Rare Metal Materials and Engineering
Volume 53, Issue 9, September 2024
Available online at www.rmme.ac.cn

Science Press

Cite this article as: Xu Chengyu, Ji Dongfeng, Zhang Yun, et al. Polishing of Titanium Alloy Blade Root with Elastic Magnetic Tool[J]. Rare Metal Materials and Engineering, 2024, 53(09): 2413-2419. DOI: 10.12442/j.issn.1002-185X.20230806.

ARTICLE

Polishing of Titanium Alloy Blade Root with Elastic Magnetic Tool

Xu Chengyu[1], Ji Dongfeng[1], Zhang Yun[2], Zhu Yongwei[1]

[1] College of Mechanical and Electrical Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 211106, China; [2] Department of Mechanical Engineering, Tsinghua University, Beijing 100084, China

Abstract: Removal of milling marks at the root fillet of titanium alloy blade is a tough work because of the interference between the polishing tool and the workpiece. A polishing method based on elastic magnetic tool was proposed. The software ANSYS Maxwell was used to simulate the effect of different pole orientation arrangements on the magnetic field distribution. A comparison of polishing effect was made between elastic and inelastic magnetic pole carriers. The processing parameters of the elastic magnetic tool polishing for the blade root were optimized by orthogonal experiment (Taguchi) method. Results show that compared with the inelastic magnetic polishing tool, the elastic magnetic polishing tool with polyurethane as the pole carrier can effectively improve the surface quality of the polished workpiece. Under the optimal processing parameters (rotational speed=900 r/min, feeding rate=6 mm/min, machining gap=1.5 mm and abrasive size=10−14 μm), the original milling marks at the blade root are effectively removed and the average surface roughness R_a is dropped from 0.95 μm to 0.12 μm, which verifies the feasibility of the elastic magnetic polishing tool in the surface finishing of the titanium alloy blade root.

Key words: titanium alloy blade; root fillet; elastic magnetic polishing tool; processing parameters; surface roughness

As a key component of the aircraft engine, the processing quality of aero-engine blade greatly affects the power performance of the engine, thus affecting the flight performance of the aircraft[1–3]. The blades are usually subjected to large centrifugal force, high temperature, high pressure and high frequency vibration during operation[4–5]. The harsh working environment easily leads to fracture, thermal fatigue, creep failure, etc, at blade root, which causes great damage to the aircraft. Titanium alloy is one of the important materials for aero-engine blades due to its excellent comprehensive mechanical properties. However, the thermal conductivity of titanium alloy material is low. The sharp rise in temperature in the working area during machining leads easily to burns on the surface of the blade, which affects the service life of the blade. In order to ensure mechanical properties of titanium alloy blades[6], it is necessary to improve the fatigue strength of the blade, which is closely related to its surface quality, such as surface roughness, surface residual stress and surface microstructure[7–8].

In recent years, many researchers have studied the influence of aero-engine blade surface roughness on its performance. Suder et al[9] found that the performance deterioration of high-speed axial compressor rotor can be attributed to surface roughness. Alqallaf et al[10] used the computational fluid dynamics tools to simulate the effect of surface roughness on compressor performance, and found that increased blade surface roughness significantly reduces compressor efficiency and affects the performance of the entire thermodynamic cycle. The influence of wall surface roughness on the performance of the axial transonic compressor was studied[11], and it was indicated that the rise in surface roughness of both end wall and blade causes the deterioration of compressor performance. The effect of surface roughness on the profile loss of a high subsonic compressor airfoil at number Re=1.5×10^5 was numerically simulated by Wang et al[12]. The surface roughness mainly determines the loss generation process by affecting the structure of the Laminar separation bubble. The variation trend is similar to that of surface roughness. The

Received date: December 12, 2023
Foundation item: Joint Funds of the National Natural Science Foundation of China (U20A20293)
Corresponding author: Zhu Yongwei, Ph. D., Professor, College of Mechanical and Electrical Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 211106, P. R. China, E-mail: rmeeywzhu@nuaa.edu.cn

abovementioned studies have shown that the surface roughness of the blade plays a key role in the aerodynamic performance of the aero-engine.

