

Research on the Remanufacturing Based on Ultrasonic Mechanical Aluminizing and Micro Arc Oxidation

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Abstract. In this research alumina ceramic layer on the surface of workpiece was obtained using ultrasonic mechanical aluminizing and micro arc oxidation to realize remanufacturing. Aluminum layer was gotten on the surface workpiece using ultrasonic mechanical aluminizing method. The theory of ultrasonic mechanical plating was studied. Alumina ceramic layer of high hardness and wear resistance was achieved using micro arc oxidation method. The influence of current density to the characteristic of ceramic layer was investigated. The technology described in this paper can be used for the remanufacturing of worn workpiece.

Introduction

Remanufacturing is a kind of technology to recover the shape, dimension and capacity of the workpieces of degraded products and reuse them. It makes the performance specifications of remanufactured components may achieve or even exceed those of new products from traditional manufacturing through remanufacturing engineering design and a series of advanced manufacturing technology on the basis of capability invalidation analysis and life-span evaluation[1]. Remanufacturing can favorably reduce a large portion of resource and energy consumptions as well as environmental emissions[2].

Surface engineering is the key support technology of remanufacturing[3]. The alumina ceramic layer obtained via micro arc oxidation has the excellent properties of wear-resisting, corrosion-resisting, heat-resisting and high temperature oxidation resisting etc. Remanufacturing can be accomplished by getting alumina ceramic layer on the worn workpiece surface using micro arc oxidation method after aluminum film was plated on the workpiece surface[4].

The methods of aluminizing on workpiece surface are as following: (1)Hot-dip aluminizing. It is carried out under high temperature, of high energy consumption, in which quality of workpiece surface is difficult to control. (2)Thermal spraying. The plating layer of which is porous. (3)Vacuum aluminizing. The equipment of which is expensive and the production efficiency is low. (4) Electroplating. The production efficiency of which is low and can't be implied to quantity production. (5) Mechanical aluminizing.

Mechanical plating is a kind of surface treatment process in which the workpiece as well as metal powders, impingement medium (normally are glass beads), dispersant, accelerant and liquid medium are put into a rotary cylinder, a flow circumstance of impact, rub and grind is formed as the cylinder rotate, therefore the metal powders form plating layer on the surface of workpiece by the effect of mechanical impact and physical and chemical deposition at room temperature and atmospheric pressure [5].

Compared with hot-dip coating and electroplating, mechanical plating has following merits: Firstly, there is no hydrogen embrittlement and annealing softening after mechanical plating. Secondly, mechanical plating is prone to green manufacturing or cleaner production [6]. Finally, mechanical plating is of low cost and high productivity.

Unfortunately, the traditional mechanical plating is not suitable for workpiece of big bulk and of complex shape due to the rolling and collision of the workpieces in the rotary drum during the plating process. It's necessary to reform the mechanical plating method to overcome its above shortcoming. Sergey V. Komarov et al presented a novel method for dry mechanical plating using ultrasonic vibrations [7-8]. In this paper we present a novel wet ultrasonic mechanical plating process by integrating the principles of mechanical plating and ultrasonic shot peening.

Micro-arc oxidation is a kind of new surface modification technology developed on the basis of anode oxidation. Its theory is to carry out discharge of plasma in electrolyte on the surface of aluminum, magnesium, titanium or their alloy, and generate ceramic coating of oxide in-situ through complex reaction of electrochemistry, thermochemistry, and plasma chemistry etc. The ceramic coating of alumina formed through micro-arc oxidation on the surface of aluminum and its alloy has excellent properties of wear resisting, corrosion resisting, heat resisting and high temperature oxidation resisting. The micro-arc oxidation process of aluminum has been used widely because of its above advantages[9].

Anical Aluminizing

During the mechanical plating, tin salt and ferric salt is used to generate driving metals tin and iron or their cations, which can induce aluminum to deposit on the substrate surface of the workpiece. The driving metals remain in the plating layer, distribute in the clearance or boundary of the aluminum powder particles.

The plating layer is a multiphase mixing system which is composed of plating metal powders, driving metals and clearances. The plating metal powder is the main component. Under the dual effects of mechanical and chemical bonds combination of occlusion, plating layer and substrate are bonded together.

In traditional mechanical shot peening, the high speed balls will generate impact loading as they reaching the workpiece surface. This impact loading can be replaced by ultrasonic vibration of the shot pin in ultrasonic shot peening.

