Study on Electrolytic Composite Polishing Process Using Rotating Electrode

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Abstract: Electrolytic composite polishing technology is a special processing technology developed on the basis of electropolishing theory. Essentially, the electrolysis is added to the effect of mechanical polishing in order to improve the polishing efficiency and reduce the loss of the polishing material. However, the control of polishing quality has always been a difficult point in the study of electrolytic composite polishing process. In order to explore the suitable parameters of electrolytic composite polishing process and improve the polishing quality, this experiment designed the experiment of electrolytic composite polishing of 304 stainless steel workpiece. Through the single variable factor experiment, the electrolyte composition, abrasive particle size, interelectrode gap and electrode were respectively made. The variable experiment of the rotational speed and the relative motion speed, by analyzing the experimental result data, the variation law of the univariate factors affecting the polishing quality is obtained.

Keywords: Rotating electrode; Electrolytic composite polishing; Special processing; Polishing quality

1. Introduction

Metal surface polishing is a kind of surface leveling technology. It is one of the processes that have been mastered and applied to production and life since the beginning of human manufacturing activities. It has a long history and the most extensive use. With the development of production conditions, the polishing process that was originally done by hand was gradually replaced by mechanical operation. In modern times, due to the emergence of various chemical agents, scientists began to study the corrosion and dissolution mechanism of metals in chemical media. The theoretical basis of electrochemical machining is Faraday's law proposed by British scientist Faraday in 1833. In the 1930s, electropolishing technology applied to actual processing appeared. In the 21st century, the Fritz-Haber Institute in Germany made submicron electrochemical processing, and electrochemical processing carried out material removal by ion dissolution, making it possible for microfabrication [1].

Electrolytic mechanical composite polishing process is a processing method combining electrochemical processing with mechanical grinding processing. It is an electrochemical etching process that has the advantage of high electrolytic etching efficiency when processing difficult-to-machine materials, and combined with mechanical grinding to make the surface to be glossed [2-3]. Electrolytic mechanical compound polishing processing as a new type of processing technology, compared to pure electrolytic processing, the workpiece surface obtained is better in roughness and higher processing precision. And it is much more efficient than ordinary mechanical polishing, and the surface of the workpiece is strengthened after being processed due to stress removal. Therefore, electrolytic mechanical composite polishing will play an increasingly important role in the field of finishing [4-5].

In order to explore the suitable parameters of the electrolytic composite polishing process and improve the polishing quality, this experiment designed an experiment of electrolytic composite polishing of 304 stainless steel workpieces. Through the univariate factor experiment, variable experiments of electrolyte composition, abrasive grain size, interelectrode gap, electrode speed and relative motion velocity were performed. By analyzing the experimental results data, the variation law of single variable factors affecting the polishing quality is obtained.

2. Electrolytic Mechanical Composite Polishing Processing Experimental System

The machine tool used in the rotary electrode electrolysis composite polishing stainless steel surface processing experiment is independently designed and developed by the research group and is specially used for electrochemical machining. The electrolytic machining machine used in this research institute adopts HNC-08M numerical control system, which can carry out three-axis linkage control and has wide application range. In addition to the electrolytic composite polishing process, it can also be used in electrochemical machining experiments such as electrolytic wire cutting, electrolytic grinding, and electrolytic composite grinding.

As shown in Figure 1, the experimental processing equipment - CNC electrolytic processing machine, including electrolytic power supply, control system, machine tool transmission system, electrolyte filtration system, machine tool body and auxiliary system.

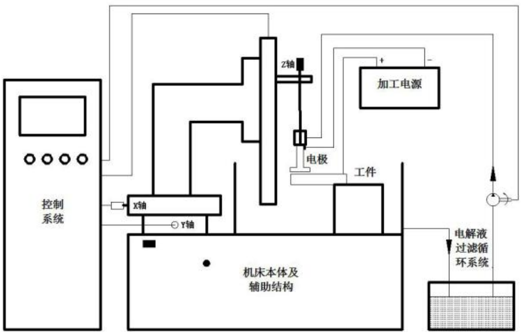

Figure 1. Schematic diagram of composite polishing processing test system

3. Experiment and Analysis

Surface roughness is the basic technical index of polishing processing, and a sophisticated instrument can accurately measure its value, which is convenient for analysis of experimental results. Therefore, we choose surface roughness as its criterion. The main criterion for polishing quality is surface roughness. Due to the electrolysis of the electrolyte, by-products such as by-products may affect the brightness of the surface light. Therefore, the lower the surface roughness of the workpiece after processing under the initial conditions of the same roughness, the better the polishing effect.

