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The Study on Burr Removal Rate Along the Cutting Radial Distance in U-type Flow Channel

Chul-Bae Son*, Jung-Hee Lee**, Jae-Seob Kwak**,#

*Hanguk Precision Co., LTD., **Department of Mechanical Engineering, Pukyong National Univ.

절삭 반경에 따른 U-type 유로 형상의 버 제거율에 관한 연구

손출배*, 이정희**, 곽재섭**,#

*한국정밀(주), **부경대학교 기계공학과

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ABSTRACT

As increasing demand for precise machining in advanced disciplines, especially in semi-conductor, aeronautical and automotive industries, the magnetic abrasive deburring(MAD) which is able to eliminate micro-sized burr on complex surface in less time has drawn the attention in the last decades. However, the performance of MAD is subject to shape and size of a tool. Therefore, this study aim to identify deburring behavior of MAD in U-type flow channel by measuring the length rate of burr removal in radial distance of the cylindrical tool under four process factors. In order to evaluate the deburring effect of MAD on the surface, finishing regions are divided based on center of the circular cutting tool. As a results, it was defined that the amount of burr removal in a downward direction moving toward flow channel from the top surface was higher than upward direction. This is because the magnetic abrasives were detached from magnetic lines of force due to geometrical shape.

Keywords : Magnetic Abrasive Deburring(자기연마 디버링), Burr Removal Rate(버 제거율), U-type flow channel (U-type 유로), Cutting Radial Distance(절삭 반경)

1. Introduction

It is difficult to fabricate and finish hard materials with precise accuracy and high surface quality required in advanced technology fields. A magnetic abrasive deburring(MAD) known as an effective process could achieve high levels of finishing and uniform surface in less time and cost compared to conventional finishing processes. This is because a changeable tool made of ferrous particles and abrasive powder removes undesired parts and enhance surface cleanness simultaneously alon g free-form workpiece without damages while traditional tools have limitations of controllability and defects due to rigidity. Based on the benefits, previous research has been attempted to investigate effects of the MAD

Corresponding Author : jskwak5@pknu.ac.kr
Tel: +82-51-629-6139, Fax: +82-51-629-6125

process on flat and tubular types of workpiece but it has been still regarded as the immature technology in many aspects.[1-6]

Therefore, present work aims to study the performance of the rate of burr removal on u-type flow channel along a radial direction of circular shape of the tool. All experiments were conducted by $L_9(3^4)$ orthogonal array and then experimental results were analyzed in comparison with the length ratio of burr removal. In addition, S/N ratio was applied to determine the main influence on deburring performance.

2. Experimental methods

2.1 Evaluation burr removal

In order to verify deburring effect along the tool path on the top of the surface, the rotational regions were divided into two areas based on a center line as showed in Fig. 1. It was represented that the circular tool on the plane moved toward a low level of flow channel from surface was an downward region while a reverse side denoted the upward region. After experimentation was carried out, the deburring ratio by length, L_{BR}, was measured and compared at each radial direction as follows.

$$L_{BR} = \frac{L_{deburring}}{L_{total}} \tag{1}$$

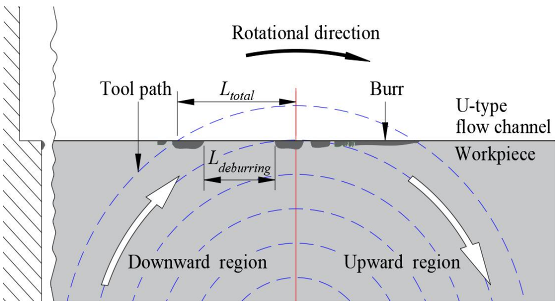

Fig. 1 Evaluated removal regions in radial direction

2.2 Experimental apparatus and conditions

Fig. 2 showed a MAD device employed in this study. It consisted of a BLDC motor, a DC supplier and a cylindrical steel rod wrapped around multiple coils. When current was supplied to the rod, magnetic flux density was induced to the steel rod and a magnetic field was generated between the workpiece and inductor in accordance with Faraday's law. This phenomenon made magnetic abrasives to be attached on the electromagnet tool in presence of the magnetic field and led to cutting unexpected parts on surface.