Aero-engine blades are usually milled by computerized numerical control machining centers, so it is inevitable to produce uneven milling marks on the blade surface. It is necessary to remove milling marks and to reduce its surface roughness by polishing. Aero-engine blade surface is a 3D free-form surface, and especially the radius of curvature in the chamfer area of the blade root is small. The processing space is narrow. Tool interference is easy to occur during the polishing process of blade root, which makes its processing really tough[13]. A belt grinding method which can obtain longitudinal micro-marks was proposed[14–15]. The grinding path was optimized by means of the "point to point" method, and the surface roughness of the blade root after grinding is less than R_a=0.4 μm. The relationship between the dressing parameters of polishing wheel and the surface roughness of the blade being ground was investigated[16]. The surface quality of the blade root is improved by optimizing the processing parameters. A novel rotary chemical mechanical polishing (R-CMP) for integral impeller was proposed[17]. After R-CMP, the surface roughness R_a of the blade root was reduced from 1.664 μm to 0.559 μm.

Although a few studies have been conducted on the finishing or polishing of blade root fillet, there are still some problems with the polishing of blade roots which are waiting for the solutions[18]. The radius of the blade root fillet is very small. Serious interference will occur during large-area machining, resulting in poor surface quality and surface consistency at the root fillet of blades. In this research, a new polishing tool was designed to ensure non-interference in the machining process and to improve the coverage of the surface area in blade root machining. A new method for polishing blade root fillets based on elastic magnetic tool was proposed, and the influence of its magnetic pole arrangement on the magnetic field distribution was studied. A comparison of polishing effect was made between elastic and inelastic magnetic pole carriers. Based on the robot machining platform, the mapping relationship between processing parameters (rotational speed, feed rate, machining gap and abrasive size) and surface roughness of the workpiece was studied, which may provide a basis for the selection of processing parameters of magnetic polishing of aero-engine blade roots.

1 Design of Magnetic Polishing Tool and Its Magnetic Field

1.1 Structure design of magnetic polishing tool

Axial magnetic poles and radial magnetic poles are often used in magnetic polishing process. The maximum magnetic induction intensity of axial magnetic poles is around 60% of that of radial magnetic poles[19]. The magnetic field lines of radial magnetic pole are distributed along the radial direction, and the magnetic abrasive particles are gathered into brushes at the edge of the magnetic pole, which can not only conduct lapping process but also avoid tool interference between the tool and the blade root surface, so radial magnetic poles were chosen in this study.

In previous studies, the magnetic field distribution state of the magnetic pole was changed by grooving the magnetic pole[20]. But as the usual magnetic material, sintered NdFeB is a hard and brittle material[21]. It is easy to fracture during the grooving process. Therefore, a method of combined pole structure was proposed to design the magnetic field distribution of the magnetic polishing tool. The magnetic polishing tool structure is shown in Fig.1.

1.2 Effect of magnetic pole arrangement of the magnetic polishing tool on magnetic induction intensity

Magnetic induction intensity is a very important factor influencing magnetic polishing processing. The larger the magnetic induction intensity, the more the abrasive grains adhered to the tool and the higher the processing efficiency. The magnetic field lines always start from the N pole and enter the nearest S pole, forming a closed magnetic circuit. In the magnetic field, magnetic abrasives were magnetized and arranged in the direction of the magnetic field lines to form "magnetic brushes". If the position and direction of the N-S magnetic pole are different, the direction of the magnetic field lines are also different, which inevitably affects the polishing pressure direction applied to the workpiece surface. A large magnetic field gradient is conducive to the tumbling renewal of the abrasive, which can improve the self-sharpening of the abrasive, the polishing efficiency and even the surface quality of the workpiece after polishing[22].

