Experimental Study on Crack Arrest of Thin Plate Based on Surface Nano-coating Technology

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Abstract: Multiple cracks can penetrate through wallboard structure after long-term service, and they have difficulty in repairing and irreplaceability in engineering, aiming at this problem, a nano-coating surface treatment technology is proposed to repair cracks of the thin plate. Firstly, vibration fatigue test is carried out on thin plates until fatigue cracks appears, and then the cracked thin plate is treated by the surface nano-coating technique. Furthermore, the vibration test of the thin plate under the first-order bending resonance state and a certain initial stress level is performed. The results show that the crack growth rate of the thin plate is reduced and the fatigue life is improved by the nano-coating treatment of the local surface. By comparing the crack arresting effects of two different coating materials, it is found that the NiCrAl coating has better crack arresting effect than that of the ZrO_2 coating.

Keywords: Cracks; Wallboard structure; Nano-coating surface treatment; Fatigue test; Crack arresting

1 Introduction

Crack defects exist widely in materials and engineering structures, which not only reduces the load-carrying capacity of materials and engineering structures, but also shortens the real effective life of products on service. Especially for the core components of high value-added mechanical equipment (such as construction machinery, ships, aircraft, large compressors) with microcrack damage that repairing crack damage can save resources and energy, and have significant economic benefits [1]. As a gradual development process, fatigue failure usually includes three stages: initiation or formation of cracks, stable expansion of cracks and instability of cracks. For some components which have inevitably introduced crack defects in the process of manufacturing for use, the first consideration is how to use the crack arresting method to control the crack propagation and improve the fatigue life. How to ensure the reliability of key components of the equipment during the effective life period and avoid failure of parts due to cracks during work has become a core technical problem in manufacturing engineering. Therefore, the research on repairing cracks and crack arresting methods has important theoretical and practical value for valuable, key

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components and parts with long processing cycles, high precision requirements and special materials or special processing.

According to the study of crack formation and propagation in fracture mechanics, the method of crack arresting can be divided into three methods as reducing stress intensity at crack tip, reducing stress concentration at crack tip and introducing compressive stress [2]. The crack arrest methods for reducing stress intensity at crack tip include bonding repair of composite materials and crack filling. Bonding repair is a method of using bonding technology to patch composite materials in the damaged areas of structural parts to be repaired, to improve the local area, and to extend their service life. Bonding repair is a method of using bonding technology to patch composite materials in the damaged areas of structural parts to be repaired, to improve the local area, and to extend their service life [3, 4]. Crack filling method is based on the mechanism of crack closure effect. Introducing artificial polymers into cracks, such as epoxy resin and mineral oil, may lead to premature crack closure and subsequent crack delay. And this concept is used to improve the crack propagation crack arrest method [5]. The crack arrest methods for reducing stress concentration at crack tip include drilling crack hole and adding reinforcing rib. The principle of crack arrest by drilling near the crack tip is to remove the plastic zone at the crack tip and improve the stress concentration at the crack tip under cyclic loading, thus delaying the fatigue crack growth of the structure [6]. The crack arrest method of reinforcing bar is to weld reinforcing rib in the local area around the crack, increase the load capacity of the structure and improve the stress condition around the crack, thus restricting the crack opening [7]. The introduction of compressive stress arrest methods includes laser shock enhancement, electromagnetic thermal effects and shallow pit methods. Laser shock strengthening is the use of laser-induced high-intensity shock wave pressure to cause micro-plastic deformation of the material surface of the treated specimens, resulting in the formation of residual compressive stress layer, which effectively reduces the tensile stress level of metal components under alternating loads, thus effectively delaying the crack growth rate and ultimately increasing the fatigue life of parts [8]. The specific process of the electromagnetic heating effect is to pass the high-voltage pulse current along the perpendicular line of the crack to the conductor member and the current around the crack generates Joule heat. The material at the crack tip melts to form a welded joint to achieve the purpose of crack arrest [9]. Nishimura T [10] studied the effect of setting shallow pits at the crack tip to prevent fatigue crack propagation. Studies have shown that the fatigue test limit of the test piece with shallow pit is increased by 2.2 times and the crack propagation life is increased by 50 times compared with the case where no shallow pit is provided.

However, some of the above listed crack arrest methods have certain limitations. For example, although the drilling holes method and the setting of the shallow pit are easy to operate, it has to damage the test piece, which will weaken the bearing capacity of the section excessively, and it is not conducive to the structural stress, so they can only be used as a temporary repairing measure; the crack arrest effect of crack filling depends on the nature of filler and whether the filler penetrates into the tip of fatigue crack effectively. The depth of the filler penetrates into the crack tip depends on the loading level and filling method when filling. Therefore, the crack arrest effect is uncertain. The reinforcement rib method can be used as a temporary remedy for large-scale mechanical equipment, but it is not suitable for semi-buried cracks and crack prevention through cracks in sealed vessels. Conventional welding methods are prone to residual stress, stress corrosion cracking, hydrogen embrittlement and other by-products, reducing the overall performance of the micro-cracked metal structural member, so that the life is reduced. Although the laser impact strengthening can effectively improve the fatigue life of the material within a certain range, it is actually a metal surface strengthening method for the surface crack. Although effective, but for the ubiquitous semi-buried cracks and occurs in thick-walled parts of the non-penetrating cracks, this method is not fully applicable.