In order to tightly hold mixture of iron and abrasive particles during the finishing process without separation, it was recommended to apply bounded type mixture which produced under high pressure and temperature with inert gas due to stable bonding force. Although sintered magnetic abrasives brought better performance in surface finish, it had drawbacks to less productivity and cost efficiency as well as cleanness for complex surface having a number of valleys and peaks because of rigid shape of the tool. Therefore, in this paper, an un-bounded type brush which used silicone oil as a bonding media to join averaged 150㎛ of iron and averaged 2㎛ of abrasive powder. Total quantity of mixture was about 1.5g.

The workpiece was die steel STD-11 widely used in the die and mold parts due to the high level of

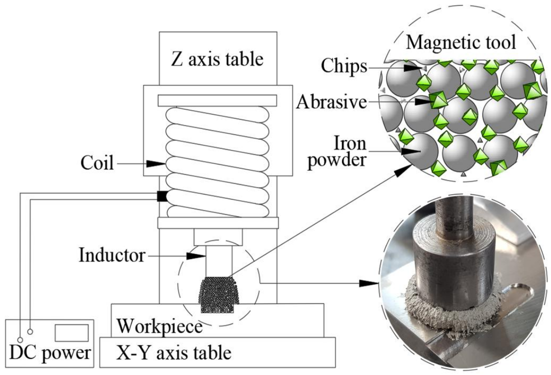

Fig. 2 Experimental apparatus and working principle

hardness, compressive strength and chemical stability. U-type flow channel of hardened steel having 55 HRC was fabricated by an end-milling machine with Φ6 of 2-flute flat end-mill. Total length and depth were 25mm and 0.5mm respectively considering distribution of magnetic abrasives during operation.

Other conditions were listed in Table 1. Supplied current was kept as 4.5A to maintain maximum magnetic force and operating time was 3 minutes taking into account tool wear and adhesive ability.

2.3 Process factors and evaluation methods

From Table 1, controllable four process parameters with three levels were working gap, rotational speed, viscosity of silicone oil and weight ratio of mixture.

It was noted that the performance of MAD assisted by magnetic force was dependent upon magnetic flux density, B. As can be seen the Eq. (2), abrasive pressure acting on magnetic abrasives for fine surface, P, was directly proportional to magnetic flux density.

$$P = \frac{B^2}{2\mu_0}\left(1 - \frac{1}{\mu_m}\right) \qquad (2)$$

Therefore working gap was varied by 3 steps to evaluate deburrring characteristics in different distribution of magnetic flux density. Magnitude of magnetic flux density at each level was measured every 4mm by a gauss meter(TM-601, Kanetec) considering inductor diameter, about 16mm. From the Fig. 3 which showed the variation of magnetic flux intensity, high values were obtained at the lower space between both ferrous materials. Rotational speed of the flexible brush affecting tangential force was determined as one of the experimental factors with 400, 500 and 600rpm. Higher viscosity of the bonding media prevented abrasives to move outward, so silicone oil was applied instead of mineral oil with predetermined levels. Weight ratio of abrasive particles identified an important factor to adhere to the electromagnet, hence each of weight percentage was varied from 25% to 75%.

All the simulations were carried out using Taguchi's orthoganl method and then experimental results were observed by the video microscope system (SV-35, Sometech) to verify the effects of MAD in tool rotational direction. Based on the results, S/N ratio was conducted to evaluate the main effects of process parameters on burr reduction.

Table 1 Experimental conditions

Items	Conditions
Workpiece	STD-11(55 HRC)
Abrasive size(㎛)	2, Green carbide(SiC)
Iron particle size(㎛)	150
Bonding material	Silicone oil
Current(A)	4.5
Working gap(mm), A	0.5, 1.0, 1.5
Tool speed(rpm), B	400, 500, 600
Viscosity of silicone oil(cs), C	150,000, 200,000, 250,000
Weight ratio(Fe/GC), D	1, 2, 3

