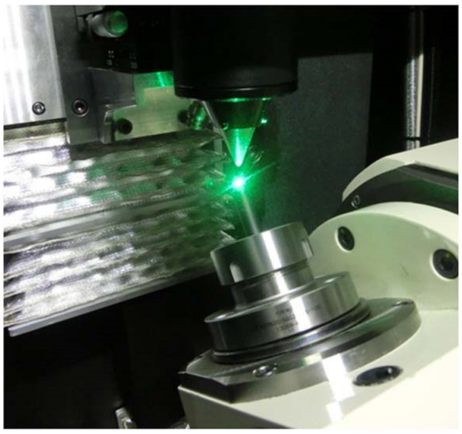
Microdrilling Technology using Short Pulsed-laser



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In recent years, laser machining is highly anticipated as a technology to replace machine processing and electrical discharge machining. The reason is because this type of non-contact machining involves no tool wear and can be applied to metals and a wide range of other materials including nonconductive crustaceous materials and resins. There is a great need for the application of short-pulse laser machining to various industrial fields, as well as types of parts processing since a finer and higher-quality machined surface is obtained. But efficiency and quality can hardly be reconciled, resulting in an obstacle to wide penetration. Mitsubishi Heavy Industries, Ltd. (MHI), having proved that one method of short-pulse laser machining significantly differs from another in machining ability, reports here examples of laser-applied micro drilling.

1. Introduction

Laser machining is being tried in a variety of fields for application since it can be widely applied not only to metals, but also to brittle and other nonmetal materials on the condition that an appropriate source of light is selected for the material to be machined. In particular, in the recent situation of growing demand for high-accuracy and high-grade micro drilling, conventional laser drilling could no longer meet quality requirements such as for hole diameter accuracy and surface integrity due to its significant thermal effects on the material, but the use of picosecond and other short pulses has enabled ablation (evaporation/sublimation) processing-based, high-accuracy and high-grade machining. Between higher-efficiency and higher-accuracy/grade, however, the problem of antinomy has been pointed out, and a solution to this problem is required for adaptation to production. In an effort to solve this problem, MHI has developed a micro-laser process machine where the helical drilling process is employed (1).

This paper compares helical drilling with percussion machining as a typical method of micro drilling for machining ability, as well as for machining quality, to prove the former's superiority. It then introduces superior method-based examples of micro drilling together with the "ABLASER" micro-laser process machine developed by MHI.

2. Comparison of short-pulse laser machining methods

2.1 Characteristics and problems with machining methods

Figures 1 and **2** outline different laser machining methods and **Table 1** indicates their characteristics. Percussion machining is a method to drill holes by irradiating a pulsed laser beam in a fixed place without allowing the beam to move or rotate (Figure 1). At present, it is used as a method of micro drilling, but since the expanse due to light concentration by a lens is transcribed,

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the cut surface always assumes a tapered shape. On the other hand, helical drilling for machining irradiates a pulsed laser beam while allowing the beam to rotate at a high speed after being adjusted to the desired hole diameter (Figure 2).

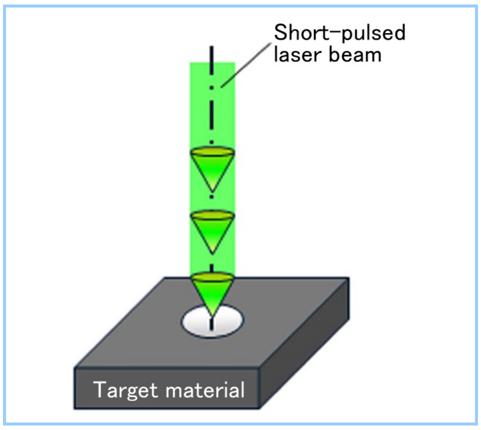

Figure 1 Percussion machining method
Percussion machining drills holes by irradiating a pulsed laser beam in a fixed place without allowing the beam to move or rotate.