Maxwell software was applied to establish a three-dimensional model and to simulate the distribution of the induced magnetic field on the surface of workpiece under different magnetic pole settings. The pole arrangements were N-S-N-S, N-N-N-N, N-N-S-S and N-S-S-N, and the maximum magnetic induction intensities were 3.831, 3.776, 3.771 and 3.776 T, respectively, as shown in Fig.2. When the magnetic poles are set in the form of N-S-N-S, the workpiece is subjected to the action of the N pole and the S pole in turn during the polishing process. An obvious magnetic field strength gradient is formed at the edges of the magnetic poles, and the magnetic induction intensity is the largest. As the magnetic induction intensity increases, the polishing load increases. The polishing efficiency is improved. Fig. 3 shows the distribution of

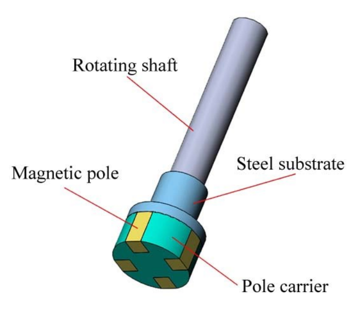

Fig.1 Schematic illustration of magnetic tool

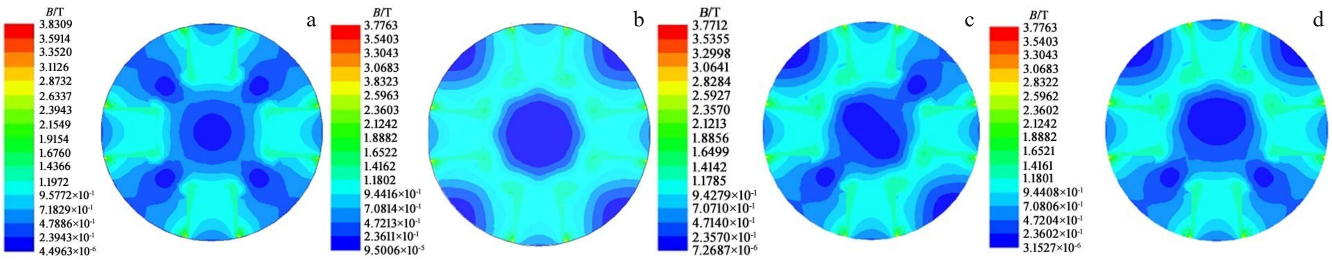

Fig.2 Polar arrangement simulation cloud diagrams: (a) N-S-N-S, (b) N-N-N-N, (c) N-N-S-S, and (d) N-S-S-N

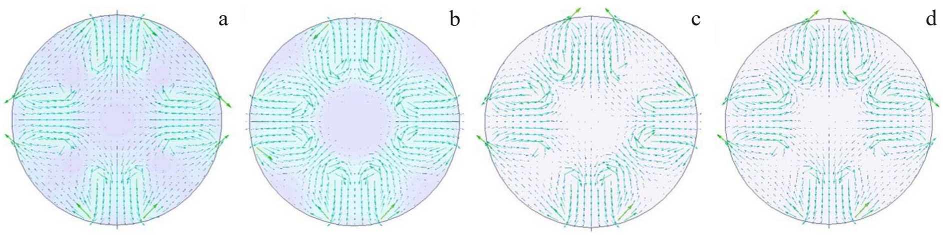

Fig.3 Magnetic field line distribution under different magnetic pole settings: (a) N-S-N-S, (b) N-N-N-N, (c) N-N-S-S, and (d) N-S-S-N

magnetic field lines under different pole arrangements. Under the arrangement of N-S-N-S, a magnetic circuit is formed between each adjacent magnetic pole. The number of magnetic field lines close to the workpiece increases, which is favorable for magnetic polishing processing. Therefore, the N-S-N-S magnetic pole setting can achieve a higher surface roughness improvement rate than other arrangements.

2 Comparison of Polishing Between Elastic and Inelastic Magnetic Tools

In order to study the influence of magnetic pole carrier on the processing effect of engine blade root, both elastic pole carrier and inelastic pole carrier were experimented, with other parameters keeping unchanged. The surface roughness and surface morphology of the blade were set as the indicators.

2.1 Experimental setup and design

The schematic illustration of the magnetic polishing platform for engine blade roots is shown in Fig. 4. The experimental platform is composed of ABB robot, electric spindle, magnetic polishing tool and the workpiece blade. The blade is fixed on the workbench after positioning and the magnetic polishing tool is clamped on the electric spindle. The electric spindle is connected with the robot end effector through the flange. The posture of the tool is adjusted through the robot control program to avoid interference collision between the tool and the workpiece and to keep the machining gap constant between the tool and the workpiece. The tool draws the magnetic particle brush and feeds on the surface of the blade to realize the magnetic polishing of the blade root.