The principle of wet ultrasonic mechanical plating is similar to that of ultrasonic shot peening. The ultrasonic vibration system provides power for the impingement medium (glass beads) to produce high speed andpeen the metal powders onto the surface of workpiece to form cladding film.

The Design of Wet Ultrasonic Plating Equipment

The schematic diagram of wet ultrasonic plating equipment is shown in Figure 1. It mainly includes the ultrasonic generator, ultrasonic transducer, amplitude transformer horn, and plating tank.

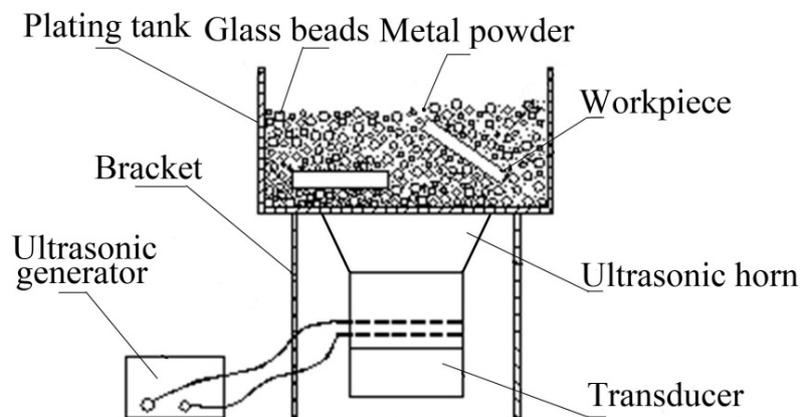


Fig. 1 The schematic diagram of wet ultrasonic mechanical plating equipment

The workpiece, metal powders, impingement medium (glass beads), dispersant, accelerant and liquid medium are placed into a resonant plating tank. The tank is set into a high-frequency vibration

by using an ultrasonic transducer attached to the tank bottom. This initiates a chaotic motion and collision of the glass beads and the powder particles inside the tank that results in the grinding of the particles, thereby hammering them further into the workpiece surface.

The structure of ultrasonic transducer is shown in Figure 2. Piezoelectric ceramic transducer was chosen. In order to satisfy the resonance condition, it is designed that the sum of the thicknesses of rear cover plate, the piezoelectric ceramic slices and electrode equals quarter wavelength of ultrasonic vibration, and the thickness of front cover plate equals quarter wavelength of ultrasonic vibration, i.e. $t_1=63.4\text{mm}$ [10].

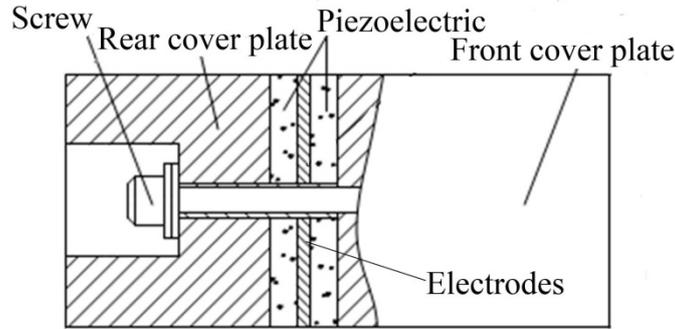


Fig. 2 The structure of ultrasonic transducer

The resonance frequency of the ultrasonic transducer is 20 kHz . The front cover plate is of LY12 aluminum material, its diameter is 60mm , the density $\rho_1=2.7\text{g/cm}^3$, the propagation speed of ultrasonic vibration in it $c_1=5.07\times 10^5\text{cm/s}$. The rear cover plate is of 45 carbon steel material, its diameter is 60mm , the density $\rho_3=7.85\text{g/cm}^3$, the propagation speed of ultrasonic vibration in it $c_3=5.1\times 10^5\text{cm/s}$. The diameter of piezoelectric ceramic slice is 56mm , the diameter of its inner hole is 16mm , the thickness is 6mm , the density $\rho_2=7.5\text{g/cm}^3$, the propagation speed of ultrasonic vibration in it $c_2=3.57\times 10^5\text{cm/s}$. The thickness of electrode $t=3\text{mm}$, its diameter is 56mm .