Through independent design and development of processing equipment, we carried out experimental research on several important variables of electrolyte composition, abrasive grain size, inter-electrode gap, electrode speed and relative motion speed, and summarized the influence of various variables on electrolytic composite polishing process.

3.1. Determination of experimental conditions for mechanical electrolytic composite polishing

The material preparation for the electrolytic composite polishing process includes the polishing material of the tool electrode, the electrolyte component, the workpiece material, etc. The tool electrode and the workpiece to be machined are made of 304 stainless steel. For the material of the mechanical polishing part, we have selected abrasives with different particle sizes. The single phase electrolyte is selected from sodium chloride, sodium chlorate and sodium carbonate solution.

Based on the experimental materials used and the experimental equipment prepared by the research team, we conducted experimental studies on several important variables such as processing voltage, interelectrode gap, electrode rotation speed, relative movement speed of the electrode, abrasive grain size and electrolyte composition. According to the standard of polishing quality, the influence of each variable on the electrolytic composite polishing process is summarized. Only one cycle pass (going and returning) is performed during the polishing process.

3.2. Effect of electrolyte composition on roughness

In general, sodium chloride has higher electrolysis efficiency than sodium chlorate, and sodium chlorate has higher electrolysis precision than sodium chloride, but the effect of electrolytic polishing on stainless steel remains to be explored. In addition, we also choose sodium carbonate as an additive, added to the sodium chloride and sodium chlorate electrolyte, and also choose to mix sodium chloride and sodium chlorate for electropolishing experiments. Other parameters are as follows: machining voltage 12V, inter-electrode gap 1.5mm, electrode speed 200r/min, relative motion speed 50mm/min, abrasive grain size 1000 mesh. The surface roughness values of the processed workpiece are shown in Table 1 and Figure 2.

Table 1. Processing experimental data of electrolyte components

Experimental group number	Electrolyte component (quality score)	Surface roughness (unit:m)	
		Before processing	After processing
1	8%NaClO3	2.98	1.02
2	8%NaCl	2.50	3.86
3	8%NaClO3+1%Na2CO3	2.68	2.80
4	8%NaCl+1%Na2CO3	2.87	4.12
5	6%NaClO3+2%NaCl	2.70	3.11
6	6%NaCl+2%NaClO3	2.80	3.78

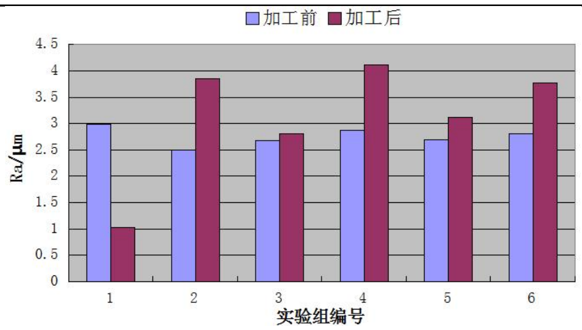

Figure 2. Experimental results of electrolyte component variables

It can be seen directly from Table 1 and Figure 2 that the surface roughness of the first group is reduced by 8% NaClO3, and the roughness of the other groups is not lowered. In particular, in the experimental group containing sodium chloride in the electrolyte component, the roughness increased significantly.

Figure 3. Processing experiment results of experimental groups 2, 5, and 6

The mass fractions of sodium chloride in the electrolytes of the experimental groups 2, 5, and 6 were 8%, 2%, and 6%, respectively. It can be seen from Figure 3 that pits are formed on the surface after processing, and the larger the concentration of sodium chloride, the more pits are pitted. These pits were observed with a metallographic microscope to obtain a metallographic micrograph of Figure 4.

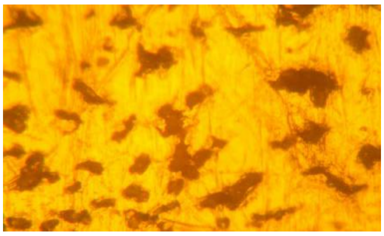

Figure 4. Metallographic microscopic state of pits

It can be seen from the metallographic micrograph that the pits are caused by stray corrosion. At the same concentration, the sodium chloride solution has higher conductivity and higher electrolysis efficiency than the sodium chlorate solution, but due to the large electrical conductivity, the passivation film cannot be formed, and the metal surface is continuously electrolyzed. Even if there is mechanical polishing, the pits and pitting formed by stray corrosion cannot be scraped off.