2.2 Experimental conditions

The workpiece was TC4 titanium alloy blade. The rotational speed was 600 r/min, the feed speed of the tool along the blade surface was 10 mm/min, the machining gap between the magnetic tool and the blade surface was about 1 mm, the

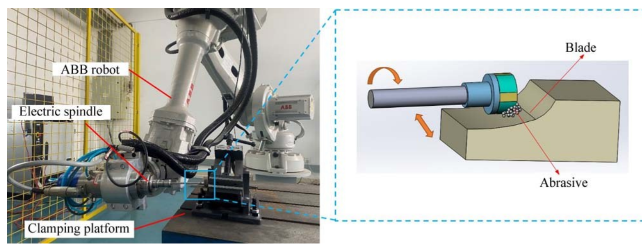

Fig.4 Experiment device and schematic illustration of experiment platform

abrasive size was 10–14 μm, and the processing cycles were 9 times. The radial magnets were made of rubidium iron boron which is a strong magnetic material. The inelastic magnetic tool and the elastic magnetic tools are shown in Fig.5.

As shown in Fig.6, the blade surface roughness was measured at five points perpendicular to the direction of the polishing trajectory using a hand-held roughness measuring instrument and the average value was taken as the evaluation criteria.

2.3 Results and discussion

The surfaces of the blade roots before and after magnetic

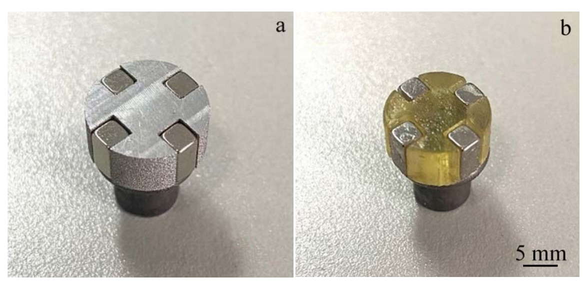

Fig 5 Appearances of inelastic magnetic pole carrier (a) and elastic magnetic pole carrier (b)

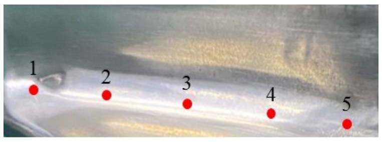

Fig.6 Surface roughness measurement point

polishing are shown in Fig.7. There are obvious scratches, pits and microcracks on the initial surface of the blade root before polishing. After polishing with inelastic magnetic tool, a large number of scratches and pits are removed from the surface of the original blade root. New smaller scratches are formed in the magnetic polishing process in one direction and the surface quality is improved. The magnetic pole carrier of the inelastic magnetic tool is aluminum alloy. Although magnetic brushes have feasibility characteristic, the rigidity characteristics of magnetic pole carrier still affects the accessibility of magnetic abrasives and easily causes a certain difference in the penetrating depth of the abrasive grains into workpiece during processing, resulting in a poor uniformity of the machined surface. The polyurethane elastic pole carrier makes the tool have better flexibility and adaptability. The initial scratches and pits of the workpiece are removed after polishing. There are no obvious defects on the surface. The texture is dense and uniform. The surface quality is significantly improved.

Fig. 8 shows the average surface roughness of blade root after polishing with inelastic and elastic magnetic polishing tools. The fluctuation of surface roughness value among measurement points with inelastic magnetic tool is larger than that with elastic magnetic tool, and the consistency of surface quality is poor. The difference in the surface roughness of the workpiece surface after polishing with the elastic magnetic polishing tool is small and the surface uniformity is good. The average roughness of the blade root after polishing with the inelastic and elastic magnetic tools are R_a=0.246 μm and R_a=0.203 μm, respectively. The elasticity of polyurethane elastic layer plays an important role in magnetic polishing process.

