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Study on Surface Micro-Texture of Ti2AlNb-based Alloy Cladding Layer by Ultrasonic and Temperature Field Assisted Milling

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Abstract

Ti2AlNb-based alloy is difficult to machine due to its high thermal deformation resistance, significant work hardening and poor surface processing quality. In this paper, Ti2AlNb alloy cladding layer was prepared on Ti-6Al-4V substrate by laser cladding technology. Combined with ultrasonic vibration and temperature field assisted milling composite processing technology, the influence of ultrasonic amplitude and preheating temperature on the surface texture morphology of the alloy was investigated. The results show that ultrasonic vibration can change the material removal method, change the machined surface from ordinary parallel tool marks to regular periodic grid micro-texture, and significantly improve the surface texture regularity. Moderate preheating can improve the cutting stability through the thermal softening effect of the material, and effectively suppress the processing defects such as ploughing and tearing. As the preheating temperature increases from 30°C to 200°C, the surface roughness continues to decrease, and the texture quality is gradually improved. Too high preheating temperature (300°C) will lead to excessive softening, sticking and thermal damage of the material, resulting in surface texture distortion and significant increase in roughness. Within the range of experimental parameters, 200°C preheating coupled with 2μm ultrasonic amplitude can obtain the optimal surface morphology and processing quality.

Keywords

Ti2AlNb Based Alloy; Ultrasonic Assisted Milling; Temperature Field Auxiliary; Surface Texture

1. Introduction

Titanium-aluminum intermetallic compounds have become the core candidate materials for high-temperature structural parts in the aerospace field due to their low density, high specific strength, excellent high-temperature mechanical properties and creep resistance, and are widely used in the manufacturing of key components such as aero-engine blades and turbine disks [1,2]. The material has good high temperature oxidation resistance, which can effectively extend the service life of components, and meet the stringent requirements of modern aviation equipment for lightweight, high thrust-weight ratio and high energy efficiency development [3]. However, TiAl alloy has its own inherent characteristics such as high room temperature strength, weak plastic deformation ability, high thermal deformation resistance and low thermal conductivity. It is prone to work hardening, severe tool wear and large cutting resistance during machining. It is a typical difficult-to-cut material. It is difficult to obtain a machined surface with regular morphology and excellent quality by conventional mechanical milling, which seriously restricts its precision machining and engineering application process [4,5]. In order to improve the cutting performance of difficult-to-cut materials, domestic and foreign scholars have developed a variety of auxiliary cutting technologies, among which ultrasonic vibration assisted milling and temperature field preheating assisted milling are the most widely used. Ultrasonic vibration assisted milling can change the traditional continuous cutting mode by giving the tool high-frequency micro-amplitude vibration, realize pulse intermittent cutting, effectively reduce the cutting force and improve the material removal form [6]. Temperature field preheating assisted milling can increase the substrate temperature of the workpiece in advance, reduce the hardness and deformation resistance of the material by thermal softening, weaken the work hardening effect, and improve the cutting stability [7]. At present, the research on single assisted milling process has been relatively mature, while the research on coupling assisted milling combined with ultrasonic vibration and preheating temperature field is relatively rare. In particular, there is a lack of research on composite milling process for laser cladding to prepare Ti2AlNb alloy cladding layer. The surface texture evolution law and forming mechanism under the synergistic effect of different process parameters are still unclear. Therefore, in this paper, Ti2AlNb-based alloy cladding layer was prepared by laser cladding technology with Ti-6Al-4V as the substrate. The ultrasonic and temperature field coupling assisted milling method was used to explore the influence of ultrasonic amplitude and preheating temperature on the surface texture morphology, micro-texture and surface roughness of the cladding layer. The surface forming mechanism of Ti2AlNb alloy under composite processing conditions was revealed, and the optimal process matching parameters were determined, in order to provide experimental basis and technical reference for high-efficiency and high-quality precision milling of Ti2AlNb-based alloy cladding layer.

2. Experimental Design

2.1. Experiment Preparation

The cladding material used in this experiment is Ti2AlNb-based alloy powder with a particle size range of 45~105μm (chemical composition is shown in Table 1).

