Study on magnetic abrasive finishing combined with electrolytic process

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Abstract. In order to improve polishing efficiency of magnetic abrasive finishing (MAF) for polishing metal material, we proposed an effective plane magnetic abrasive finishing combined with electrolytic process. The polishing efficiency of stainless steel SUS304 surface can be improved about 50% by electrolytic magnetic abrasive finishing (EMAF) that has been reported in previous research. The hardness of workpiece surface can be reduced since passive films are generated on the machined surface by electrolytic process. Simultaneously, the generated passive films can be easily removed by friction between magnetic particles and workpiece generated mechanical machining force. Therefore, MAF process combined with electrolytic process can significantly minimize the surface roughness in a shorter finishing time. In this study, we focused on researching the combinations of the first finishing step (EMAF step) time and second finishing step (MAF step) time for EMAF process. The optimal experimental results of EMAF process showed that the surface roughness R_a can be reduced to less than 30 nm at 4 min first finishing step, the surface roughness R_a can be reduced to 20 nm at 10 min second finishing step. Furthermore, we also analyzed experimental results through observing the change in size of mixed magnetic abrasive.

Introduction

With the development of magnetic abrasive finishing technology, MAF process has been widely used to polishing flat, spherical surface, cylindrical surface and workpiece of complex shaped and so on. In recent years, the researchers not only optimized and improved the parameters of magnetic abrasive finishing, but also engaged in the research of magnetic abrasive finishing combined with a variety of processes in order to improve surface polishing quality and polishing efficiency. Among them, Zou et al. developed magnetic abrasive finishing combined with electrolytic process methods for respectively polishing plane workpiece and internal surface of tube. A large number of experimental results indicate that the polishing efficiency and surface polishing quality can be improved through magnetic abrasive finishing combined with electrolytic process for finishing metal material [1, 2]. Pulak. M. Pandey et al. used experimental investigations to show that the chemo assisted magnetic abrasive finishing is effective [3]. Amit Singh et al. reported the quantitative improvement in material removal and surface finish in EMAF has been compared with MAF for a stipulated time period through comparative experiments [4].

If the compound machining time is too long or too short, it will affect the polishing efficiency. This study focused on investigating the combination of the first finishing step (EMAF step) time and second finishing step (MAF step) time for EMAF process. Since passive films generated on surface by electrolytic action in EMAF step, the hardness of passive films is smaller than the hardness of stainless steel SUS304 material [5, 6]. However, the generated passive films will be too thick if the EMAF step time is too long; the generated passive films will be too thin if the EMAF step time is too short. Too thick passive films can't be completely removed by magnetic brush in EMAF step, and too thin passive films can't completely remove protruding portions of workpiece surface in EMAF step. The above two cases will reduce polishing efficiency. Hence, it is essential to find the optimal matching conditions of passive films generated rate and MAF removal rate for EMAF process. After each polishing step, the surface roughness is measured by contact roughness meter (Mitutoyo), the surface profile is evaluated through 3D non-contact optical profiling microscopy (Wyko, Vision NT1100), and scanning electron microscope (SEM, HITACHI S4500).

Basic polishing principle of EMAF process

In this research, the EMAF process includes two finishing steps which are 1st finishing step (EMAF step) and 2nd finishing step (MAF step). The schematic of stainless steel plane processing system is shown in Figure 1. When turning on DC constant voltage power, the protruding portions of workpiece surface will be preferentially leveled and the passive films will generate on the workpiece surface by electrolytic process. Simultaneously, using the magnetic abrasive particles of magnetic brush to exert friction on the workpiece surface, the passive films can be easily removed in the 1st finishing step. It can be considered that electrolytic function takes a primary effect to remove material and decrease hardness of workpiece surface; MAF process is used to effectively remove generated passive films in the 1st finishing step. However, MAF process can't completely remove generated passive films from electrolytic process in the 1st finishing step. Thus, MAF step as the 2nd finishing step is very necessary to be performed after the 1st finishing step, in order to realize efficient precision polishing of workpiece surface.