3 Effect of Processing Parameters on Average Surface Roughness of Blade Root

3.1 Experimental setup

The experimental setup and platform are the same as those in Section 2. In this section, orthogonal experiments are used to explore the influence of rotational speed, feed rate, machining gap and abrasive size on the surface roughness of the blade root polished by elastic magnetic polishing tool, so as to obtain the appropriate combination of processing parameters to achieve optimal processing effect. The experimental factors and level parameters are shown in Table 1. There are 4 factors, 3 levels for rotational speed, feed rate and machining gap, and 2 levels for abrasive particle size. The level for those factors is different, so a quasi-level orthogonal experimental design table Lq (3^4) was adopted. In order to ensure the uniformity of the blades root quality of each group of polishing experiments, blade root was fully and evenly polished by sandpaper and the residual abrasive debris on the surface was removed by ultrasonic cleaning. The initial surface roughness of the blade root was R_a=1.115 μm.

3.2 Results and discussion

The influence of processing parameters on the surface roughness was obtained by range analysis. The k_i value represents the average value of the experimental indicators at level i for each factor. The smaller the surface roughness, the better the polishing effect. The results of orthogonal experiments are shown in Table 2.

From the above experiment results, it can be seen that the factors affecting the surface roughness are in the following order: rotational speed>machining gap>feed rate>abrasive size. The optimal combination of processing parameters is as follows: rotational speed=900 r/min, feeding rate=6 mm/min, machining gap=1.5 mm and abrasive size=10–14 μm.

In order to intuitively observe the influence of every factor on the surface roughness of blade root after polishing, the influence of four main processing parameters on surface roughness is plotted according to the orthogonal experiment results, as shown in Fig.9.

The rotational speed and machining gap have a great influence on the surface roughness of blade root. The rotational speed determines the number of actions between the magnetic abrasives and the workpiece. As the rotational speed increases, the number of collisions between the abrasives and the workpiece increases. The extrusion friction effect of the abrasive on the workpiece increases, and a lower surface roughness is obtained. As the rotational speed continues to increase, the roughness increases. This is because the further increase in rotational speed leads to an increase in the centrifugal force of the abrasive grains. When the centrifugal

Fig.7 Comparison of surface morphologies before polishing (a) and polished with inelastic magnetic tool (b) and elastic magnetic tool (c)

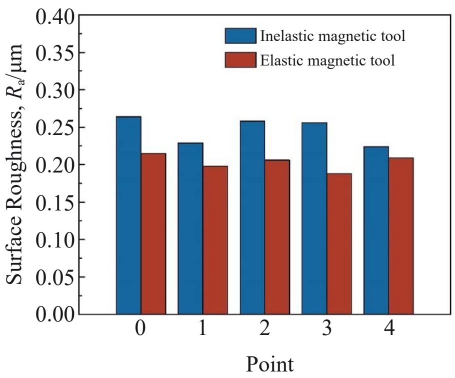

Fig.8 Average surface roughness of blade root after polishing with inelastic and elastic magnetic tools

Table 1 Factors and levels of orthogonal test

Symbol	Factor	Level		
		1	2	3
A	Rotational speed/r·min^{-1}	600	900	1200
B	Feed rate/mm·min^{-1}	6	10	14
C	Machining gap/mm	1	1.5	2
D	Abrasive size/μm	10–14	20–30	10–14

force of a magnetic abrasive grain is greater than its centripetal force, it is thrown away from the processing area.

The surface roughness increases with the increase in feed rate. In the situation that the polishing times keeps unchanged, the feed rate determines the relative movement distance between the abrasive and the workpiece in the unit time. When the feed rate is low, the contact time between the abrasive and the workpiece is sufficient and the trajectory density is large. The surface roughness of the workpiece is reduced. As the feed rate increases, the contact time between the abrasive and the workpiece surface is insufficient, resulting in the inability to completely remove the scratches and pits on the original surface of the workpiece, and the surface roughness of the workpiece increases.

The surface roughness decreases firstly and then increases with the increase in machining gap. When the machining gap is too small, the fluidity, flipping and self-sharpening ability of the magnetic abrasives in the "abrasive brush" are poor. Part of the magnetic abrasives adhere to the magnetic pole end-face and it is not participated in the polishing process, which leads to higher surface roughness. Moreover, the small machining gap enhances the magnetic induction intensity and reduces the length of the "abrasive brush". The load of the magnetic abrasives on the surface of the workpiece increases, and the flexibility of the "abrasive brush" decreases. Prolonged processing time causes the abrasive particles to scratch the surface of the workpiece again. When the machining gap is too large, the magnetic induction intensity in the machining gap is reduced, and the magnetic induction force acting on the magnetic abrasive is weakened. The rigidity of the "abrasive brush" decreases, which reduces the processing capability of the "abrasive brush". Therefore, it is impossible to obtain a lower surface roughness.