Thermal spraying technology is an important branch of surface engineering. It heats a certain linear and powdery material to a molten or semi-melted state by a heat source such as flame, arc or plasma, and sprays the accelerated droplets at high speed to the substrate to form a coating. In recent years, coating repair technology has been applied and developed to repair improperly machined parts, extend the life of parts, and even repair parts, making old as new. The combination of spray technology and laser technology can significantly improve the coating performance. Laser remelting technology can basically eliminate the defects such as pores and cracks generated during spraying, increase the number of grain boundaries and obtain fine-grained structure, enhance the inside of the coating and the coating-matrix, and reinforce the bonding strength between the two materials to make the ordinary materials obtain excellent wear resistance, corrosion resistance, thermal shock resistance, high hardness and high fatigue strength. Shin and Hsu [11] used a container vacuum method to infiltrate a sealing material (such as epoxy resin) into the crack of the sample to achieve crack closure and have a crack-stopping effect; Song et al. [12] used a pressurized nitrogen gas to ring the oxygen resin mixture filled into the crack, which can better promote the crack closure and prolong the life of the crack member. The cold spray solves the thermal spray oxidation and phase change problem, which is simpler than the low pressure plasma spray (LPPS) system. Kazuhiro Ogawa and Dowon Seo [13] used cold spray technology instead of welding to repair cracks, and introduced the application of cold spray technology in nickel-based turbine blade repair. L. Shepeleva et al. [14] compared the advantages and disadvantages of laser cladding coating and plasma cladding coating, and pointed out that the laser cladding layer has higher hardness than the plasma cladding layer, without cracks and pores. Metallic plasma spray coatings are widely used in the aerospace industry for the repair of engine components. However, inherent defects in coatings limit such repairs and shorten the life of the parts. Most scholars focus on spray process research [15,16]. Huang et al[17,18] proposed a surface nanotechnology in 2005, and by mechanically rubbing the surface of the material, the crystal structure of the surface layer of the material is changed to make the elastic modulus, yield limit and strengthening limit of the material. At present, the research on thermal spraying in the crack arrest of thin plates has not been reported in the literature.

In this study, the vibration fatigue test of the thin plate test piece is first carried out until the fatigue crack appears, and the first-order natural frequency with time curve is obtained. Then, the APS plasma spraying technology was used to spray the cracked thin plate test piece with NiCrAl coating and NiCrAl transition layer plus ZrO_2 functional layer composite coating to repair the crack of the thin plate. Finally, the vibration test of the thin plate in the first-order bending resonance state and a certain initial stress level was carried out to observe the crack propagation time and expansion rate of the repaired thin plate test piece with coating, and analyzed of the effect of NiCrAl coating and ZrO_2 coating on crack propagation of cracked specimens.

2 Preparation of test specimens

Two kinds of thin plate test pieces with different sizes are designed. The processing material is 45# steel, and the NiCrAl coating is coated on both sides of the crack-containing thin plate test piece A2 by the APS plasma spraying method, and the NiCrAl transition layer plus ZrO_2 functional layer composite coating is coated on both sides of the crack-containing thin plate test piece B2.

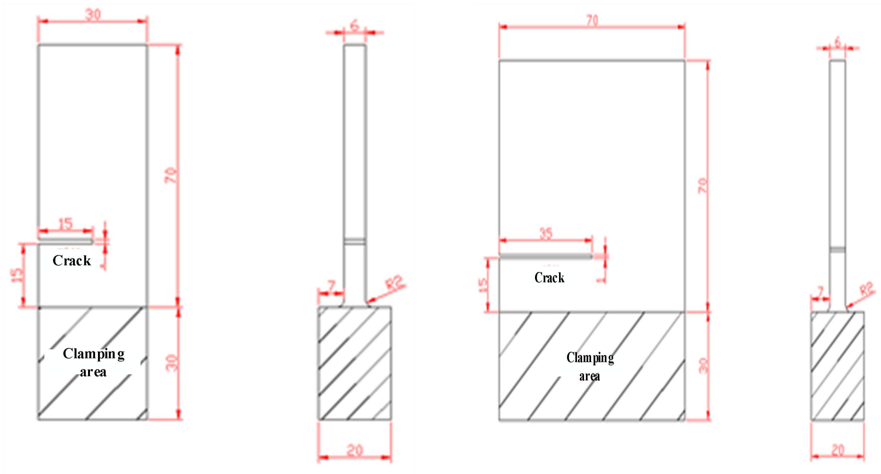
2.1 Specimens structural size

In order to facilitate the clamping of the test piece, a clamping area of 30 mm thick and 20 mm thick (shaded area in the Fig) is designed to form the structure shown in Fig. 1. The specific structural dimensions of the thin plate test piece are shown in Table 1.

Table 1. Main size parameters of thin plate test piece

Specimens Number	Length/mm	Width/mm	Thickness/mm
A	70	30	6
B	70	70	6

The specific structure of the thin plate test piece is shown in Fig. 1.



(a) Specimen A (b) Specimen B

Fig. 1. Specimens structure size

2.2 Specimens processing

Two kinds of thin plate test specimens are processed by 45# steel, two pieces each, numbered A1-A2, B1-B2; Using the wire cutting method, the penetrating groove is cut at a height of about 15 mm from the clamping zone. The cutting width of the wire cutting is 0.18 mm, the width of the groove is 1 mm, and the groove length is1/2 of the width of the thin plate test piece. The actual specimen is shown in Fig.2.

Fig. 2. Physical diagram of the thin plate test piece

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2.3 Preparation of coating

Plasma spraying is currently the most widely used thermal spraying process, producing good coating performance, long service life and high reliability. The principle of plasma spraying is shown in Fig. 3. Since there is enough energy to melt almost any powdered coating material, the plasma spray gun has one or more cathodes (electrodes) and an anode (nozzle) in the spray chamber. When the process gas flows through the spray booth, a direct current is applied to the cathode, thereby creating an arc between the anode and the cathode. A powerful arc discharges electrons from the atmospheric molecules creating a plasma plume. When unstable plasma ions recombined into a gaseous state, a large amount of thermal energy is released. The spray material is injected into the hot gas stream, melted and sprayed onto the substrate to form a spray coating.