Ti-6Al-4V was selected as the test substrate. In order to ensure that the surface of the test substrate has ideal smoothness and organizational consistency, the surface of the substrate is milled by CNC machine tools and flat-end milling cutters. After the milling is completed, ultrasonic cleaning and drying treatment are carried out. Aiming at the difficult machining characteristics of Ti2AlNb-based alloy, such as large thermal deformation resistance, narrow processing window, easy to produce work hardening and fast tool wear, four-edge cemented carbide milling cutter (ST300-S4-08020) is selected for milling.

Table 1. Chemical composition of Ti2AlNb based alloy powder (wt.％)

element	content	element	content
Ti	Bal.	O	0.10
Nb	41.78	H	0.0023
Al	10.13	N	0.014

2.2. Test Scheme

Before the laser cladding test, the Ti2AlNb powder was first placed in a vacuum drying oven for no less than half an hour of drying treatment. The parameters selected in the cladding are laser power of 1200W, scanning speed of 12mm/s, powder feeding amount of 9g/min, spot diameter of 3mm, and overlap rate of 40%. The machine tool used in the milling experiment is a vertical three-axis machining center (VMC850E). The ultrasonic and temperature field assisted milling platform is shown in Figure 1, and the milling experimental parameters are shown in Table 2.

Table 2. Milling test scheme

number	Temperature/ ℃	ultrasonic amplitude/ μm	spindle speed/ (r/min)	cutting depth/ mm	feed speed/ (mm/min)
1	200	0	2400	0.10	150
2	200	2			
3	30	2			
4	100				
5	200				
6	300				

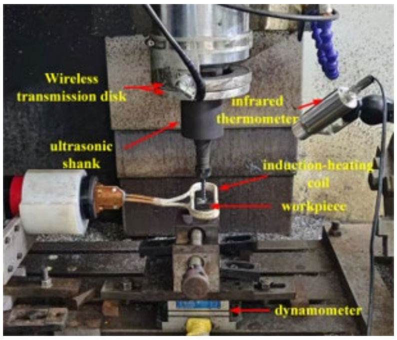

Figure 1. Ultrasonic and temperature field assisted milling platform

3. Analysis of Effect

3.1. Effect of Ultrasonic on Machined Surface Texture

As shown in Figure 2, in order to explore the influence of ultrasonic amplitude on the machined surface texture, ultrasonic machining experiments were carried out under the conditions of ultrasonic amplitude of 0μm and 2μm, and the surface morphology was characterized by laser confocal microscopy image 3D measurement system. The results show that when the ultrasonic amplitude is 0 μm, the surface texture is messy and has no obvious directional characteristics. The surface of the sample only forms a parallel continuous texture consistent with the tool feed trajectory. The texture extends uniformly but has no periodic structure. The overall surface morphology is single and there is no obvious regular fluctuation. When the ultrasonic amplitude is 2μm, the surface morphology changes significantly, and the surface presents a regular periodic stripe texture. The stripe spacing is related to the ultrasonic vibration frequency and feed rate, forming a neatly arranged and evenly distributed grid-like periodic micro-texture. The texture regularity is greatly improved, and there are no obvious defects or local protrusions. Based on the results, it is concluded that in the absence of ultrasonic machining, the coupling effect between the tool and the workpiece is steady-state cutting, and the surface topography is only dominated by the conventional feed cutting trajectory ; in ultrasonic assisted machining, the tool is superimposed with high-frequency micro-amplitude vibration on the basis of feed motion, which is accurately coupled with the plastic deformation behavior of the material after preheating, forming a composite cutting path superimposed by feed trajectory and ultrasonic vibration trajectory, and finally inducing regular periodic micro-texture. This textured surface can effectively improve the friction contact state, surface lubrication performance and change the surface roughness characteristics. It provides favorable conditions for improving the friction and wear performance of parts. The formation mechanism can be attributed to the periodic coupling effect of ultrasonic high-frequency impact and material removal process.