The surface roughness increases with the increase in the abrasive grain size. In a unit volume, the smaller abrasive size leads to an increase in the number of "abrasive brushes", which contributes to the flow and tumble of the abrasive. A finer processing texture on the surface of the workpiece is

Table 2 Orthogonal test plan and test results

Test No.	A	B	C	D	Surface roughness, R_a/μm
	Rotational speed/r·min^{-1}	Feed rate/mm·min^{-1}	Machining gap/mm	Abrasive size/μm	
1	600	6	1	10–14	0.185
2	600	10	1.5	20–30	0.188
3	600	14	2	10–14	0.207
4	900	6	1.5	10–14	0.145
5	900	10	2	10–14	0.175
6	900	14	1	20–30	0.169
7	1200	6	2	20–30	0.186
8	1200	10	1	10–14	0.168
9	1200	14	1.5	10–14	0.181
K_1	0.580	0.516	0.522	1.066	
K_2	0.489	0.531	0.514	0.543	
K_3	0.535	0.557	0.568		
k_1	0.193	0.172	0.174	0.177	
k_2	0.163	0.177	0.171	0.181	
k_3	0.178	0.186	0.189		
R	0.030	0.014	0.018	0.004	
Order	A>C>B>D				
Optimal term	A2	B1	C2	D1	

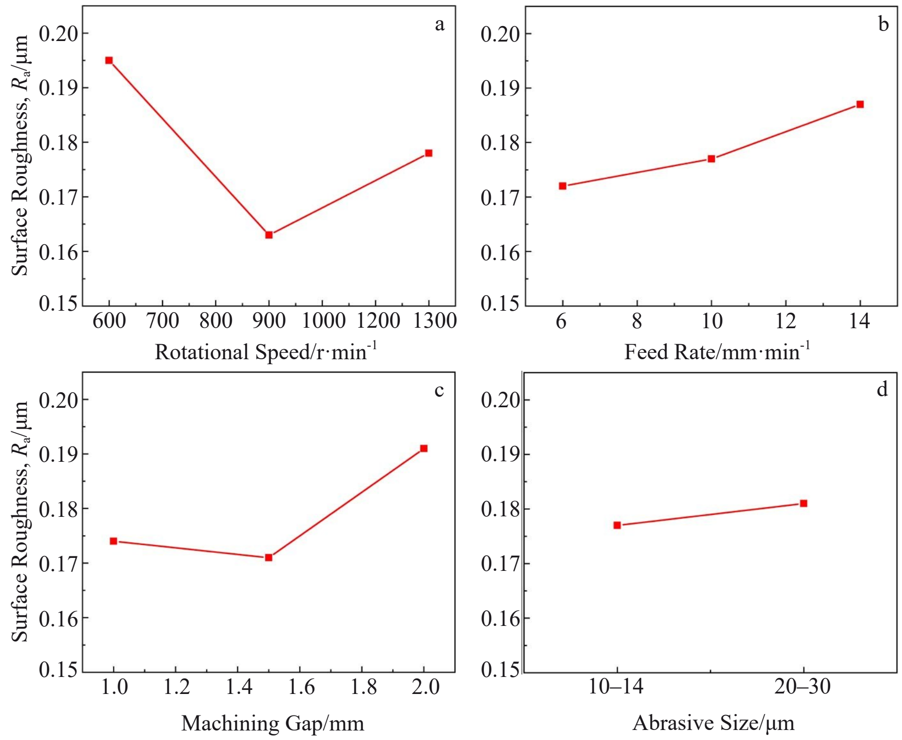

Fig.9 Effect of factors on surface roughness after polishing: (a) rotational speed; (b) feed rates; (c) machining gap; (d) abrasive size

produced, the surface roughness is lower, and the processing effect is better. When the abrasive particle size is larger, more obvious marks are left on the surface of the blade root after the polishing process, resulting in larger surface roughness. Therefore, the previous marks can be removed in the case of keeping other process parameters constant, and the smaller the magnetic abrasive, the lower the surface roughness.