3 Vibration fatigue and crack propagation test

In the vibration test process, the3-D waterfall map is obtained by sweeping to identify the natural frequency of the specimen. Taking the natural frequency of the test piece as the excitation frequency, the test piece is in resonance state. Study crack propagation law of the test piece under the condition of the first-order bending

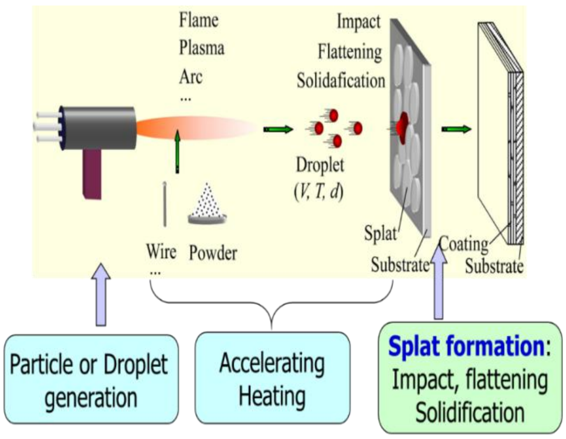

Fig. 3. Schematic diagram of plasma spraying

Spray on both sides of the plate, the coating position is shown in Fig. 4.

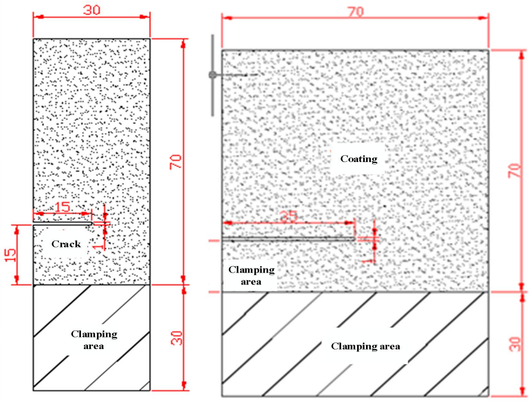

Fig. 4. Schematic diagram of coating application position

Fig. 5 shows a physical diagram of the coated plate test piece.

Fig. 5. Specimen with coating

resonance state and the initial stress level, and the crack arrest performance of different coatings on the thin plate test piece is analyzed.

3.1 Test task

A set of orthogonal tests was designed to study the crack arrest test of different coatings on thin-walled plates. The test tasks are shown in Table 2.

3.2 Test device

Set up the vibration test system, the main equipment is shown in Table 3. The electromagnetic vibration table and its controller, power amplifier, etc., provide an excitation source for the vibration of the thin plate test piece; the strain gauge converts the current signal into a voltage signal through a strain gauge, and inputs it to the LMS acquisition front end to test the strain of the thin plate test piece. Considering that the strain gauge is very easily damaged during the vibration test, an acceleration sensor is simultaneously arranged on the blade to monitor the vibration amount of the blade. The site of the vibration test of the thin plate test piece is shown in Fig. 6.

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Table 2. Test Task

Number	Test Task
A1/A2	Resonance frequency of test plate A1/A2 with time under 9g acceleration excitation resonance;
B1/B2	Resonance frequency of test plate B1/B2 with time under 10g acceleration excitation resonance;
A2/B2	The change of resonance frequency with time under the condition of 9g acceleration excitation resonance of thin plate A2 after test coating repair; The change of resonance frequency with time under the condition of 10g acceleration excitation resonance of thin plate B2 after test coating repair;

Table 3 The main components of the system

Name	Model	Main performance parameters
Electromagnetic vibration table	Dongling ES-10-240	Frequency Range 5-5000Hz; Maximum acceleration 1000g
Accelerometer	PCB-352C22	Sensitivity 10mv/g; Frequency response 13kHz
Strain gauges	BX120-3AA	Resistance 120; Strain limit 20000μm/m
Strain conditioner	INV1861A	8 channels; Calibration value 0.5mV/μ; Frequency response DC-10kHz
Data acquisition instrument	LMS SCADAS III	8 channels; Sampling Rate 102.4kHz; Support multiple input modes
Data mining analysis software	LMS Test. lab	Time domain waveforms, spectrum, 3D waterfall maps, etc. can be generated online

Fig. 6. Thin plate vibration test site

3.3 Installation method and sensor arrangement of thin wall test piece

The fixture is designed and prepared according to the test requirements and the characteristics of the test piece. The fixture is optimized by finite element software to ensure that the fixture does not resonate within the vibration frequency range of the test piece. The test piece is fixed on the fixture by bolt connection to form a cantilever structure. In order to acquire the natural frequency of the test piece in the test, an acceleration sensor is arranged at its root to monitor the vibration signal. A strain gauge is placed in the dangerous part of the test piece to monitor the vibration stress. The clamping method of the test piece and the arrangement of the sensor are shown in Fig. 7.