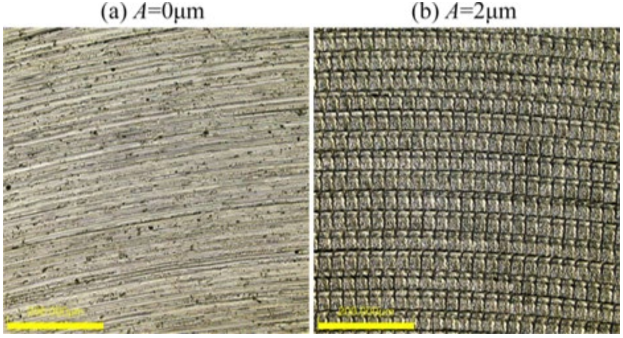
(a) *A*=0μm (b) *A*=2μm

Figure 2. Surface texture of Ti2AlNb based alloy under different ultrasonic amplitude milling treatment

3.2. Effect of Preheating Temperature on Machined Surface Texture

As shown in Figure 3, when the preheating temperature increases from 30°C to 200°C, the surface roughness Sa gradually decreases from 962nm to the lowest point of 730nm. In this temperature range, proper preheating helps to improve the surface texture and make the surface smoother and more delicate. Ti2AlNb alloy is a typical difficult-to-cut intermetallic compound material. It has high strength and relatively poor plastic deformation ability at room temperature, and is prone to ploughing, tearing and local spalling during milling. As the temperature increases, the material undergoes a certain degree of thermal softening, and the tool cutting and material removal processes are more stable, so the surface roughness gradually decreases. When the temperature continues to rise to 300°C, the surface roughness Sa rises sharply to 1237nm. Too high temperature causes the surface quality to become very rough. This may be due to excessive softening of the material, resulting in excessive sticking and thermal deformation, or thermal damage such as oxidation / ablation on the surface of the material.

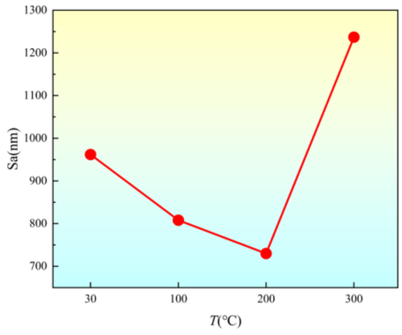

Figure 3. Surface roughness of Ti2AlNb-based alloy under different preheating temperature milling treatment

As shown in Figure 4, when the preheating temperature is 30℃, the surface texture presents a fine but relatively fuzzy periodic grid structure, the regularity of texture arrangement is low, and there are small defects and inhomogeneity in the local area. At this time, the plastic deformation ability of the material is limited, the superposition effect of tool path and ultrasonic vibration in the cutting process is not fully utilized, and the texture quality is general. When the preheating temperature is 100℃, the periodicity and clarity of the surface texture are significantly improved, the grid-like texture is arranged more evenly, the contour is more distinct, and the local defects are significantly reduced. Moderate preheating improves the plasticity of the material, makes the material removal more uniform in the cutting process, the coupling effect between the tool and the workpiece more stable, and the texture quality is obviously optimized. When the preheating temperature is 200℃, the regularity and consistency of the surface texture reach the peak, the grid texture is neatly arranged, the boundary is clear, and there is no obvious defect or distortion, showing a high-quality periodic micro-texture morphology. At this time, the coupling effect of preheating temperature and ultrasonic assisted cutting is optimal, the plastic deformation of the material is accurately matched with the tool trajectory, and the texture quality is the best. When the preheating temperature is 300℃, the surface texture is obviously distorted and coarsened, the grid structure is destroyed, the texture boundary is blurred, and the material accumulation and deformation traces appear locally. Too high preheating temperature leads to excessive softening of the material. During the cutting process, the material is prone to adhesion and uneven plastic flow, the tool path is disturbed, the periodic characteristics of the texture are destroyed, and the forming quality is significantly reduced.

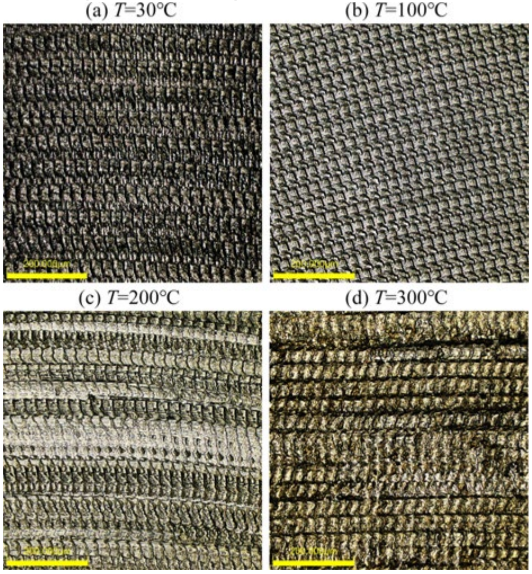

Figure 4. Surface texture of Ti2AlNb based alloy under different preheating temperature milling treatment