3.3 Verification of optimal processing parameters

According to the analysis results, the optimal combination of processing parameters is as follows: rotational speed=900 r/min, feed rate 6=mm/min, machining gap=1.5 mm and abrasive size=10 – 14 μm. Using this combination of parameters for verification experiment, the appearances of blade root and the surface morphologies of blade root before and after polishing are shown in Fig.10 and Fig.11, respectively.

The blade root surface is relatively flat after polishing and the scratches are lighter. The texture is finer and more uniform. The surface quality is significantly improved. The initial surface roughness of the blade root is R_a=0.95 μm, and it drops to R_a=0.12 μm after polishing, which meets the demand for engine blade root. The initial surface roughness of the blade root in the orthogonal experiment is slightly larger than that in the verification experiment. Therefore, after polishing for the same time under optimized process parameters, the surface roughness of the blade root in the verification experiment is slightly smaller than that in the orthogonal experiment. The surface roughness reduction rate ΔR_a is calculated by the following formula:

$$\Delta R_a = \frac{R_{a_1} - R_{a_2}}{R_{a_1}} \times 100\% \quad (1)$$

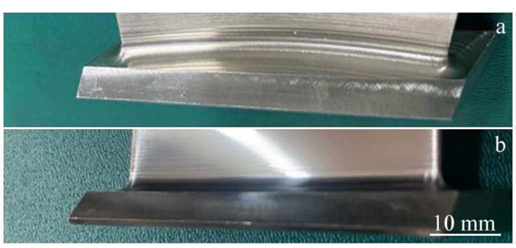

Fig.10 Appearances of blade root before (a) and after (b) polishing

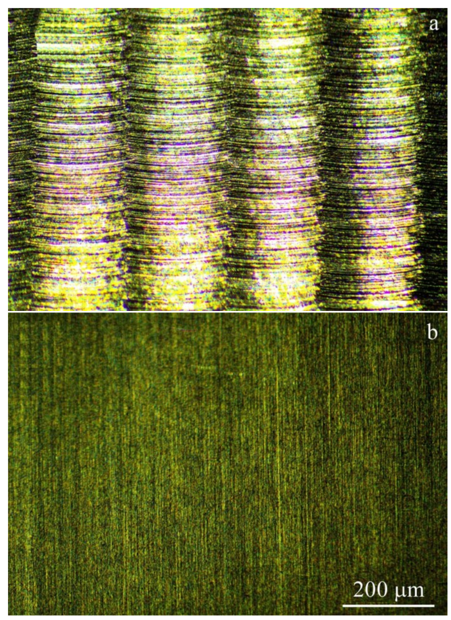

Fig.11 Surface morphologies of blade root before (a) and after (b) polishing

where R_{a_1} is the original surface roughness value and R_{a_2} is the surface roughness value after polishing.

The reduction rate of the surface roughness in the orthogonal experiment and verification experiment is 87% and 87.4%, respectively. The difference between them is minimal. The verification experiment was carried out under the optimal process parameters, the surface roughness of the blade root decreases at the largest rate, and the surface morphology is significantly improved.

4 Conclusions

1) The magnetic pole carrier of the magnetic polishing tool has an important influence on the polishing quality of the blade root. The elastic magnetic polishing tool with polyurethane as the carrier can achieve a lower surface roughness than the inelastic magnetic tool with aluminum alloy as the pole carrier when polishing the titanium alloy blade root.

2) An orthogonal test is conducted to study the effect of influencing factors, including rotational speed, feed rate, machining gap and abrasive size, on the surface roughness in magnetic polishing of blade root. The factors affecting the surface roughness are in the following order: rotational speed>machining gap>feed rate>abrasive size.

3) Under the processing parameters combination of rotational speed=900 r/min, feed speed=6 mm/min, machining gap=1.5 mm and abrasive size=10−14 μm, the surface roughness of the blade root after polishing is the smallest (R_a=0.12 μm). A remarkable improvement in surface roughness is obtained.