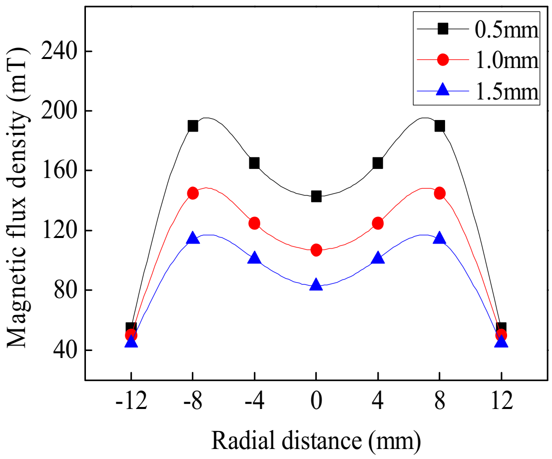

Fig. 3 Distribution of magnetic flux density

3. Results and Discussion

3.1 Burr removal in tool radial direction

In order to verify the deburring performance in the tool rotational direction, all simulations were planed using designed of experimental method as listed in Table 2. Fig. 4 showed the removal percentage at each region. As can be seen, the higher length ratio of burr removal in the downward direction which flowed down a slot area from the top surface was observed rather than the upward direction. This was because the performance of MAD was largely affected by magnetic field lines formed between workpiece and the electromagnet tool. In case of the downward region illustrated in Fig. 5(a), the multi-layered cutting tool was able to take away undesired parts by tangential force with rotating abrasive particles in the same working direction. After worn abrasives were passed or separated, new ones were easily rearranged along the magnetic field lines. On the other hand, some parts around periphery magnetic abrasives were fallen into the slot area from the magnetic lines of force and deposited on the bottom of the channel due to geometrical shape as shown in Fig. 5(b). It was noted that the upward

Table 2 Taguchi's $L_9(3^4)$ orthogonal array table

Exp. no.	Process parameters			
	A	B	C	D
1	0.5	400	150,000	1
2	0.5	500	200,000	2
3	0.5	600	250,000	3
4	1.0	400	200,000	3
5	1.0	500	250,000	1
6	1.0	600	150,000	2
7	1.5	400	250,000	2
8	1.5	500	150,000	3
9	1.5	600	200,000	1

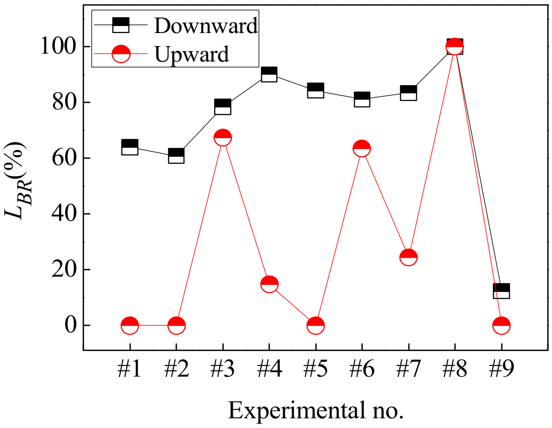

Fig. 4 Comparison to deburring effect in directions

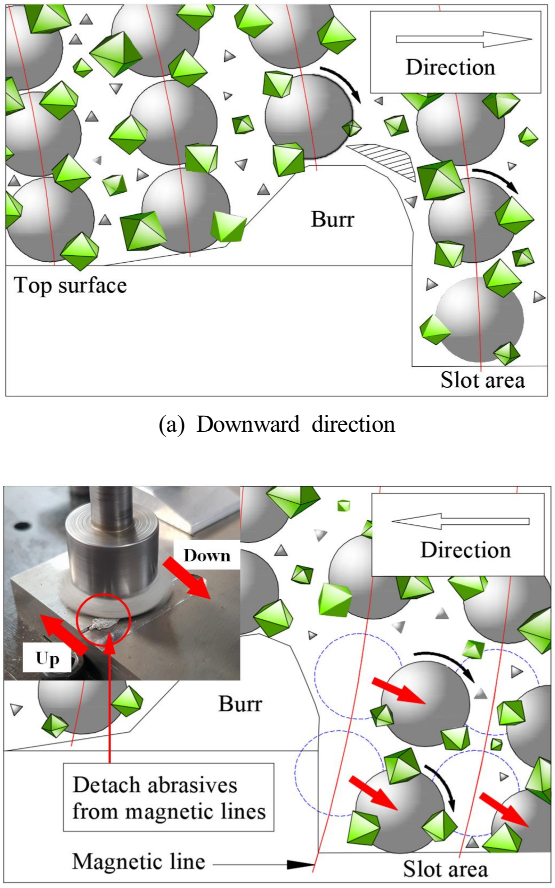

Fig. 5 Removal principle in tool rotational direction

region where abrasives flowed from the low level of U-type channel to the top surface was less efficiency since reduction in quantity of magnetic substances resulted in decreasing resultant force on the surface.