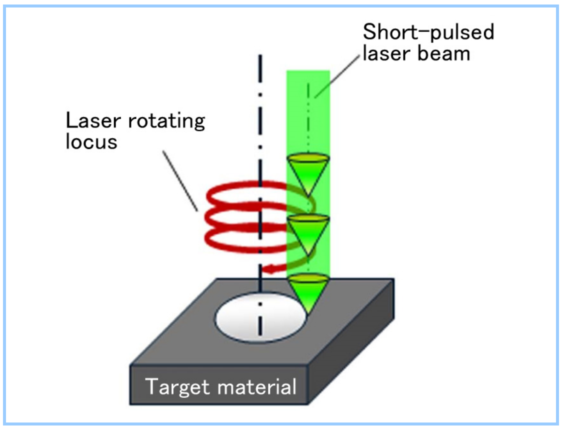

Figure 2 Helical drilling method
Helical drilling adjusts the laser beam to the desired hole diameter and irradiates a pulse laser while allowing it to rotate at a high speed.

Table 1 Machining method features

	Percussion machining	Helical drilling
Hole diameter accuracy	Inferior	Superior
Tapered shape control	Unavailable	Available
Machining efficiency	Low	High
Machining quality	Inferior	Superior

If laser beams have the same amount of energy per unit area, the machining efficiency per pulse is considered constant and it has so far been conjectured that there is no difference between percussion machining and helical drilling. At the same time, there are few cases where superiority in terms of machining quality has been quantitatively compared, and therefore it was difficult to examine the optimum machining method.

2.2 Comparison between percussion machining and helical drilling

Percussion machining was compared with helical drilling for machining efficiency and machining quality. Two different types of material were used for machining; one was SUS420 as a metal material and the other was single crystal silicon as a brittle material.

(1) Machining efficiency evaluation test

Machining efficiency tests were conducted by irradiating a laser beam on the material to be machined as shown in **Figure 3**(a), with the amount of energy per pulse fixed and the number of pulses per unit time altered, and the volumes removed were thereby compared. The per-pulse energy was set at a value that can realize less thermally-affected ablation machining. For helical drilling, the beam's turning radius was adjusted so that the per-unit area volume of energy should become the same as that for percussion machining. **Figure 4** shows the test results. The vertical axis represents the volume removed per unit time as machining efficiency and the horizontal represents the per-unit time number of pulses. Helical drilling was found to be six times higher for SUS420 and 1.8 times higher for single crystal silicon than percussion machining in terms of efficiency. In helical drilling of both SUS420 and single crystal silicon, the machining efficiency increases with the increasing number of pulses per unit time while, at and over a certain number of pulses, it decreases. This is supposedly because ablation processing remained as such until it came to a certain domain, but when the amount of energy irradiated became too large, dissemination in the form of heat took place, worsening abrasion-derived machining efficiency. It was found from the above that short pulse laser-based helical drilling has the optimum conditions for machining. Since the optimum conditions for machining depend upon the material to be machined, it is important in practicing high-efficiency helical drilling to accumulate expertise for machining.

