardness curve of laser cladding perpendicular to the scanning path section

4.3. Surface roughness comparison

The cladding layer obtained by applying ultrasonic vibration and not applying ultrasonic vibration is placed flat to establish coordinate axis. The X-axis of the coordinate axis is the length direction of the test block cladding layer, that is, the scanning direction of laser cladding, and the Y-axis is the width direction of the test block cladding layer. In the direction of the Y-axis, the displacement between the point and the datum surface was measured at 0.1mm intervals. A total of 8 points were taken, and Fig. 11 was obtained.

The surface roughness can be calculated by the following formula:

$$R_a = \frac{1}{n}\sum_{i=1}^{n} |y_i| \, , \tag{9}$$

where y_{i} is the displacement between the measurement point and the reference plane of the cladding layer on the test blocks, mm ; n is the number of sampling points along the Y-axis of laser cladding.

Calculated:

The surface roughness of the cladding layer without ultrasonic vibration is

R_a = 0.0363mm = 36.3 μm.

The surface roughness of the cladding layer with ultrasonic vibration is

R_a = 0.0230mm = 23.0 μm.

The calculated results show that the surface roughness of the cladding layer with ultrasonic vibration is significantly reduced by 36.6% compared with that without ultrasonic vibration. Analysis the reason of applying ultrasonic vibration, at the same time of laser cladding, ultrasonic vibration caused by acoustic streaming effect as well

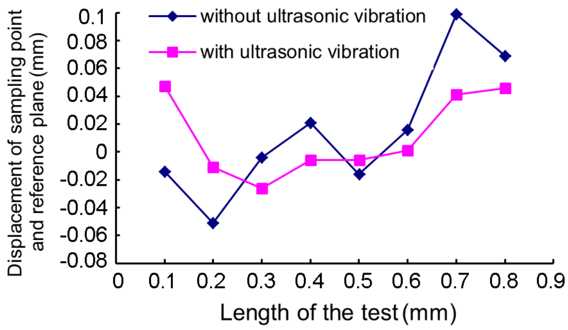

Fig. 11. Displacement of sampling point and reference plane along the Y-axis direction of the laser cladding layer.

as to the molten pool is similar to the effect of stirring, make the cladding process cooling condition is good, molten pool of liquidity has improved, to improve the tension on the surface of the molten pool, thus get the surface cladding layer is flat and level.

5. Conclusions

Regardless of whether ultrasonic vibration is applied or not, the temperature distribution of laser cladding shows an approximately elliptical shape. Compared with laser cladding without applying ultrasonic vibration, the temperature change applied by ultrasonic vibration is softer and the temperature gradient is smaller. The temperature of the melt pool and the substrate both become larger, but the melt temperature of the melt pool is smaller than that of the substrate.

With ultrasonic vibration can effectively reduce the temperature gradient inside the cladding layer and the interface between the cladding layer and the substrate, reduce the residual stress, and achieve the purpose of reducing or even eliminating cracks in the cladding layer and the interfacial bonding zone.

The ultrasonic frequency increases, and the temperature increases everywhere along the Z-axis. As the scanning speed increases, the temperature along the Z-axis decreases as a whole. As the ultrasonic frequency increases, the temperature gradient from the cladding layer to the interface decreases. The scanning speed decreases, and the temperature gradient from the cladding layer to the interface area also decreases.

Compared to the cladding layer without ultrasonic vibration, the microstructure of the cladding layer obtained by applying ultrasonic vibration is finer and denser due to the effect of ultrasonic cavitation, and the microhardness is increased by 1.37 times and the surface roughness is reduced by 36.6%.

Acknowledgements

This work was financially supported by Xinjiang uygur autonomous region high-tech research and development project (201513102) and Xinjiang uygur autonomous region youth natural science fund project (2017D01C062).

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