The most effective simulation in all the experiments was no. 8 corresponding to 1.5mm of working gap, 500rpm of rotational speed of the tool, 150,000cs of silicone oil viscosity and 1:3 of weight ratio of GC and Fe particles. It showed that all the existing burr in observed areas were removed.

3.2 Evaluation of the main effect

In practical, it was important to get uniform surface with high quality in all the regions. To evaluate the effects of considering process parameters on burr removal by length, obtained results were analyzed by S/N ratio.

As can be seen in Table 3, a dominant effect of burr removal along the tool rotational direction was mixing ratio of magnetic mixture accounting for 38.7% followed by viscosity of silicone oil, working gap and rotational speed corresponding to 31.8%, 15.8% and 13.7% respectively.

The large amount of iron particles of mixture improved surface cleanness since tension energy each abrasives in presence of the magnetic field increased tool strength. Consequently, the stiff tool enhanced adhesive ability to easily remove micro or nano-sized particles on the surface.

When the tool was rotated in certain speed, the magnetic abrasives were rearranged itself along the magnetic field. During this process, silicone oil played an important role in the bonding medium as well as lubricant to circulate and restrict abrasive particles. In order to replace worn particles to new ones without additional supply during operation, low viscosity about 150,000cs was the most effective among the considered three levels.

With regard to working gap, 1.0mm was the best rather than 0.5 and 1.5mm. As can be seen in Fig. 3, large space between the inductor and workpiece had low flux density directly related to normal force for penetration of the surface. As a result, it led to less performance than other levels. Although the narrow working gap had higher magnetic flux density, it restricted abrasives' movement for replacement.

The moderate tool speed, about 500rpm, brought high efficiency in burr removal of U-type flow channel. This was because low speed results in accumulation of particles in the slot area due to less tangential force. In contrast, tool located at periphery of the magnetic brush rapidly moved outward at 600rpm because centrifugal force was higher than resultant force acting on magnetic abrasives.

According to the Fig. 6, the best configuration in this study was A2B2C1D3 which was equal to 1.0mm of working gap, 500rpm of tool rotational speed, 150,000cs of silicone oil viscosity, and 1:3 of weight ratio of GC and Fe particles.

Table 3 The results of S/N ratio for each factor

Factors	Levels			Difference
	1	2	3	
A	32.33	34.69	30.16	4.52
B	33.04	34.05	30.09	3.92
C	35.76	26.63	34.79	9.12
D	26.14	33.82	37.22	11.08

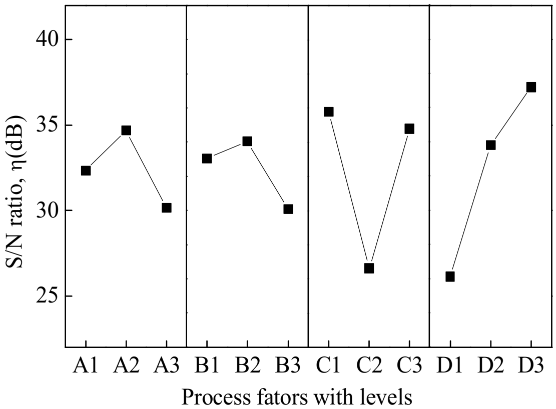

Fig. 6 The effects of burr removal in radial regions

4. Conclusions

The main objective of this study aimed to analyze the deburring characteristic of MAD operation on U-type flow channel along the tool rotational regions. To evaluate the length ratio of burr removal, regions were divided into downward and upward regions based on the center line. After all simulations were conducted following conclusions can be drawn :

1. It showed that deburring effects were different in the tool rotational regions. The downward direction which flowed into the slot area from the top surface had higher performance compared to the reverse direction. At the upward region, magnetic abrasives were fallen out the magnetic lines of force due to geometrical shape, so it led to less efficiency of burr reduction.
2. Simulation no. 8 showed the best results among the 9th simulations corresponding to 1.5mm of working gap, 500rpm of tool spindle speed, 150,000cs of silicon oil viscosity, 1:3 of weight ratio of GC and Fe powder. It showed that the length ratio of burr removal was near 100%.
3. In accordance with results of S/N ratio, the optimal combination was A2B2C1D3 which was equal to 1.0mm, 500rpm, 150,000cs and 1:3.
4. According to the S/N ratio for each factor, the most significant parameter of burr removal was mixing ratio with contribution of 38.7% followed by silicone oil viscosity, working gap, and rotational speed corresponding to 31.8%, 15.8% and 13.7% respectively.

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