4. Conclusion

In this paper, Ti2AlNb-based alloy cladding layer was prepared by laser cladding process using Ti-6Al-4V as the substrate, and ultrasonic vibration and preheating temperature coupling assisted milling experiments were carried out. The effects of ultrasonic vibration and preheating temperature on the surface texture morphology and roughness characteristics of Ti2AlNb alloy were systematically investigated, and the formation mechanism of surface texture under composite process was clarified. The main conclusions are as follows:

(1) Ultrasonic vibration has a significant modification effect on the surface texture. Under the condition of no ultrasonic assisted machining, the milling surface only has the parallel texture formed by the conventional tool feed, no periodic micro-texture, and the surface morphology is single and the regularity is poor. After the introduction of 2μm ultrasonic amplitude, the high-frequency micro-amplitude vibration of the tool and the feed motion form a composite cutting trajectory, which is effectively coupled with the plastic deformation behavior of the material after

preheating and softening. The periodic grid micro-texture with regular arrangement and uniform distribution is generated on the machined surface, which effectively optimizes the surface texture structure, improves the surface lubrication and friction contact state, and provides a good surface basis for improving the friction and wear performance of the component surface.

(2) The effect of preheating temperature on the milling surface quality of Ti2AlNb alloy shows a significant regulation law of first optimization and then deterioration. In the temperature range of 30℃～200℃, with the increase of preheating temperature, the thermal softening effect of the material is enhanced, which effectively improves the difficult machining characteristics of Ti2AlNb alloy, such as poor plasticity at room temperature, easy to produce ploughing and tearing defects, and the stability of the cutting process is significantly improved. The surface roughness Sa is reduced from 962nm to the lowest value of 730nm, and the clarity and regularity of the surface mesh texture are continuously improved. The texture quality is the best at 200°C.

(3) High preheating temperature will seriously deteriorate the surface processing quality. When the preheating temperature rises to 300°C, the material is over-softened, and the cutting process is prone to material adhesion, uneven plastic flow and surface thermal oxidation damage. The tool path is significantly disturbed, and the periodic grid texture is distorted, coarsened or even failed. The surface roughness Sa rises sharply to 1237nm, and the surface defects increase significantly. In summary, within the range of experimental process parameters, the composite processing technology of 200°C preheating temperature coupled with 2μm ultrasonic amplitude can achieve the optimal matching of material plastic properties and ultrasonic cutting effect, and can obtain high-quality machined surface with regular morphology, few defects and low roughness. It is the preferred process combination for milling Ti2AlNb-based alloy cladding layer.

References

[1] Gao G, Xiang Y, Qiao H, et al. Modeling on cutting force considering tool flank wear in ultrasonic vibration-assisted milling Ti3Al[J]. Wear. 2025, 566-567: 205761.

[2] Fan T, Yao C, Tan L, et al. The influence of induction-assisted milling on the machining characteristics and surface integrity of γ-TiAl alloys[J]. Journal of Manufacturing Processes. 2024, 118: 215-227.

[3] Tu L, Zhang Y, Yu Q, et al. Machinability and tool wear mechanism in the high-speed milling of TiAl alloys with different microstructures[J]. Journal of Materials Research and Technology. 2025, 36: 6229-6239.

[4] Wang X, Zhuang B, Wu T, et al. Microstructure evolution characterization of Ti2AlNb intermetallic alloys subjected to side milling[J]. Materials Today Communications. 2025, 42: 111257.

[5] Li G, Zhang F, Hong B, et al. Study on surface properties of heat-treated Ti-6Al-4V alloy after electropulsing-assisted ultrasonic peening[J]. Wear. 2026: 206793.

[6] Wang Y, Gao G, Ming Z, et al. Temperature-controlled ultrasonic vibration assisted machining response and improvement mechanism for Ti2AlNb alloy manufactured by directed energy deposition[J]. Chinese Journal of Aeronautics. 2026: 104091.

[7] Xu D, Shen Z, Zhang K, et al. Material removal and surface formation mechanisms in laser-assisted milling of γ-TiAl alloy[J]. Journal of Materials Processing Technology. 2026, 352: 119319.