Figure 5. Processing experiment results of experimental groups 1, 3, and 4

Experimental groups 3 and 4 were processed after adding sodium carbonate. It can be seen from Figure 5 that the electrolytic solution of sodium carbonate mixed with a neutral electrolyte electrolyzes the surface of the stainless steel to make the surface black, forming a dense and difficult to scrape oxide film. It reduces the brightness of the metal surface and deviates from the principle of polishing. In the first set of experiments, the workpieces were electropolished only with sodium chlorate electrolyte, the surface had no stray corrosion on the pits, and there was no black dense oxide. Therefore, we chose a single-phase sodium chlorate solution as the electrolyte for subsequent processing experiments.

3.3. Effect of abrasive grain size on roughness

The abrasive is selected from a diamond polishing paste, which is bonded to a polishing disc, and the number of meshes is selected to be 1000 mesh, 1500 mesh, 2000 mesh, 2500 mesh, and 3000 mesh for processing experiments. Other process parameters are: processing voltage 12V, interelectrode gap 1.5mm, electrode speed 200r/min, relative motion speed 50mm/min, electrolyte composition 8% NaClO3 electrolyte.

After the electrolytic polishing process is completed, the surface roughness and the thickness variation of the five experimental pieces are measured respectively. The recorded data is shown in Figure 6.

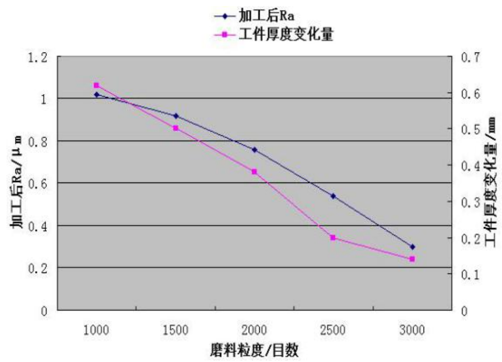

Figure 6. Effect of abrasive grain size on polishing effect

According to the experimental results, the analysis shows that the larger the abrasive grain size, the lower the surface roughness value of the stainless steel workpiece after processing. When the polishing paste with small abrasive grain size is used, the removal efficiency of the workpiece material is high, and the polishing of the workpiece can be removed by one polishing. When electropolishing is performed using an abrasive having a small particle size and a small particle size, it is necessary to perform multiple polishing to remove the turning pattern, which is suitable for finishing. Taking into account the polishing quality and polishing efficiency, we selected 2500 mesh abrasive grain size and performed electrolytic composite polishing experiments of other variables.

3.4. Effect of inter-electrode gap on roughness

After the workpiece and tool electrodes are installed, the zero point of the workpiece coordinate system needs to be corrected. The zero point of the XY axis is the center position of the cylindrical stainless steel workpiece. The zero point determination of the Z axis requires the use of a 0.05 mm feeler gauge to lower the tool electrode into contact with the upper surface of the workpiece and to check the gap with a feeler gauge. If the feeler gauge is clamped, set this point to the Z-axis zero point. The inter-electrode gap is adjusted by the numerical control program, and the Z value is set to 0.5, 1.0, 1.5, 2, 2.5, and 3, respectively, and the running program is subjected to an electrolytic polishing process experiment. Other experimental parameters are as follows: processing voltage 12V, abrasive particle size 2500 mesh, electrode speed 200r/min, relative motion speed 50mm/min, electrolyte composition 8% mass fraction of $NaClO_3$ electrolyte.

The roughness of the stainless steel surface is measured after processing and the dimensional changes before and after the workpiece processing, the data is organized, and the relationship variables are plotted as shown in Figure 7 below:

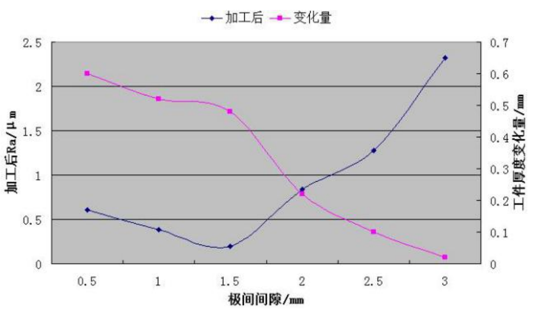

Figure 7. Effect of the inter-electrode gap on the polishing effect

It can be seen from the figure that the inter-electrode gap is nonlinearly related to the surface roughness value after polishing of the workpiece, and the variation of the inter-electrode gap causes a minimum value of the processed Ra. The reason for this phenomenon is that when the inter-electrode gap is less than 1 mm, the pressure of the tool electrode on the machined surface is large. Although the blade left by the cutting process can be quickly removed, at the same time, since the mechanical polishing effect is greater than the electrolysis, the surface of the workpiece is left with scratch marks, which affects the surface roughness value. Therefore, it is necessary to find a gap that balances mechanical polishing and electrolysis. In several experiments, the polishing effect was best when the gap was 1.5 mm, and the removal efficiency of the material was also high. When the gap is increased to 2.5 mm or more, the workpiece size is basically unchanged, and the polishing effect is not obvious. It shows that the tool electrode has less contact with the surface of the workpiece at this time, the pressure is small, the mechanical polishing does not function, and the workpiece cannot be polished effectively by electrolysis alone.

3.5. Effect of electrode speed on roughness

Electrode rotation speed is an important variable in electrolytic compound polishing. The range of mechanical polishing wheel speed is usually 100-300 rpm. Therefore, we chose the electrode speeds of 150, 200, 250, 300, and 350 for processing experiments. Other experimental parameters are as follows: processing voltage 12V, abrasive particle size 2500 mesh, inter-electrode gap 1.5mm, relative motion speed 50mm/min, electrolyte group is 8% mass fraction of $NaClO_3$ electrolyte.

The roughness of the stainless steel surface is measured after processing, the data is organized, and the relationship variables are plotted as shown in Figure 8 below:

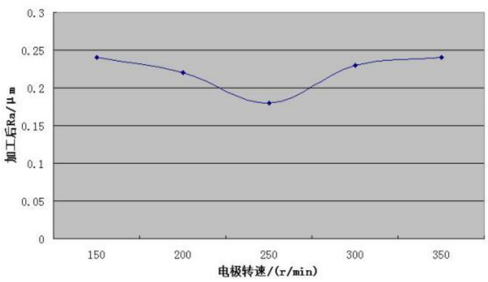

Figure 8. Effect of the inter-electrode gap on the polishing effect

Analysis of the experimental results shows that the influence of the change of the rotational speed of the electrode on the surface of the electrolytic composite polished stainless steel is not obvious in the range of the commonly used mechanical polishing speed. However, it can be seen from the figure that when the electrode rotation speed is 250 rpm, the Ra value after polishing is the smallest, and the influence of the electrode rotation speed on the polishing quality is low relative to other variables. The relationship between the electrode speed and the relative motion speed of the electrode and the workpiece is high, and it is necessary to comprehensively study the influence of the changes of these two variables on the effect of the electrolytic composite polishing process.

3.6. Effect of relative motion speed on roughness

The relative movement speed of the electrode and the workpiece refers to the running speed of the trajectory of the tool electrode during the electropolishing process, which can be set by a numerical control program. The feed rate of electrolytic polishing is generally below 100mm/min, so we chose 20, 30, 40, 50, 60, 70mm/min for the experimental study of electrolytic polishing of 304 stainless steel. Other experimental parameters are as follows: processing voltage 12V, abrasive grain size 2000 mesh, interelectrode gap 1.5mm, electrode speed 250r/min, electrolyte component 8% mass fraction of $NaClO_3$ electrolyte.
The roughness of the stainless steel surface is measured after processing, the data is organized and the relationship variables are plotted as shown in the following 9:

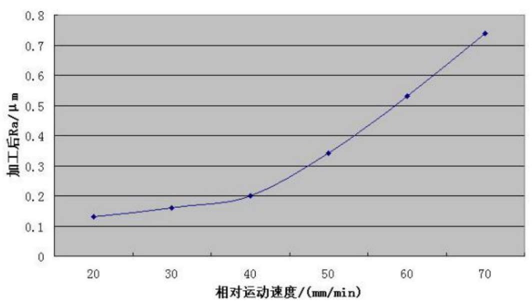

Figure 9. Effect of relative motion speed on machining effect

It can be seen from the change of the surface roughness value in the figure that the lower the running speed of the tool electrode during processing, the lower the surface roughness and the better the polishing quality. The reason for this phenomenon is that the moving speed of the electrode is low, the closer the trajectory of the electrode is, and the more fully polished the metal surface is, the better the surface effect is. However, the moving speed of the electrode is not as low as possible. Under certain voltage and electrode speed conditions, the moving speed of the electrode is too low, and the electrolytic polishing product cannot be eliminated in time, and a short circuit is likely to occur. It burns the surface of the workpiece, leaving traces of electrolysis. Therefore, under the condition that the electrode rotation speed and the voltage are constant values, the moving speed of the electrode has a minimum value. Considering that the smaller the moving speed of the electrode, the longer the processing time, we chose 30mm/min as the relative moving speed of the electrode for subsequent processing experiments.