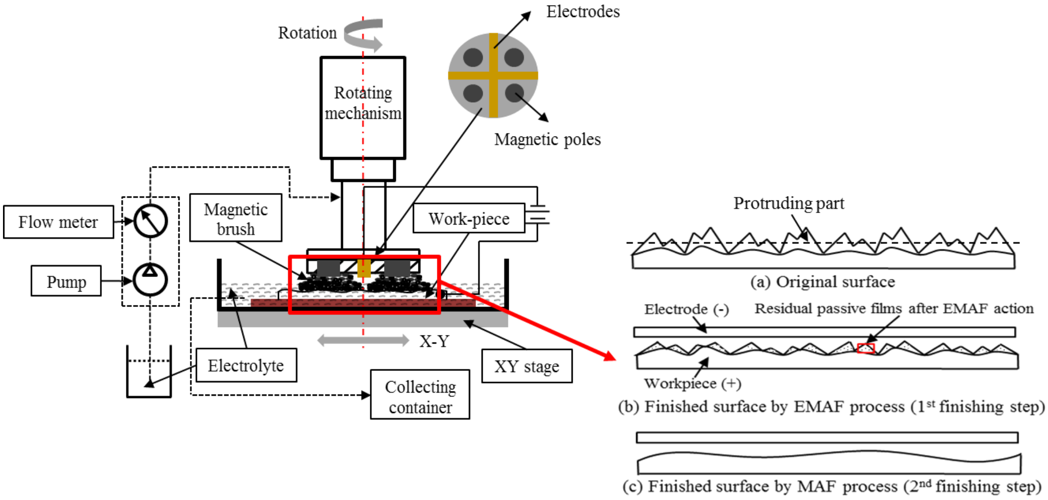


Fig. 1 Schematic of stainless steel plane polishing system

Experimental results and discussions

The detailed experimental conditions of EMAF process were decided and shown in Table 1. The original surface roughness R_a of workpiece was approximate 0.16 ~ 0.2 μm. The mixed magnetic abrasive consisted of quantitative electrolytic iron powder with 149 μm in mean diameter and quantitative #8000 WA particles. The working gap was adjusted to 1 mm, the rotational speed of complex machining tool was selected at 450 rpm, and the feeding speed of X-Y stage was adjusted to 5 mm/s. The working voltage was selected at 12 V. The $NaNO_3$ electrolyte concentration was selected as 20 wt%. The total finishing time of EMAF process was selected at 30 min. We focused on investigating the combinations of the first finishing step time and second finishing step time for EMAF process, in order to obtain optimal polishing effect. The combinations of total finishing time were respectively 2 min (EMAF step) + 28 min (MAF step), 4 min (EMAF step) + 26 min (MAF step), and 6 min (EMAF step) + 24 min (MAF step). The finished surface was respectively measured and observed after EMAF step, each 10 min MAF step and remaining time of MAF step.

Table 1 Experimental conditions of EMAF process

Workpiece	SUS304 plane (100 × 100 × 1 mm)
Original roughness	0.18 ~ 0.2 μm
Mixed magnetic abrasive	Electrolytic iron powder: 149 μm
	WA particles: #8000
	Oily grinding fluid
Working gap	1 mm
Feeding speed of stage	5 mm/s
Rotational speed of tool	450 rpm
Working voltage	12 V
Electrolyte concentration	20 wt% ($NaNO_3$)
Polishing time (30 min)	2 min (EMAF) + 28 min (MAF) 4 min (EMAF) + 26 min (MAF) 6 min (EMAF) + 24 min (MAF)

Figure 2 showed the change in roughness R_a and material removal M as a function with different EMAF processing time. Through comparing the experimental results of EMAF process under different combinations of EMAF step time and MAF step time, it can be noted that the surface roughness R_a drastically decreased in the EMAF step, the material removal M in the first finishing step was obviously more than the material removal M in the second finishing. Furthermore, the optimal experimental result of EMAF process showed that the surface roughness R_a can be reduced to less than 30 nm at 4 min EMAF step, the surface roughness R_a can be reduced to 20 nm at 10 min MAF step. In other words, the optimal surface accuracy can be obtained at 14 min EMAF process under the combination condition of 4 min EMAF step and 26 min single MAF step.

