Springer

KSME

Journal of Mechanical Science and Technology 24 (2010) 275~278
www.springerlink.com/content/1738-494x
DOI 10.1007/s12206-009-1170-1

Selection of an optimized method for pitting processes with sustainability as an important factor †

Ryuichi Saitoh[1], Hiroki Yamakiri[1], Tsuneo Kurita[2]
Shinsuke Kondoh[2], Nozomu Mishima[2] and Shinya Sasaki[1,*]

[1]*Department of Mechanical Engineering, Tokyo University of Science, Tokyo, Japan*
[2]*Environmentally Conscious Design and Manufacturing Research Group, AIST, Tsukuba, Japan*

(Manuscript Received May 8, 2009; Revised October 25, 2009; Accepted October 30, 2009)

Abstract

Recent engineering products must meet the demand for downsizing and sophistication. Environmentally benign manufacturing has also become a key technology for sustainable development. Striking a balance between product quality and environmental impact in manufacturing processes has become an important issue in the design of eco-friendly products. However, despite this increasing demand from the industry, there is dearth of research on the environmental impact of processing as compared to studies on conventional manufacturing factors such as cost and time. We have tried to clarify the relationship between quality and environmental impact directly from experimental data. The pitting process that we chose as our experimental process is one of the most general and important processes in the industry. In this paper, we discuss a basic concept for selecting optimal processing methods and conditions for the pitting process from the aspect of employing an environmentally benign process. By applying our study to the industry, engineers can easily conduct processes that are not only high in quality but also low in environmental impact.

Keywords: Sustainable development; Environmentally benign process; Process quality; Desktop-size machine tool

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1. Introduction

Engineering products continue to need to be downsized and sophisticated. Miniaturization and sophistication are becoming increasingly important for communication and medical devices. Such products will certainly not only become lighter in weight but will also possess increasingly more functions in the future. However, the industry still has much work to do as concerns about environmental problems continue to grow. Not only high quality but also environmental consciousness is required in recent manufacturing processes. Environmentally conscious manufacturing has become a key technology for sustainable development. In response to this demand, engineers are designing and developing eco-friendly products with the concept of reducing life-cycle environmental impact. As a result, the balance between product quality and environmental impact in the manufacturing process has become an important issue. However, one of the major obstacles to employing environmentally benign processes is the lack of information. Despite the increasing demand from the industry, studies on the environmental impact of processing methods lag behind those on conventional manufacturing topics such as cost and time issues. Therefore, we have tried to clarify the relationship between quality and environmental impact directly from experimentally demonstrated data. We focused on the effects related to the pitting process, which is one of the most general and important processes in the industry. Machining, electrical discharged machining (EDM), and laser machining methods were adopted for our experiments on the pitting process. Environmental impact was monitored during processing, and process quality was measured after the experiments.

In this paper, we discuss a basic concept for selecting an optimal processing method and condition for the pitting process from the aspect of employing an environmentally benign process. If this study is applied to the industry, we expected that engineers can easily conduct processes that are not only high in quality but also low in environmental impact.

2. Experiments

2.1 Pitting process

Pitting is the one of the fundamental processes that accompanies cutting, welding, and plastic forming processes. It is also an important process in the industry because the process

† This paper was presented at the ICMDT 2009, Jeju, Korea, June 2009. This paper was recommended for publication in revised form by Guest Editors Sung-Lim Ko, Keiichi Watanuki.

*Corresponding author. Tel.: +81 3 5228 8389, Fax.: +81 3 5228 8389
E-mail address: s.sasaki@rs.kagu.tus.ac.jp

Table 1. Processing conditions.

Machining	
Tool	Carbide drill
Machining fluid	Water-insoluble oil
Revolution	10,000 rpm
Feed rate	0.1, 1, 5 mm/sec
EDM	
Electrode	Copper rod
EDM fluid	Distilled water
Circuit	RC circuit
Resistance	220 Ω
Power voltage	180 V
Capacitor	1, 10, 100 nF
Laser	
Laser type	Pulsed YAG laser
Frequency	10 kHz
Average output	3 W
Scan rate	0.5, 1, 3 mm/sec

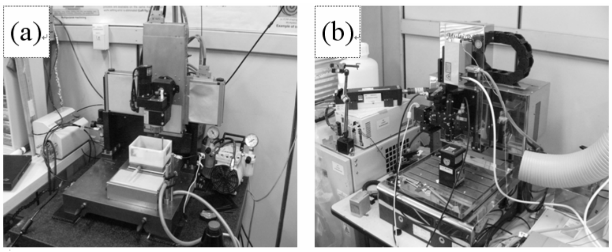


Fig. 1. Schematic diagram of the processing apparatus: (a) Machining and EDM, (b) Laser.

ing precision greatly influences a product's value. For example, the product value of inkjet printer heads is determined by the pitting quality. For this reason, we selected the pitting process as our evaluation target.