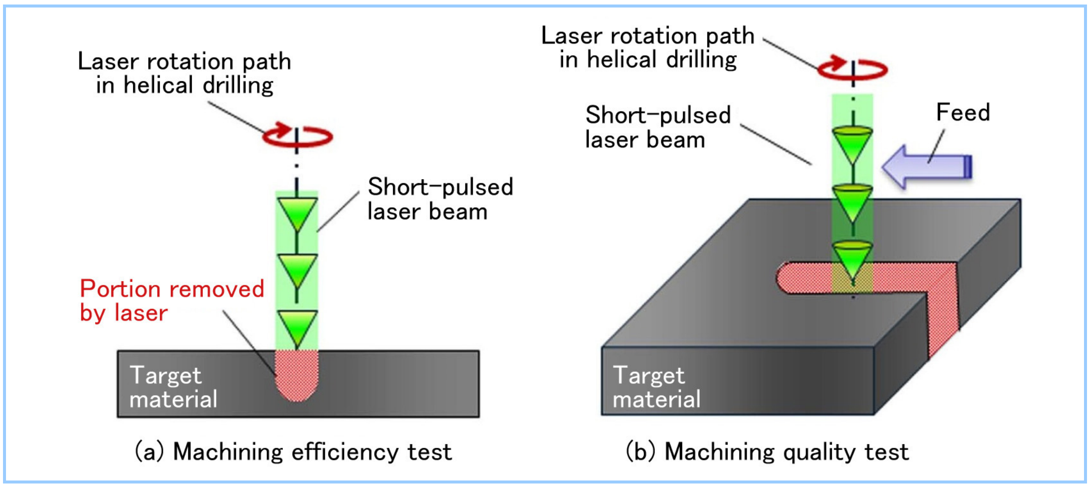

Figure 3 Schematic diagram of short-pulse laser machining method comparison test
(a) In machining efficiency comparison tests, the volume removed by laser irradiation was compared as machining efficiency.
(b) In machining quality comparison tests, the laser-cut surface was observed under SEM for comparison.

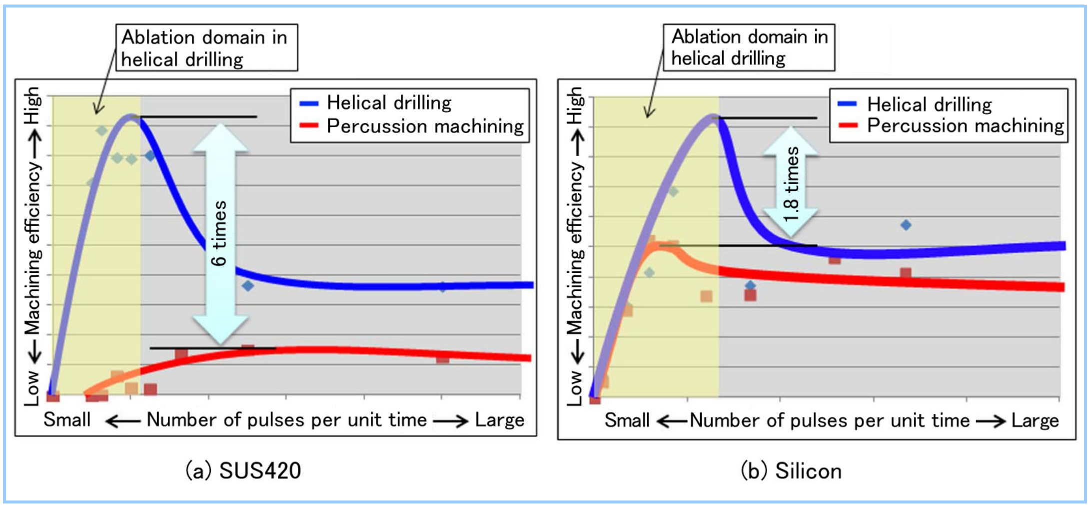

Figure 4 Machining efficiency test results
In helical drilling, machining efficiency is 6 times higher for (a) SUS420 and 1.8 times higher for (b) silicon.

(2) Machining quality evaluation test

The feed rate was applied to percussion machining and helical drilling for cutting in order to compare the machining quality on the cut surface (Figure 3(b)). Cutting conditions including the energy of the laser being irradiated and the pulse frequencies were the same for both percussion machining and helical drilling.

Figure 5 shows the results of cut surface observation under SEM for each process. Both SUS420 and single crystal silicon obtained from helical drilling a cut surface that was better in terms of surface integrity. The cut surface observation found that some matter that had re-melted supposedly due to the thermal effects of the laser had been left on the percussion-machined surface, while helical drilling had a smooth cut surface free from re-melted matter, proving favorable ablation processing. Like the results of the aforementioned machining efficiency tests, it was clear that helical drilling was less likely to result in thermal fusion of the target material than percussion machining, even under the same conditions for machining.