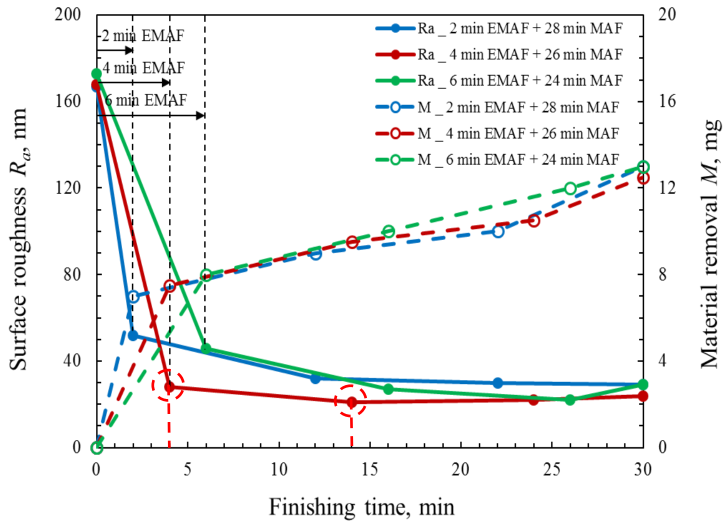


Fig. 2 Change in surface roughness R_a and material removal M as a function with different EMAF processing time

The non-contact 3D measurement of unfinished surface and finished surface after two different finishing steps under the combination condition of 4 min EMAF step and 26 min MAF step were shown in Figure 3. It can be regarded that the protruding part of original surface can be rapidly removed after the EMAF step through the obtained macroscopic confocal image. However, some deep concave hairlines still retained on the finished surface after the first finishing step. Then, it can be found that the depth of residual concave hairlines obviously became shallow after the MAF step through the obtained macroscopic confocal image. Moreover, the number of scratched hairlines on the finished surface slightly increased after the second finishing step. It is because that the finished surface was excessively polished by magnetic brush in order to completely remove residual concave hairlines.

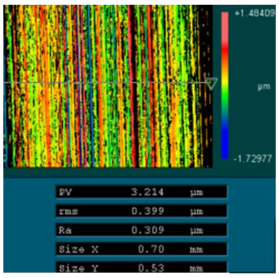
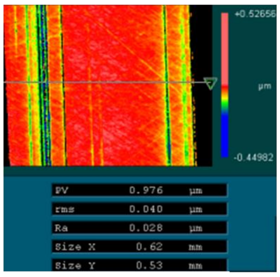
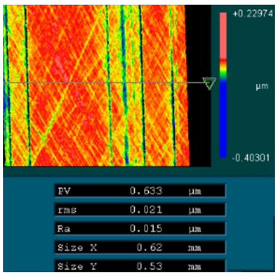
Before finishing	After first finishing step (EMAF step)	After second finishing step (single MAF step)
		

Fig. 3 Non-contact 3D measurement of unfinished surface and finished surface after two different finishing steps under the combination of 4 min EMAF step and 26 min MAF step case