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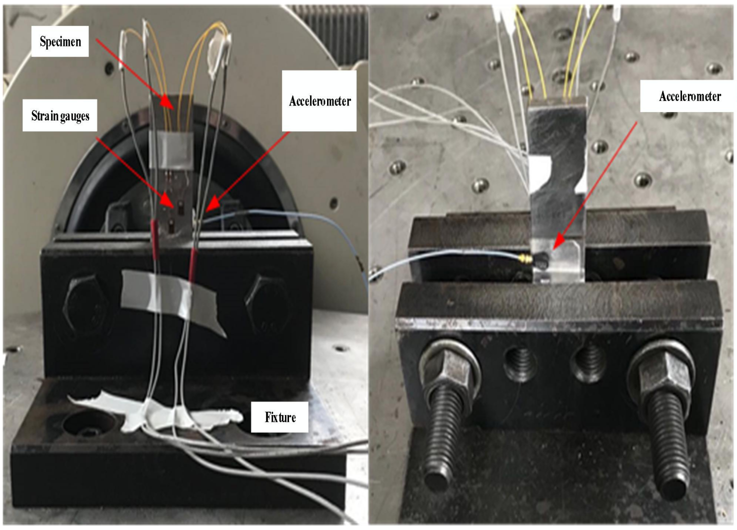

Fig. 7. Test piece clamping method and sensor arrangement

3.4 Test methods and procedures

(1) First, the natural frequency of the test piece is roughly estimated by hammering method;

(2) Then, select the appropriate frequency range, and the frequency sweeping time domain signal of the test piece is obtained by means of a vibration table sweeping frequency, and the frequency point corresponding to the peak value of the waterfall graph is the natural frequency of the test piece;

(3) According to the results of stress distribution, the maximum stress point is located at the root of the thin plate test piece. The stress is calibrated by strain gauge at this position, then the vibration test is carried out according to the calibration results;

(4) During the test, the downtime is determined according to the change of the resonance response monitored by the acceleration sensor. The natural frequency of the test piece after a certain period of vibration is obtained by the frequency sweep method, and the data is recorded, and then the resonance test is continued. In order to investigate the effect of coating on the crack growth characteristics of cantilever thin plate specimens, the tests are continued until the natural frequency of the specimens decreases to the lower limit of the set frequency (where the natural frequency decreases by 15%).

(5) The above procedure is repeated to test the crack propagation of the test piece after the coating is applied.

4 Test results and analysis

4.1 Test results of thin plate without coating

Take thin plate A2 as example, the natural frequency of the test piece was roughly estimated by hammering to be 803.93Hz, as shown in Fig. 8. Select the frequency range of 700Hz-850Hz, and use the vibration table to obtain the natural frequency of the test piece at 804Hz, as shown in Fig. 9.

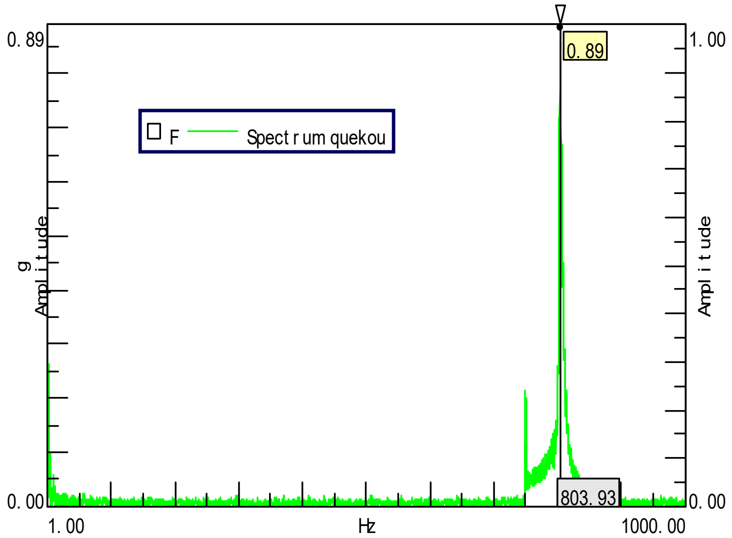

Fig. 8. Hammer diagram of thin plate A2

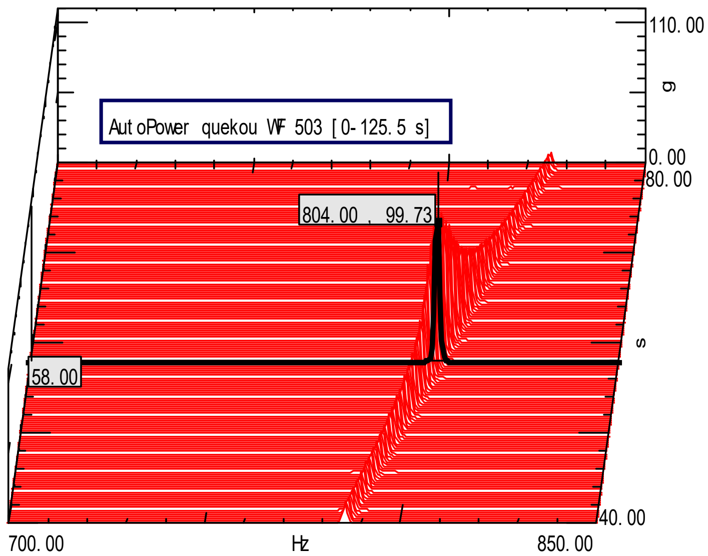

Fig. 9. Waterfall of thin plate A2

The given basic excitation amplitude of the electromagnetic vibration table is 9g, the test piece A1/A2 is excited according to the natural frequency value obtained by the frequency sweep, and the natural frequency value of the thin plate test piece after different time is recorded. The natural frequency variation law of the thin plate test piece A1/A2 is drawn and shown in Fig 10.