3.7. Effect of machining voltage on roughness

According to Faraday's law of electrolysis, the processing voltage is a variable that can be quantitatively analyzed in electrolytic processing. In general, the larger the processing voltage, the stronger the electrolysis ability and the higher the material removal efficiency. At the same time, the number of electrolytic by-products increases, and the greater the stray corrosion, the less easily the amount of electrolyte is controlled. And for different electrolyte components, the applicable voltage is also different. Therefore, under the existing experimental conditions, we chose to carry out the processing experiment of electrolytically polishing stainless steel metal surface by increasing the voltage range of 5-15V by 1V. Other experimental conditions were as follows: relative motion speed 30 mm/min, abrasive particle size 2500 mesh, interelectrode gap 1.5 mm, electrode rotation speed 250 r/min, electrolyte composition 8% mass fraction of $NaClO_3$ electrolyte.
After the end of the experiment, the surface roughness and dimensional change of the workpiece were measured, and the data was recorded and plotted. The relationship between the variables is shown in Figure 10:

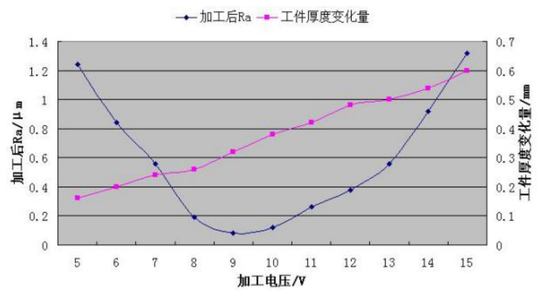

Figure 10. Effect of processing voltage on electrolytic composite polishing

According to the surface roughness and dimensional change of the workpiece after machining, it can be seen that the larger the voltage, the greater the thickness variation of the workpiece, which is consistent with the theoretically deduced conclusion. It shows that electrolytic composite processing also follows the basic law of electrolytic processing, and the amount of metal dissolved in the anode workpiece is proportional to the electrical voltage. However, for the surface roughness value of the workpiece, when the machining voltage is varied within the range of 5 to 15 V, Ra has an extreme value. For this phenomenon, the reasonable reason we summed up is: when the voltage is small, the electrolysis of the workpiece is weak, and only the mechanical polishing effect of the abrasive grains on the polishing disc is weak for the polishing effect of 304 stainless steel. When the voltage is increased, the electrolysis is enhanced, the passivation film is formed stably, and the surface electrolysis and mechanical polishing of the workpiece are cyclically performed, and the surface roughness after processing is lowered. When the voltage continues to increase, the electrolysis is greater than the mechanical polishing effect, the by-products increase, the surface of the workpiece becomes grayish and dark, the stray corrosion increases, and pits appear on the surface. The scraping effect of the abrasive grains alone cannot effectively remove the pits, thereby increasing the surface roughness.

4. Conclusion

In this paper, the surface of 304 stainless steel was electrolyzed and polished by an independently designed electrolytic processing machine. The following conclusions were obtained through experiments.

Electrolytic mechanical composite processing is effective in improving the surface quality and processing efficiency of the workpiece. The composite polishing process relies on electrolytic etching to remove most of the machining allowance, so that the surface roughness is rapidly reduced. The mechanical grinding action is used to scrape off the passivation film generated during the electrolysis process, and the surface roughness of the workpiece is further reduced to achieve a polishing effect.

In the processing experiments, the electrolyte composition has the most significant effect on the polishing quality. Under the same conditions of other process parameters, the electro-polishing processing experiments under different electrolytes have obvious differences in surface topography. Experimental studies of other process parameters such as processing voltage, inter-electrode gap, and electrode speed are essentially finding parameters that balance electrolysis and mechanical polishing. Keeping the surface of the workpiece in the electrolytic composite polishing process, the electrolysis-passivation film formation-mechanical polishing-electrolysis cycle process is stable. After a series of processing experiments, it is found that there is a difference in the surface roughness of the workpiece side by electro-mechanical composite processing and the gradual increase of the pole speed is close to the maximum speed, which will cause the head portion of the system to vibrate. In turn, the polishing quality of the workpiece is affected. For this purpose, further research is needed on the electrolytic mechanical composite processing equipment to improve the processing performance of the equipment, thereby obtaining more processing precision and surface quality.

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