The thickness of rear cover plate is calculated using following equation:

$$\tan\left(\frac{\omega t_3}{c_3}\right)\tan\left(\frac{\omega t_2}{c_2}\right)=\frac{Z_2}{Z_3} \quad (1)$$

Whereas Z_2 and Z_3 are the impedances of piezoelectric ceramic slice and rear cover plate respectively.

$$\frac{Z_2}{Z_3}=\frac{S_2\rho_2c_2}{S_3\rho_3c_3}; \quad (2)$$

Plug given data into above equations, can get:

$$t_2=16\text{mm}, t_3=15\text{mm}.$$

Experiment Methods

Preparation of Ultrasonic Mechanical Aluminum Coating on Workpiece.

The experiments were carried out using Q235 gasket of the $\phi 22\text{mm}\times\phi 10\text{mm}\times 2\text{mm}$ size as substrate workpieces, using aluminum powder of 800-grit as coating materials, and using glass bead of 40~80 grit as impingement medium. The chemical materials added into the plating tank include activator (sulphuric acid, citric acid), corrosion inhibitor (ammonium dibasic phosphate, ammonium citrate), deposit agent (stannous sulfate), dispersant (polyethylene glycol) and surfactant (lauryl sodium sulfate) etc. The specimens were taken out and washed to be tested after the ultrasonic mechanical plating had lasted for 2 minutes.

The coating thickness was measured using thickness gauge. Average value of five random points on a specimen was calculated and taken as the result. The adhesive strength was examined using following method. Square grids of 1mm on each edge were scratched on the surface of the specimen using a hard steel slide knife with a cutter edge of 30 degree. When the line is scratched, sufficient pressure should be applied to break the covering layer at one time to reach the base metal. Evaluate the adhesive strength according to whether the coating in the lattice is stripped from the substrate. The surface topography of the coating was observed using stereomicroscope.

Micro-arc Oxidation of Ultrasonic Mechanical Aluminum Coating.

The workpiece samples after ultrasonic mechanical aluminum was polished using sand paper of granularity 200, 500 and 1000 respectively, washed in acetone solution using ultrasonic, washed using ethanol, dried and carried out micro-arc oxidation. The schematic chart of the micro-arc oxidation system was shown as Fig. 3. The voltage of the pulse power supply was adjustable from 0V to 600V. The current strength was adjustable from 0A to 20A. The pulse frequency was 1000Hz. The duty ratio of the pulse was 30%. The process time was 5 minutes. The thickness of the coating was measured using film thickness tester of model TT260. The hardness of coating was measured using micro hardness tester of model HVS 1000. The surface roughness of coating was measured using roughness tester of model TR110. The surface appearance of the coating was observed using scanning electronic microscope of model JSM5600LV.

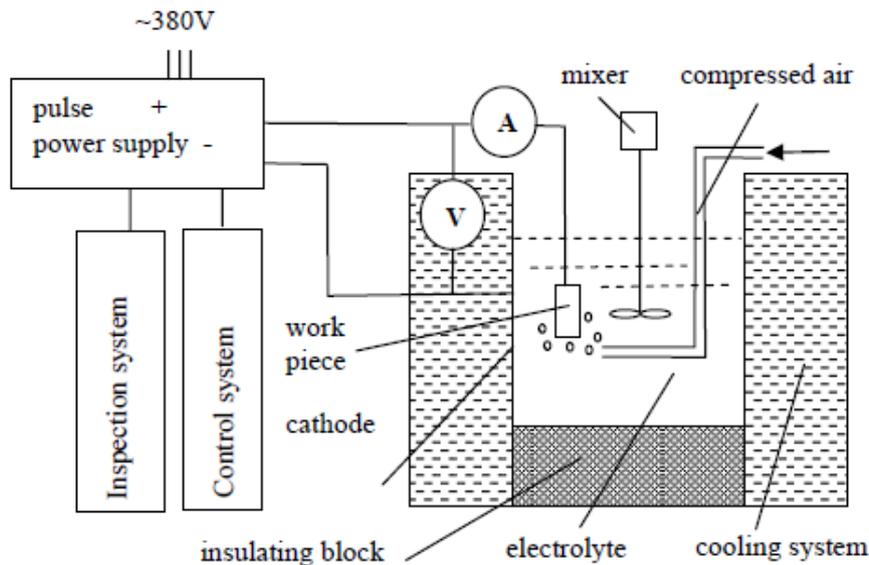


Fig. 3 Schematic chart of the micro-arc oxidation system

Experiment result and analysis

Analysis of Vibration Aided Ultrasonic Mechanical Aluminizing Process.