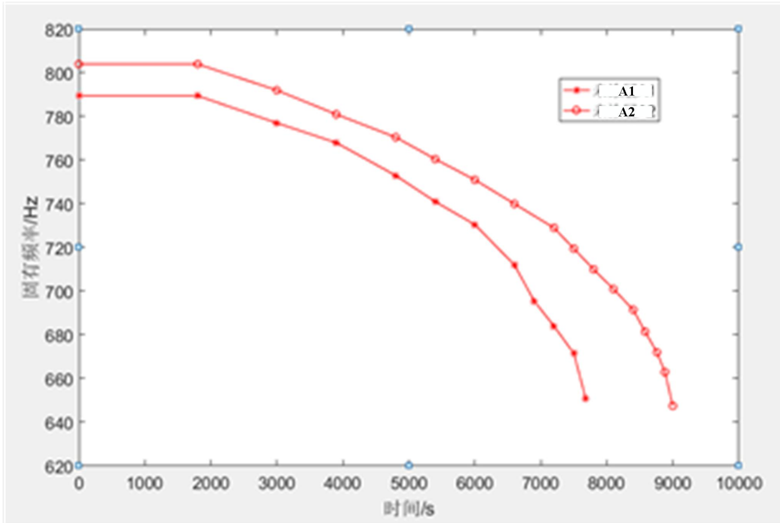

Fig. 10. Variations in the natural frequencies of thin plates A1 and A2 over time

Taking thin plate A2 as an example, the change process of the first natural frequency of thin plate under the resonant state is illustrated, and it is "slowly decreasing-fast falling". It can be seen from Fig. 10 that the initial natural frequency of the thin plate A2 is 804 Hz, and the basic excitation at a fixed acceleration of 9 g and a fixed frequency of 804 Hz is applied. After 30 minutes, the natural frequency of the thin plate A2 is still 804 Hz, indicating that the crack has not yet appeared; after another 20 minutes under this condition, the natural frequency of the thin plate A2 drops to 792 Hz, indicating that crack initiation occurs in the thin plate; then the base excitation at a fixed acceleration of 9 g and a fixed frequency of 792 Hz is applied, and after 15 minutes, the natural frequency of the thin plate A2 drops to 781 Hz. In order to observe the crack propagation phenomenon completely, the resonance time is gradually reduced and then swept to obtain the natural frequency. After 120 minutes, the natural frequency of the thin plate A2 drops sharply, indicating that the thin plate enters the crack propagation stage; after 150 minutes, the natural frequency of the thin plate A2 dropped to 647.5Hz, a decrease of 19.5%. The curves of A1/A2 natural frequencies with time almost coincide, which indicates that crack propagation has a certain regularity, and the initial natural frequencies of A1/A2 have a small deviation, which is caused by sample dispersion. Under the condition of resonant excitation, the thin plate has experienced the stages of crack initiation and crack propagation. During the test, the first natural frequency of the plate decreases slowly and rapidly, because the crack causes the decrease of the stiffness of the plate. As shown in Fig. 11, the fatigue crack generated along the notch after the plate A2 is broken.

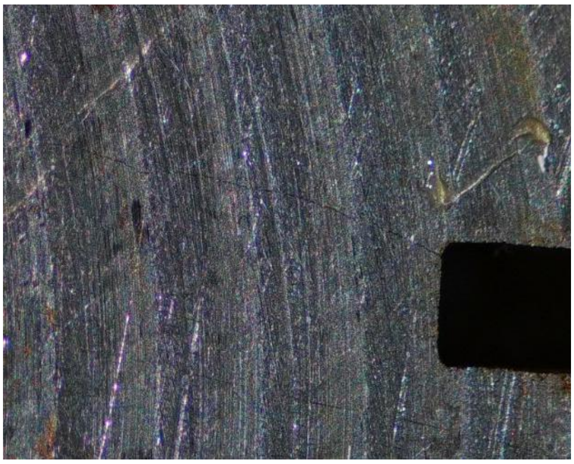

Fig. 11. Fatigue crack of thin plate A2

Similarly, the given basic excitation amplitude of the electromagnetic vibration table is 10g, the test piece is excited according to the natural frequency value obtained by the frequency sweep, and the natural frequency value of the thin plate test piece B1/B2 after different time is recorded. The natural frequency variation of the thin plate test piece B1/B2 is drawn and shown in Fig. 12.

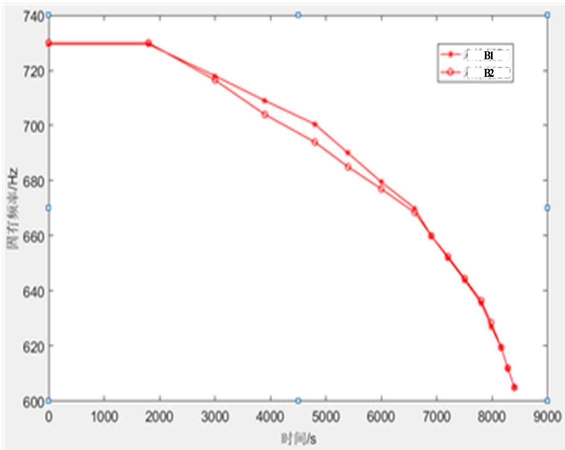

Fig. 12. Variations of natural frequencies of test pieces B1 and B2 with time

The natural frequency of the test piece B1/B2 changes with time is almost the same. The change process of the first natural frequency of thin plate under the resonant state is “slowly decreasing-fast falling” as well, further indicating that the crack propagation has certain regularity. Taking the thin plate B2 as an example, it can be seen from the Fig.12 that the initial natural frequency of the thin plate B2 is 730 Hz,

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and the basic excitation at a fixed acceleration of 10 g and a fixed frequency of 730 Hz is applied. After 30 m, the natural frequency of the thin plate B2 is still 730 Hz, indicating the crack initiation has not yet occurred; after another 20m under this condition, the natural frequency of the thin plate B2 drops to 716.5 Hz, indicating that crack initiation occurs in the thin plate; then the base excitation at a fixed acceleration of 10 g and a fixed frequency of 716.5 Hz is applied, and after 15m, the natural frequency of the thin plate B2 drops to 704Hz. In order to observe the crack propagation phenomenon completely, the resonance time is gradually reduced and then swept to obtain the natural frequency. After 110m, the natural frequency of the thin plate B2 A steep drop sharply, indicating that the thin plate entered the crack propagation stage; after 140m, the natural frequency of the thin plate B2 dropped to 605 Hz, a decrease of 17.1%.