(3) Comparison test results

The test results mentioned so far indicated that helical drilling is superior to percussion machining in realizing high-efficiency, high-accuracy micro drilling with a short-pulsed laser beam. It further became known that high-efficiency, high-quality machining of key metal/brittle materials would require each target material to be optimally conditioned so that it could be machined with the greatest efficiency.

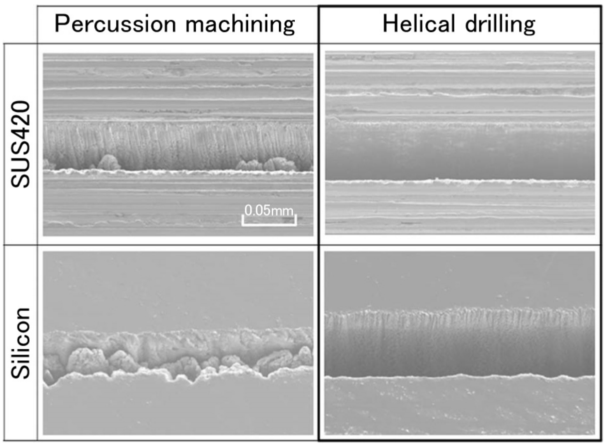

Figure 5 SEM observation results for the cut surface machined to the same machining conditions

3. Example of micro machining by helical drilling

3.1 Example of micro drilling (target material: SUS420/silicon wafer)

Figure 6 shows an example of φ0.12mm-hole drilling on a SUS420 plate (t0.3mm). Smooth machined inner surfaces and sharp edge sections indicate that there was little thermal effect on the drilling due to ablation. **Figure 7** show an example of φ0.15mm-hole drilling on a silicon wafer (t0.5mm). Like SUS420, silicon as a brittle material could be machined with little thermal effect.

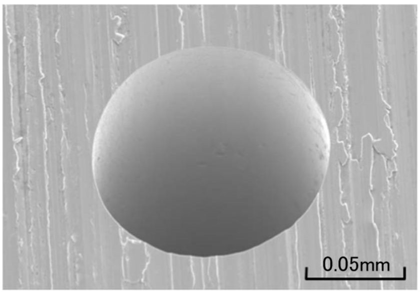

Figure 6 Micro drilling on SUS420
Material: SUS420, thickness: t0.3mm, hole diameter: φ0.12mm

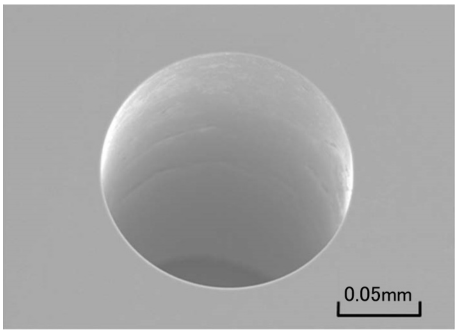

Figure 7 Micro drilling on silicon water
Material: silicon wafer, thickness: t0.5mm, hole diameter: φ0.15mm

3.2 Example of different hole shape machining (target material: SCM420 tempered)

A straight, a reverse-tapered, and a drum-shaped hole with the narrowest part of φ0.1mm were machined on a tempered SCM420 material (t0.8mm) and **Figure 8** shows an SEM observation photo of each machined section and roughness measurement results.

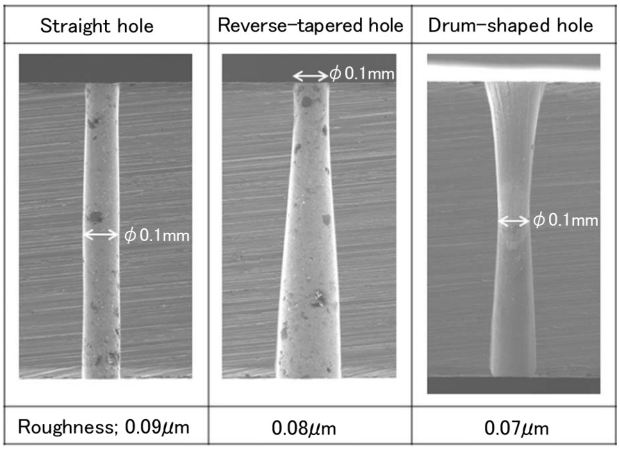

Figure 8 Example of different hole shape machining
SCM420 tempered, thickness: t0.8 mm, narrowest hole diameter: φ0.1 mm.
Can be machined to any desired tapered shape and the machined surface roughness is Ra0.1μm or less.