Through single electrolytic process experiment, we analyzed why the high polishing efficiency can be achieved in EMAF step. Figure 4 showed the SEM images under the conditions of different electrolytic process time at 12 V voltage. It can be clearly found that the numbers of micro-porous increased with electrolytic process time increased at 12 V voltage conditions; the depth of micro-porous also became deepen with electrolytic process time increased at 12 V voltage conditions; the surface morphology also changed dramatically with electrolytic process time increased at 12 V voltage conditions. After that, we also measured the hardness of finished surface. Figure 5 showed the change in surface hardness under the conditions of various electrolytic process time at 12 V voltage. It can be seen that the surface hardness decreased with electrolytic process time increased, and the surface hardness can be maximally reduced by 15 % at 6 min electrolytic process under 12 V voltage conditions. Through the results of observing SEM images and measuring surface hardness, it can be regarded that the electrolytic process not only can polish workpiece surface, but also can decrease hardness of workpiece surface. In other words, the electrolytic process played major roles to quickly remove protruding part of surface and decrease the machinability of metal surface.

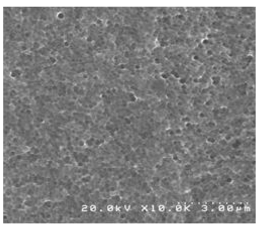
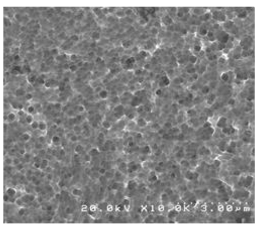
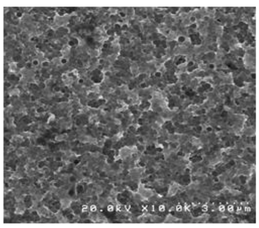
	2 min	4 min	6 min
12 V			

Fig. 4 SEM images under the conditions of different electrolytic process time at 12 V voltage

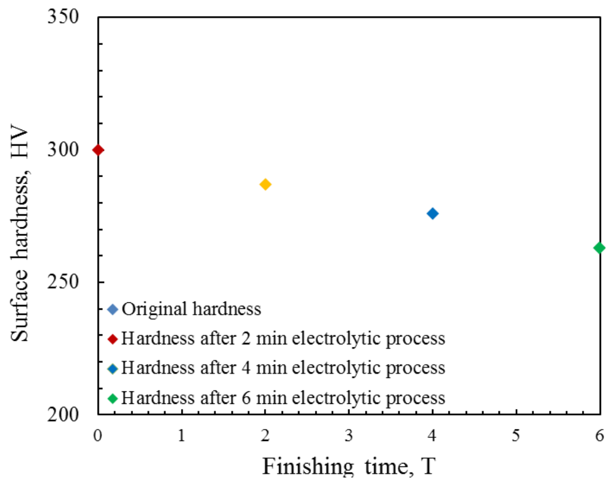


Fig. 5 Change in surface hardness under the condition of various electrolytic process time at 12 V voltage

When the magnetic brush polished workpiece, the iron powder contacted with workpiece, the iron powder can be considered as anode. Thus, the iron powder was consumed with the chemical reactions occurred. Figure 6 showed the change in size of mixed magnetic abrasive under the conditions of different EMAF step time at 12 V voltage. It can be considered that the size of mixed magnetic abrasive drastically decreased with EMAF step time increased at 12 V voltage conditions. Combined with the above electrolytic process experimental results, it is easy to understand why the optimal surface accuracy can be obtained under combination of 4 min EMAF step and 26 min MAF step condition. Since electrolytic action was not enough in 2 min EMAF step and the size of mixed magnetic abrasive drastically decreased in 6 min EMAF step, polishing efficiency was low in 2 min and 6 min EMAF step. Thus, 4 min EMAF step was considered as the optimal finishing time for EMAF process. Generated passive films from electrolytic process can be maximally removed in 4 min EMAF step.