Fig. 13 is a vibration fatigue crack generated along the notch after the thin plate test piece B2 is broken.

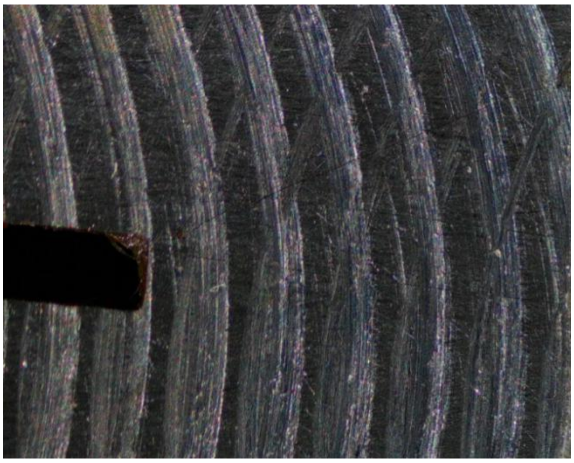

Fig. 13. Fatigue crack of thin plate B2

4.2 Test results of coated thin plate test pieces

APS technology was applied to spray different metal coatings on both sides of the thin plate to realize the repair of micro-cracks. The vibration test of the thin plate after the micro-crack was repaired by the coating was carried out to analyze the crack-arresting effect of different coating materials on micro-cracks.

First, the thin plate A2 is sandblasted, and then sprayed several times (about 30 μm each time) until the thickness of the NiCrAl coating is about 150 μm, and both sides of the thin plate are sprayed. Fig. 14 is a thin plate test piece A2 coated with NiCrAl coating, and the joint surface of the coating layer and the substrate of the thin plate is free of cracked pores, and the microstructure of the repair layer is dense and the particles having the shape of approximately spherical particles containing nano-NiCrAl particles are dispersed in the fine crystal grains.

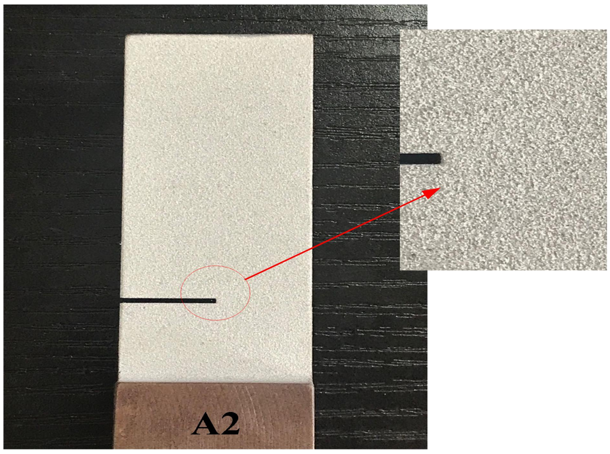

Fig. 14. Test piece A2 with NiCrAl coating

Similarly, the basic excitation amplitude of the electromagnetic vibrating table is 9 g, and the test piece A2 is excited according to the natural frequency value obtained by the frequency sweep, and the natural frequency value of the thin plate test piece over different time is recorded. Fig.15 shows the test site for the coated plate A2.

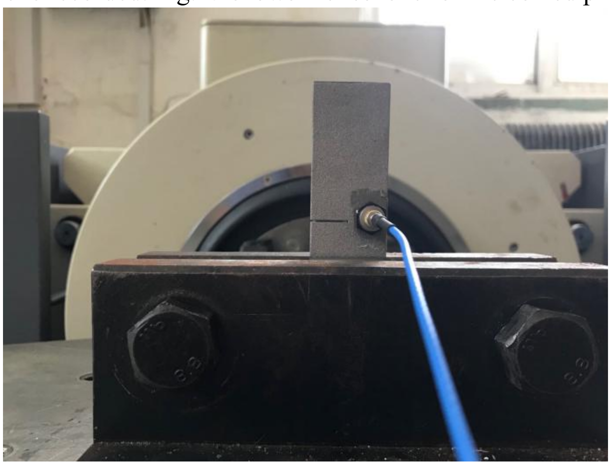

Fig. 15. Test site of coated thin plate A2

Table 4 shows the variation of the natural frequency with the resonance time after the thin plate A2 is coated with the NiCrAl coating.

Table 4. Variation of natural frequency of coated plate A2 with time

Frequency/Hz	716.5	716.5	716	713	711	709.5	708.5	707
Time/min	5	5	10	10	5	5	10	30

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The tendency of the natural frequency’s change with time of the plate A2 with and without the coating is shown in Fig. 16.

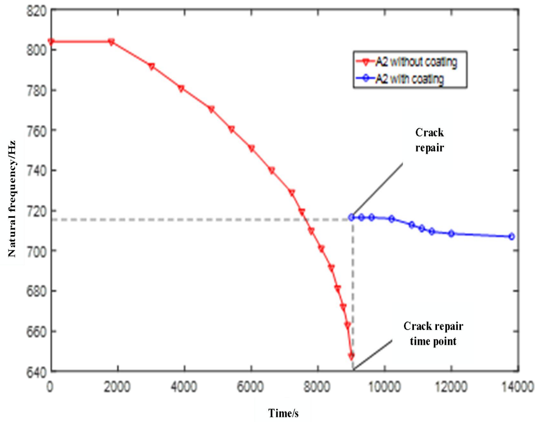

Fig. 16. Variation of natural frequency of thin plate A2 with time after repair of NiCrAl coating

As it can be seen from Fig. 16, the natural frequency of the uncoated thin plate A2 undergoes a “slowly decreasing-fast falling” change process. The initial natural frequency of 804 Hz drops to 647.5 Hz and experiences 150 minutes; after the NiCrAl coating is spayed on both sides of the thin plate A2, the natural frequency increases from 647.5Hz to 716.5Hz, and this is due to the fact that the coating can significantly improve the coating performance. During spraying, nano-coatings filled with defects such as voids and cracks, and metallurgical bonding occurred between the repairing layer and the coating. Fine particles containing a small amount of nanoparticles exist in the repair layer to refine the grain size, increase the number of grain boundaries and obtain fine grain structure. At the same time, the compactness of the structure is improved, and the bonding strength between the coating and the coating-matrix is enhanced, which makes the stiffness of the plate increase and the natural frequency increase as well.