If the beam's angle of incidence is controlled, the desired tapered shape can be machined and the machined surface roughness is Ra0.1μm or les in all cases. In straight and reverse-tapered holes, adhesion of foreign matter was observed, but this occurred only after machining, and by devising a cleaning method, etc., drum (-shaped) hole machining achieved a smooth machined surface free from any adhesion. **Figure 9** shows an SEM observation photo of different hole machining. Not only confined to drilling, the process can also be used for cutting the material into any desired shape with few thermal effects on the cut surface.

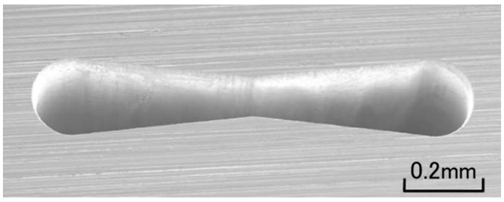

Figure 9 Example of different-hole machining
SCM420 tempered, thickness: t0.8mm

4. The "ABLASER" short pulsed-laser process machine

MHI developed the "ABLASER" short pulsed-laser process machine, in which a helical drilling method was employed, and sent it to "The 27th Japan International Machine Tool Fair (JIMTOF2014)" for referential display. **Figure 10** shows its external appearance and **Table 2** indicates its equipment specifications. Granite used for main structures and a precision scale-equipped positioning mechanism achieved machining accuracy (with an error of ±0.002 mm or less) higher than that of a conventional laser process machine. A 5-axis control device is mounted on the machine, enabling curved surfaces and complex shapes to be machined.

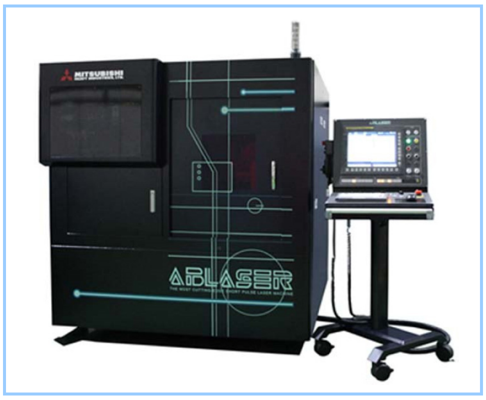

Figure 10 External appearance of ABLASER

Table 2 Specifications for ABLASER equipment

X axis (mm)	100 or more
Y axis (mm)	100 or more
Z axis (mm)	100 or more
C axis (°)	360
A axis (°)	-20－120
Positioning accuracy (mm)	0.001
NC device	FANUC30iLB
Laser optical system	Made by MHI
Taper hole control	Taper/reverse-taper
Assist gas	Dependent upon material to be machined
Width x depth x height (mm)	1,850 x 1,850 x 1,900

5. Conclusion

In this report, we proved helical drilling's predominance in the high-efficiency and high-grade performance of micro drilling with a short-pulsed laser beam, and presented examples of less thermally-affected high-grade micro drilling. From now on, MHI intends to further promote the development of such technologies for application in a variety of prospective industrial fields, not confined only to engine fuel injection nozzles or semiconductor processes, and to continue to propose optimal solutions for laser machining that meet customer needs.

Reference

1. Watanabe, T. et al., High Speed & Quality Laser Drilling Technology by Using Prism Rotator, Proceedings of the 82nd Laser Materials Processing Conference (2015-1) p. 79