The thicknesses of the aluminum coating on the workpiece surface are shown in Table 1. The SEM photographs of the aluminum coating surface and the cross section were shown in Figure 4(a) and 4(b) respectively. From above results it can be known that even aluminum coating on the workpiece surface can be achieved via wet ultrasonic mechanical plating. The coating layer is smooth and without flaws such as omission plating, peeling and inclusions.

Table 1 The thickness of aluminum-coating

Number of specimen	1	2	3	4	5
Average thickness(μm)	31.25	32.34	33.85	32.78	33.56

Analyse of Micro arc Oxidation Process.

Experiment results show that the thickness of ceramic layer increases with the increase of current density. The process of micro arc oxidation can be divided into four periods: anode oxidation period, spark discharging period, micro arc oxidation period and arc extinguishment period. The former two have no contribution to the formation of ceramic layer. The lasting time of these periods should be shortened to the least. Micro arc oxidation period takes decisive effect to the quality and thickness of ceramic layer. The lasting time of this period should be prolonged to the longest in order to increase the thickness of ceramic layer. The large the current density is, the shorter is the lasting time of anode oxidation period and spark discharging period, the longer is the lasting time of micro arc oxidation period, and the thicker is the ceramic layer. But the thickness of the ceramic layer would decrease with the increase of current density if the current density is greater than $0.2\text{A}/\text{cm}^2$ because of the chemical and electrochemical dissolution.

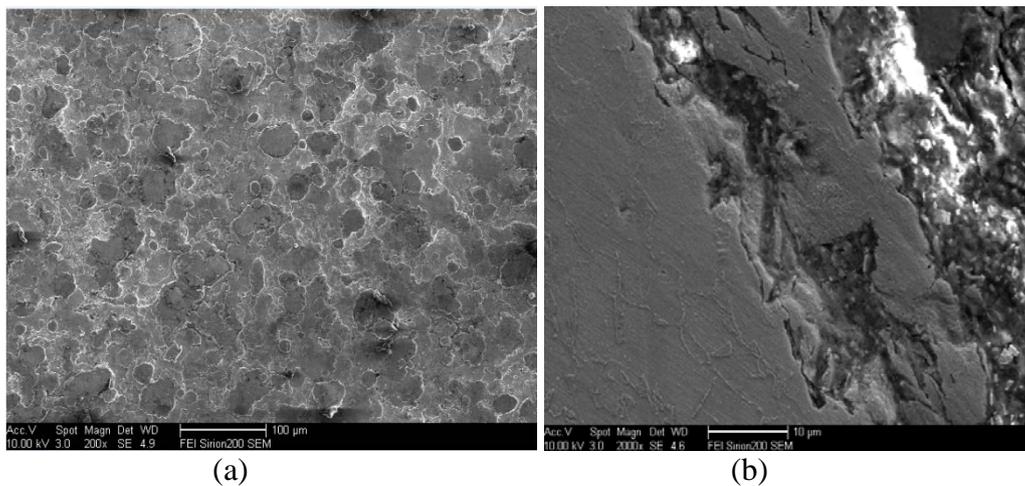


Fig. 4 The SEM photograph of the aluminum coating surface and cross section

The roughness of the ceramic layer surface increases with the increase of current density. The increase of roughness is slowly when the current density is less than $0.1\text{A}/\text{cm}^2$. But it's obviously when the current density is more than $0.1\text{A}/\text{cm}^2$.

The hardness of the ceramic layer increases with the increase of current density. The higher the current density is, the higher are the temperature and pressure in the discharging channels, and the higher is the content of $\alpha\text{-Al}_2\text{O}_3$ phase which has higher hardness. And content of $\gamma\text{-Al}_2\text{O}_3$ phase which has lower hardness is higher when the current density is lower.

Considering the thickness, hardness and surface roughness of the ceramic layer, the optimum current density is $0.1\text{ A}/\text{cm}^2$. The thickness of the ceramic layer achieved under above conditions is $39\mu\text{m}$, the surface roughness is $\text{Ra}1.5\mu\text{m}$, and the hardness is 1100HV . SEM image of the ceramic layer is shown as Fig. 5.