After spaying NiCrAl coating, the natural frequency of the thin plate A2 drops very slowly. The natural frequency only drops by 9.5Hz after 80m, indicating that the coating can improve the service life of the device. On the one hand, the crack is repaired by the NiCrAl coating, and the crack is prevented. On the other hand, the NiCrAl coating has high damping properties, which can reduce the resonance stress and prolong the fatigue life.

Similarly, the thin plate B2 is first blasted, then the 60um NiCrAl coating is sprayed as a transition layer, and the ZrO2 coating is sprayed on the surface of the functional layer. After multiple spraying, the thickness of the ZrO_2 functional layer is about 150 um, and both sides of the thin plate are sprayed. Fig. 17 is a thin plate test piece B2 coated with NiCrAl+ZrO_2 coating. The joint surface of the coating and the substrate of the thin plate is free of cracked pores. The microstructure of the repair layer is dense and the particles with nano-particles with a nearly spherical shape are dispersed in the fine crystal grains.

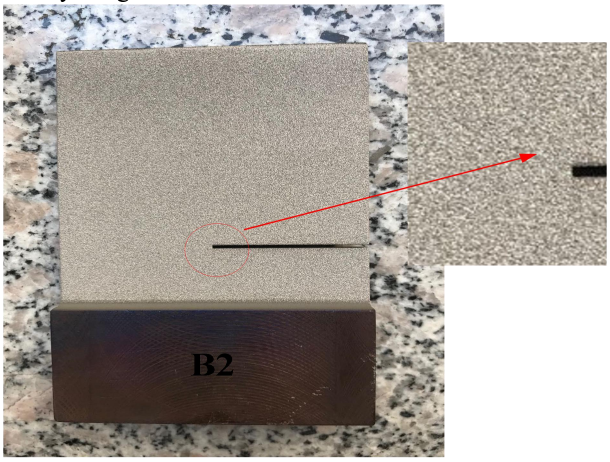

Fig. 17. Test pieces B2 with Sprayed NiCrAl+ ZrO_2 Coating

Similarly, the basic excitation amplitude of the electromagnetic vibration table is 10 g, and the test piece B2 is excited according to the natural frequency value obtained by the frequency sweep, and the natural frequency value of the thin plate test piece over different time is recorded. Fig. 18 shows the test site of the coated plate B2.

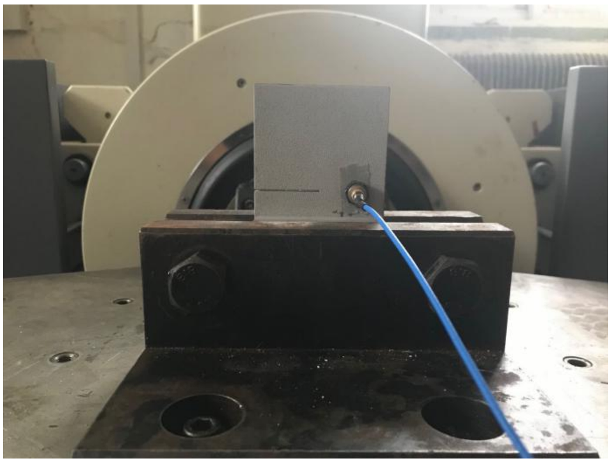

Fig. 18. Test site of coated thin plate B2

After the thin plate B2 is coated with the NiCrAl+ZrO_2 coating, the natural frequency changes with the time as shown in Table 5.

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Table 5. Variation of natural frequency of coated plate B2 with time

Frequency/Hz	624	618.5	617.5	606	596	586
Time/min	5	10	5	5	5	3

The tendency of the natural frequency's change with time of the plate B2 with and without the coating is as shown in Fig 19.

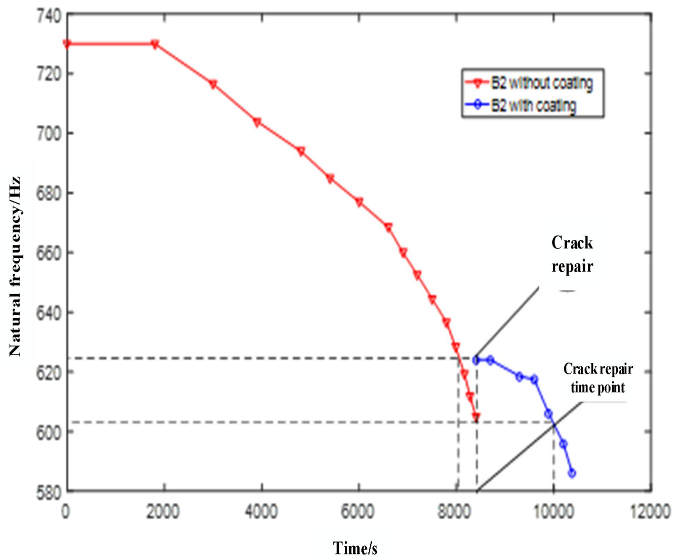

Fig.19. Variation of natural frequency of thin plate B2 with time after repair of NiCrAl+ ZrO2 coating

As it can be seen from Fig.19, the natural frequency of the uncoated thin plate A2 undergoes a "slowly decreasing-fast falling" change process as well. The initial natural frequency 730 Hz drops to 605 Hz and experiences 140 minutes; after the NiCrAl+ZrO_2 coating is spayed on both sides of the thin plate A2, the natural frequency is 605 Hz rises to 624 Hz, which further demonstrates that the coating can improve the performance of the thin plate. The nano-coating fills the defects such as voids and cracks during spraying, so that the rigidity of the plate increases and the natural frequency increases.