References

1 Xiao G J, Huang Y. *International Journal of Advanced Manufacturing Technology*[J], 2015, 83: 1697
2 Zhu Z Q, Zhang Y, Chen Z T *et al. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*[J], 2019, 234: 260
3 Xiao G, Huang Y. *International Journal of Advanced Manufacturing Technology*[J], 2015, 78: 1473
4 Salam I, Tauqir A, Khan A Q. *Engineering Failure Analysis*[J], 2002, 9(3): 335
5 Liu Yankuan, Xu Jing, Li Yao *et al. Rare Metal Materials and Engineering*[J], 2021, 50(5): 1699 (in Chinese)
6 Chen M H, Wu X C, Xie L S *et al. Rare Metal Materials and Engineering*[J], 2019, 48(6): 1717
7 Strahlantriebe I, Bundeswehr U. *J Turbomach*[J], 2000, 122: 416
8 Kong D, Jeong H, Song S J. *Journal Mechanical Science and Technology*[J], 2017, 31: 5329
9 Suder K L, Chima R. V, Strazisar A J *et al. J Turbomach*[J], 1995, 117: 491
10 Alqallaf A, Teixeira J A. *Aerospace*[J], 2021, 8: 330
11 Li Z H, Liu Y M. *Aerospace Science and Technology*[J], 2018, 78: 12
12 Wang M Y, Yang C W, Li Z L *et al. Chinese Journal of Aeronautics*[J], 2021, 34(3): 71
13 Zhao Z C, Qian N, Ding W F *et al. Journal of Manufacturing Process*[J], 2020, 57: 10
14 Xiao G J, Huang Y, Wang J. *International Journal of Advanced Manufacturing Technology*[J], 2017, 95: 797
15 Xiao G J, Huang Y. *IEEE Access*[J], 2019, 7: 28663
16 Żyłka Ł, Babiarz R. *Journal Mechanical Science and Technology*[J], 2017, 31: 4411
17 Liao L X, Zhang Z Y, Meng F N *et al. Journal of Manufacturing Processes*[J], 2021, 66: 198
18 Huai W B, Lin X J. *Sci Prog*[J], 2020, 103(3): 36850420957850
19 Jiao A Y, Zhang G F, Liu W J *et al. Advances in Mechanical Engineering*[J], 2020, 12(6): 168781402093200
20 Qian C, Fan Z H, Tian Y B *et al. International Journal of Advanced Manufacturing Technology*[J], 2020, 112: 619
21 Gao Y W, Zhao Y G, Zhang G X. *International Journal of Mechanical Sciences*[J], 2020, 177: 105601
22 Li W L, Chen Y, Cheng M C *et al. Materials*[J], 2020, 13(6): 1401

弹性磁力工具抛光钛合金叶片叶根

徐成宇[1]，季冬峰[1]，张　云[2]，朱永伟[1]

(1. 南京航空航天大学 机电学院，江苏 南京 211106)

(2. 清华大学 机械工程系，北京 100084)

摘　要：针对钛合金叶片叶根区域铣削纹理难去除、抛光工具与工件易干涉等问题，提出弹性磁力小工具头抛光工艺，实现叶片叶根区域的光整加工。采用有限元软件ANSYS Maxwell仿真不同磁极极向排布对磁场分布状态的影响，比较了弹性和非弹性磁极载体对磁力小工具头抛光叶片叶根的效果；通过正交实验法优化了弹性磁力小工具头抛光叶片叶根的工艺参数。结果表明：与非弹性磁性抛光工具相比，采用聚氨酯作为磁极载体的弹性磁力工具可以有效提高被抛光工件的表面质量。采用最佳加工参数（主轴转速=900 r/min、进给速度=6 mm/min、加工间隙=1.5 mm以及磨料粒径=10~14 μm）对叶片进行抛光实验，叶片叶根处原有的铣削加工纹理被有效去除，表面粗糙度由抛光前的0.95 μm降至0.12 μm。验证了弹性磁力小工具头抛光工艺对实现高质量钛合金叶片叶根表面光整加工的可行性。

关键词：钛合金叶片；叶根倒角；弹性磁力抛光工具；工艺参数；表面粗糙度

作者简介：徐成宇，女，1993年生，博士生，南京航空航天大学机电学院，江苏 南京 211106，E-mail：xcy069@nuaa.edu.cn