2.2 Desktop machine tool

To conduct our processing experiments, we utilized the desktop machine tool [1] shown in Fig. 1 as our base system. As previously reported, various precision products are becoming increasingly smaller. However, manufacturing facilities and production systems remain large, which is in contrast with the trend. The desktop machine tool was developed for the purpose of a small-sized manufacturing system suitable for fabricating small-sized products. This machine tool is smaller and lighter in weight than conventional tools. It features a lower driving energy, less construction material, lower consumption of machining fluid, and smaller installation space. This system is so flexible that its layout can be changed and rearranged much more easily than a system of conventional size.

2.3 Processing conditions

To clarify the relationship between process quality and environmental impact, we conducted three kinds of processing experiments separately: machining, EDM, and laser machining. Stainless steel (SUS304), which is a general material applied in a variety of miniature precision components, was selected as the test material. The pitting size was set at a diameter of 1 mm, with the pitting depth varied from 0.1, 0.5, 1, and 3 mm.

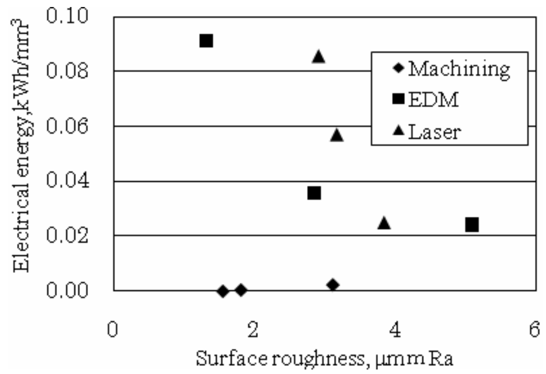
The processing conditions are summarized in Table 1. A carbide drill 1 mm in diameter was used as the machining tool. Water-insoluble oil was used for the machining fluid. The revolution speed of the tool was 10,000 rpm. The feed rate was changed in three stages in a range from 0.1 to 5 mm/sec. For the EDM tests, a copper rod 1 mm in diameter was used as the electrode. Distilled water was used for the EDM fluid. The RC circuit used for the EDM was set at a processing voltage of 180 V and a resistance of 220 Ω. The capacitance of the circuit was changed in three stages in a range from 1 to 100 nF. For the laser machining, a pulsed YAG laser was used, with the frequency set at 10 kHz and average output at 3 W. The circle scan rate was changed in three stages in a range from 0.5 to 3 mm/sec.

2.4 Processing quality and the impact

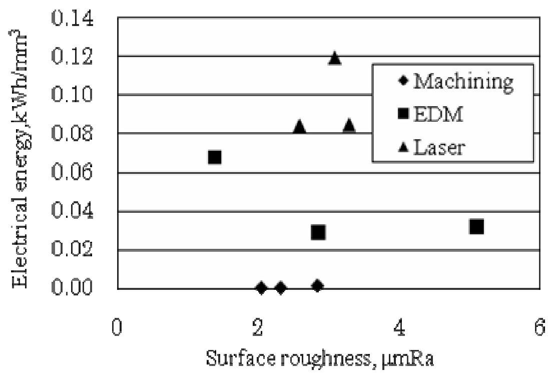
To evaluate environmental impact during experimental processing, the processing time and electrical power consumption were monitored using an electrical power meter. The aggregate environmental impact was calculated from these experimental data. The processing quality was evaluated by measuring the inner surface roughness of the processed holes using a confocal optical microscope.

3. Experimental results

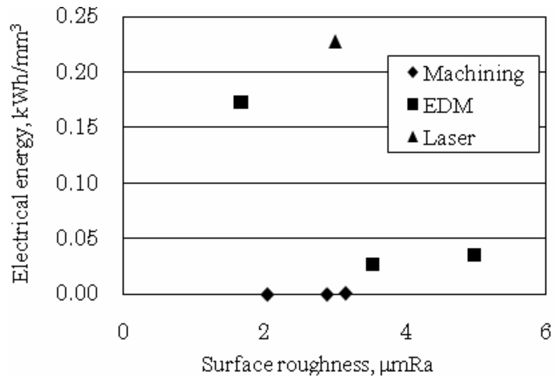
It was impossible to process holes 1 mm in depth when using laser machining at a laser scan rate of 1 and 3 mm/s. It was also impossible to process holes 3 mm in depth when using EDM at a capacitance of 1 nF, as well as when using laser machining in all conditions. As shown in Fig. 2, machining used the lowest electrical energy of all processes. For EDM, the surface roughness decreased along with increased environmental impact. The electrical current of EDM exhibited a trade-off relationship between quality and environmental impact. Laser machining produced low quality despite its relatively large energy consumption. For all methods used, surface roughness improved with larger machining feed rates and smaller capacitances of the EDM circuit. On the other hand, laser machining did not exhibit such a tendency related to the processing conditions.



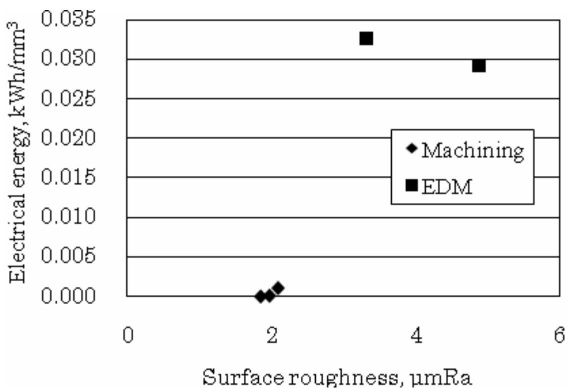
(a) Depth: 0.1 mm



(b) Depth: 0.5 mm



(c) Depth: 1 mm



(d) Depth: 3 mm

Fig. 2. Relationship between electrical energy and surface roughness.