After spaying NiCrAl+ZrO_2 coating, the natural frequency of the thin plate B2 decreases slowly compared with the uncoated thin plate, the natural frequency of the thin plate decreases from 624 Hz to 605 Hz, the uncoated thin plate costs about 10 minutes, and the coated thin plate takes about 25 minutes, and the time increases by 2.5 times.

Comparing the crack arrest effect of NiCrAl coating and NiCrAl+ZrO_2 coating, it is preliminarily judged that NiCrAl coating has better crack arresting effect than ZrO_2 coating.

5 Conclusion

The crack propagation characteristics of the thin-plate with coating are studied. The results show that the coating has a good effect on suppressing the crack propagation of the thin plate. The experimental research on the vibration fatigue crack growth characteristics of the thin plate and the influence of the coating are carried out on the thin plate specimen. The main conclusions obtained are as follows:

(1) According to the vibration fatigue test results of the pre-cracked thin plate specimen, as the vibration cycle time increases, the crack length of the thin plate further expands, the crack growth rate of the thin plate increases gradually, and the growth is faster and faster, which are certain regularity.

(2) In general, the coating has a good crack arresting effect. The coating can significantly improve the performance of the thin plate. The nano-coating fills the defects such as pores and cracks during spraying, increases the number of grain boundaries and obtains fine-grained structure, and enhances the bonding strength between the coating and the coating-substrate, which can be used to repair cracks;

(3) After the crack is repaired by the coating, the time for the natural frequency of the thin plate specimen to decrease rapidly is significantly longer than that of the uncoated one, which can delay the fatigue crack propagation of specimen and improve the service life;

(4) The test results show that the NiCrAl coating has better crack arresting effect than the ZrO_2 coating.

References

1. Jiang X F, ***Experimental Study on Laser Repair of Crack Tip***, Dalian University of Technology, 2017.
2. Yu J, ***Research on Crack Arresting and Healing Technology by High-density Pulsed Current*** , Dalian University of Technology, 2014.
3. Rathke A, Tymina Y, Haller B, Effect of Different Surface Treatments on the Composite Repair Bond Strength, ***Clinical oral investigations,*** 13 (2009) 317.
4. Yang F B, Xiao J Y, Huang X B, et al, Fatigue Characteristics of Center-Cracked Aluminum Plate One-Side-Bonded Repaired With Composite, ***Aerospace Materials & Technology,*** 38 (2008) 59-62.
5. Liu Q K, Li G S, Review of Methods for Delaying Fatigue Crack Propagation in Metal Structures, ***Equipment Manufacturing Technology,*** 288 (2018) 92-96.
6. Zhu R Y, Zhou J Z, Yi G X, The Way to Improve the Fatigue Life of Welding Components—On the Mechanism of Crack-cutting Holes, ***Journal of Hubei University of Technology,*** (1995) 133-136.
7. Yu J L, Yan X Q, Analysis on Crack Arrest Performance of Crack-stiffened Panel, ***Petro-Chemical Equipment,*** 37 (2008) 12-16.
8. Lu J Z, Zhong J W, Luo K Y, et al, Micro-Structural Strengthening Mechanism of Multiple Laser Shock Processing Impacts on AISI 8620 Steel, ***Materials Science and Engineering: A,*** 528 (2011) 6128-6133.
9. Zhang H C, Yu J, Hao S Z, et al, Application of Electro-magnetic Heat Effect on Arresting the Crack in Remanufacturing Blank, ***Journal of Mechanical Engineering,*** 49 (2013).

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10. Nishimura T, Experimental and Numerical Evaluation of Crack Arresting Capability Due to A Dimple, ***Journal of Engineering Materials and Technology,*** 127(2005) 244-250.
11. Shin C S, Hsu S H, Fatigue Life Extension by An Artificially Induced Retardation Mechanism, ***Engineering Fracture Mechanics,*** 43 (1992) 677-684.
12. Song P S, Hwang S, Shin C S. Effect of Artificial Closure Materials on Crack Growth Retardation, ***Engineering Fracture Mechanics,*** 60 (1998) 47-58.
13. Ogawa K, Seo D. Repair of Turbine Blades Using Cold Spray Technique, ***Advances in Gas Turbine Technology,*** Intech Open, 2011.
14. Shepeleva L, Medres B, Kaplan W D, et al, Laser Cladding of Turbine Blades, ***Surface and Coatings Technology,*** 125 (2000) 45-48.
15. Cavaliere P, Silvello A, Finite Element Analyses of Pure Ni Cold Spray Particles Impact Related to Coating Crack Behaviour, ***Surface Engineering,*** 34 (2018) 361-368.
16. Ward D, Gupta A, Saraf S, et al, Functional Nial-Graphene Oxide Composite as A Model Coating for Aerospace Component Repair, ***Carbon,*** 105 (2016) 529-543.
17. Chen X H, Lu J, Lu L, et al, Tensile Properties of A Nanocrystalline 316L Austenitic Stainless Steel, ***Scripta Materialia,*** 52 (2005) 1039-1044.
18. Huang H W, Wang Z B, Lu J, et al, Fatigue Behaviors of AISI 316L Stainless Steel with A Gradient Nanostructured Surface Layer, ***Acta Materialia,*** 87 (2015) 150-160.