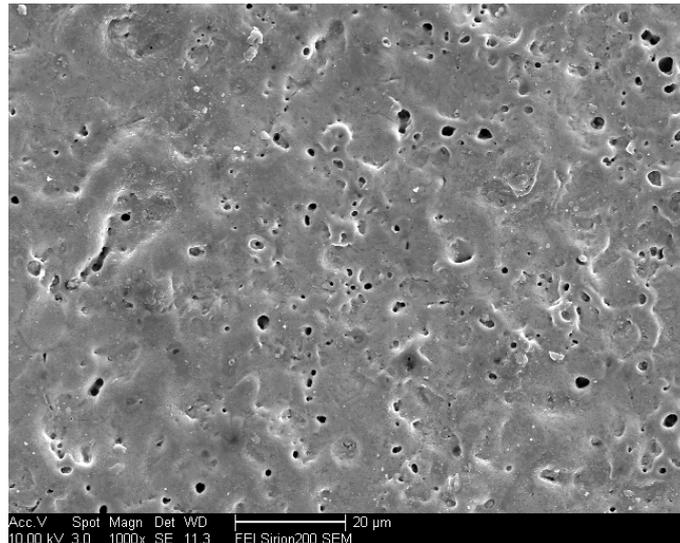


Fig. 5 SEM image of the ceramic layer

Conclusion

The theory of ultrasonic mechanical plating was studied and the ultrasonic mechanical plating equipment was designed. Aluminizing tests were carried out using the equipment. The maximum thickness of aluminum coating layer can reach 30 μm . The aluminum coating layer was converted into alumina ceramics layer via micro arc oxidation. Above processes can realize the remanufacturing of wore workpiece.

Acknowledgments

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References

- [1] XU Binshi, DONG Shiyun, SHI Peijing, States and propects of China characterized quality guarantee technology system for remanufactured parts, *Journal of mechanical engineering*. 49(2013) 84-90.
- [2] Zhichao Liu, QiuHong Jiang , Tao Li, Shiyun Dong, Shixing Yan, Hongchao Zhang ,Binshi Xu, Environmental benefits of remanufacturing: A case study of cylinder heads remanufactured through laser cladding. *Journal of Cleaner Production*. 133 (2016) 1027-1033.
- [3] TAN Jun, CHEN Jianmin, LIU Min, LI Changjiu, JIANG Bailing, Surface Engineering towards Green Manufacturing and Remanufacturing, *Journal of mechanical engineering*. 47(2011) 95-103.
- [4] Niu, Zongwei, Li Zhiyong, Li Li, Zhang, Jiayou; Wang, Aihong, Study on the green remanufacturing of ultrasonic vibration aided hot-dip aluminizing and micro arc oxidation. *Advanced Materials Research*. 139-141(2010) 394-397.
- [5] Wang Shengmin, Zhao XiaoJun, He Mingyi, Research status and development of mechanical plating, *Materials Review*, 31(2017)117-122.
- [6] Wang Shengmin, Liu li, Zhao XiaoJun, He mingyi, Cleaner production of mechanical zinc-plating, *Techniques and equipment for environment pollution control*, v(2003)83-85.
- [7] Sergey V. Komarov, Sang H. son, Naohito Hayashi, Sergey D. Kaloshkin, Oleg V. Abramov, Eiki Kasai, Development of a novel method for mechanical plating using ultrasonic vibrations, *Surface &*

Coatings Technology, 201(2007)6999-7006.

[8] Komarov Sergey V., Son Sang Han, Kaloshkin Sergey D., Kasai Eiki, A dry ultrasonic-based method for mechanical coating, *Reviews on Advanced Materials Science*, 18(2008)691-696.

[9] Wang Xuefei, Zhu Zongtao, Li Yuanxing, Chen Hui, Characterization of Micro-arc Oxidation Coatings on 6N01 Aluminum Alloy Under Different Electrolyte Temperature Control Modes, *Journal of Materials Engineering and Performance*, 27(2018), 1890-1897.

[10] Li Guihua, Zhang Xianghui, Fu Shuigen, Zuo Jing, Gao Ju, Design of ultrasonic transducer with a quarter wavelength composite exponential horn, *Machinery Design&Manufacture*, 5(2009)1-3.