Table 2. Processes and conditions with Ra < 2.0.

Hole depth 0.1			
Machining	Feed rate, mm/sec	Ra, μm	Electrical energy,kWh/mm^3
	1	1.818	0.00045
	5	1.563	0.00000
EDM	Capacitor, nF	Ra, μm	Electrical energy,kWh/mm^3
	1	1.322	0.09117
Hole depth 0.5			
EDM	Capacitor, nF	Ra, μm	Electrical energy,kWh/mm^3
	1	1.379	0.06806
Hole depth 1			
EDM	Capacitor, nF	Ra, μm	Electrical energy,kWh/mm^3
	1	1.678	0.17274
Hole depth 3			
Machining	Feed rate, mm/sec	Ra, μm	Electrical energy,kWh/mm^3
	1	1.975	0.00014
	5	1.849	0.00004

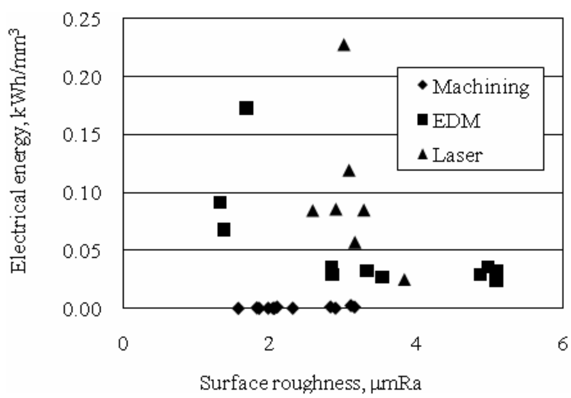


Fig. 3. Relationship between electrical energy consumption and surface roughness.

4. Discussion

In product manufacturing, the selection of a process and its conditions is one of the most important decisions for engineers. It is essential to understand the characteristics of each process and compare processes and conditions with experimental data. When selecting an optimized process, the following indicators are used.

1. The processing method has the capability to manufacture the input material into the desired form.
2. The measurements and the accuracy of the form have common differences.
3. The surface roughness is within an acceptable range.
4. The processing time is shortened.
5. The cost is lower.
6. There is less environmental impact.

Factors 1, 2, and 3 are defined as the absolute requirements as they determine the processing quality. Meanwhile, Factors 4, 5, and 6 are defined as the relative requirements for which processes may be compared and selected.

An optimized process is selected through the following steps. First, processes that meet the absolute requirements are selected. Second, an optimized process is selected based on the relative factors in all acceptable processes. However, the environmental impact is not typically considered a key factor when comparing the time and cost of a process with those of other processes, and the experimental study of such processes also lags behind.

We thus proposed a method for selecting an optimized process from the view of low environmental impact. As an example, we used the experimental data for the processing methods. All the experimental data are organized in Fig. 3. For simplification, surface roughness was defined as an absolute factor. Electrical energy was also defined as a relative factor. Assuming that surface roughness is set at Ra < 2μ m, the processes and conditions in Table 2 satisfied this requirement. Each of these conditions is consequently judged using electrical energy consumption. The process with the lowest energy consumption was selected as the optimized process. As a result, machining of holes 0.1 and 5 mm in depth and EDM of holes 0.5 and 1 mm in depth were selected.

These results showed that it was effective to select the optimized process on a hole-by-hole basis by applying our experimental data to their industrial applications.

5. Conclusions

Process quality was evaluated by measuring the surface roughness of those holes processed by machining, EDM, and laser machining.

Environmental impact was calculated by monitoring the electrical power consumption during each processing test.

Machining consumed the lowest electrical energy among all processes. For EDM, the surface roughness decreased along with an increase in environmental impact. Laser machining produced low quality despite its relatively large energy consumption.

It is possible that engineers can easily achieve processes that are not only high in quality but also low in environmental impact by applying our experimental data to industrial applications.

References

[1] T. Kurita and M. Hattori, Development of new concept desktop size machine tool, *International Journal of Machine Tool and Manufacture*, 45 (2005) 959-965.

Ryuichi Saitoh received his BS degreee from the Tokyo University of Science, Tokyo, Japan in 2009. He is currently studying towards his MS degree in the Department of Mechanical Engineering, Tokyo University of Science, Japan.

Shinya SASAKI received his BS, MS, and PhD degrees from the Tokyo Institute of Technology, Japan in 1984, 1986, and 1991, respectively. He worked for the National Institute of Advanced Industrial Science and Technology, AIST, Japan as a senior researcher from 1986 to 2007. He is a Professor in the Department of Mechanical Engineering at the Tokyo University of Science, Tokyo, Japan. His current research interests include surface design, surface modification, and tribology for eco-products and sustainable societies.