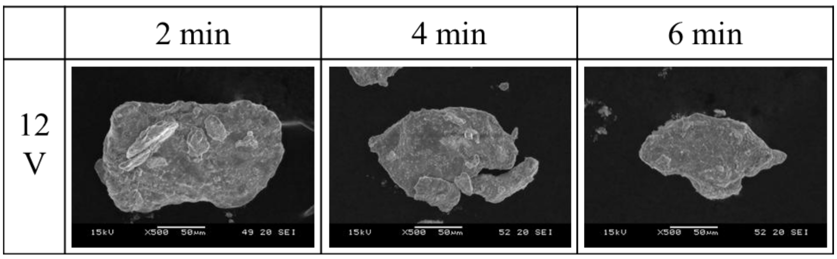


Fig. 6 Change in size of mixed magnetic abrasive under the conditions of different EMAF step time at 12 V voltage

Moreover, we also respectively measured homogeneity of surface materials after electrolytic process and EMAF process by EDX spectroscopy. The composition of original surface was shown in Figure 7 (a). Figure 7 (b), (c) respectively showed that the composition of finished surface through electrolytic process and EMAF process. Through comparing Figure 7 (a) and Figure 7 (c), it can be regarded that the composition of finished surface by EMAF process were similar to the composition of original surface. It is because the generated passive films have been completely removed by EMAF process. However, Figure 7 (b) showed that the composition of finished surface through electrolytic process were significantly different from the composition of original surface. Since a large amount of metal ions dissolved out from workpiece surface under electrolytic action and passive films generated on workpiece surface, it was main reasons for that the content of “Fe”, “Cr” elements during electrolytic process was less than the content of original surface composition; the content of "O" elements during electrolytic process was more than the content of original surface composition.

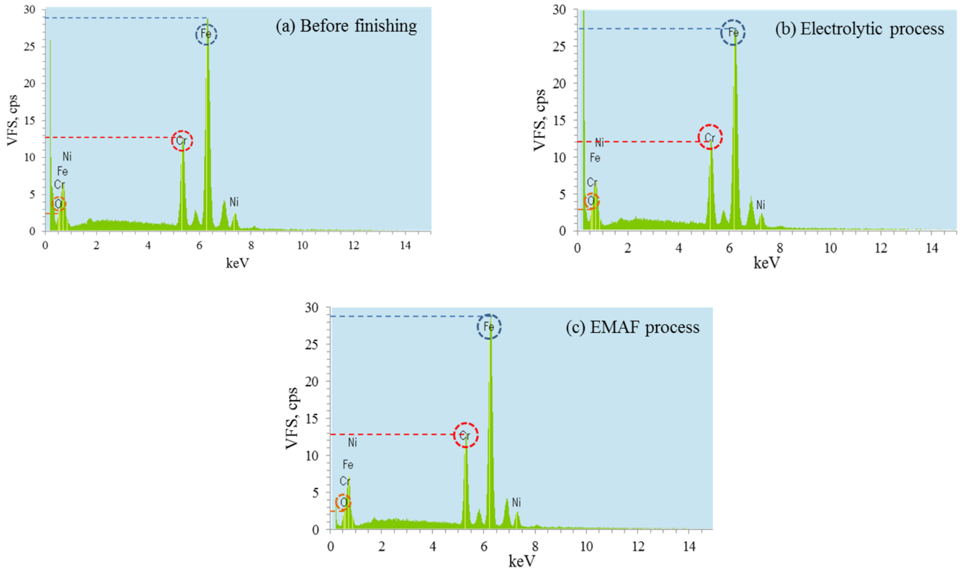


Fig. 7 EDX of original surface and finished surface after different finishing processes

Summary

This paper focused on researching the combinations of EMAF step time and MAF step time for EMAF process. The main conclusions were summarized as follows:

1. The optimal surface accuracy can be obtained at 14 min EMAF process under combination of 4 min EMAF step and 26 min MAF step condition through comparing experimental results of EMAF process.
2. Experimental results of EMAF process were analyzed and explained through single electrolytic process experimental results and the observed change in size of mixed magnetic abrasive under different EMAF step time at 12 V voltage conditions.
3. Moreover, it can be seen that the composition of finished surface by electrolytic process were significantly different from the composition of both original surface and EMAF process through analyzing EDX spectroscopy of main elements.

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