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Effect of high-frequency orbital and vertical oscillations of the laser focus position on the quality of the cut surface in a thick plate by laser beam machining

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ABSTRACT

In laser beam machining with oxygen gas, striations are formed on the cut surface due to the cyclic oxidization reaction, which is affected by the cutting conditions and the thermal properties of the workpiece. The formation of striations causes an increase in surface roughness. In order to reduce the surface roughness, we propose controlling the formation of striations by utilizing multi-DOF oscillation of the focus position of the laser. In this paper, we construct a laser machining system in which positioning control of the focus position is achieved by driving the focal lens. The effect of orbital oscillation of the laser focus position parallel to the top surface of the workpiece and vertical oscillation perpendicular to this surface on the formation of striations was evaluated by performing laser cutting tests on thick mild steel plates. The experimental results show that control of the formation of striations can be realized by choosing the appropriate oscillation conditions. The surface roughness with oscillation was less than half that without oscillation.

1. Introduction

In laser beam machining, a focused laser beam melts and vaporizes the workpiece and an assist gas jet continuously blows away the molten material [1,2]. In the laser cutting of an iron plate, oxygen gas is selected as the assist gas to accelerate the oxidization reaction and supply additional heat energy to the cut surface. The assist gas jet is fixed coaxially to the laser beam.

Laser cutting is used to machine thick plates for large structures such as ships, pressure vessels, and bridges because it can cut complex geometrical profiles and prevent residual strain developing due to the non-contact processing [3–5]. However, laser cutting forms striations on the cut surface, as shown in Fig. 1. The striations degrade the surface quality and increase the roughness of the cut surface [1,6].

Striations are formed on the cut surface during the laser machining process. It has been reported that the striations are formed as a result of a cyclic oxidization reaction which is due to the difference between the burning rate and the laser beam scanning speed [1,6–8], as shown in Fig. 2. On the other hand, Arai has reported that cyclic flow and exfoliation of the molten material causes the formation of striations [9]. In this paper, we discuss the formation of striations based on the former interpretation.

The cyclic oxidization reactions are affected by the cutting conditions, such as the laser power, the laser scanning speed and the assist gas pressure, and the thermal properties of the workpiece, such as the thermal conductivity. Therefore, in order to reduce the roughness of the cut surface, optimization of the machining conditions [6,10–12] and the flow of the assist gas to remove molten material [13–16] has been focused on.

In this paper, we propose controlling the formation of striations by utilizing multi-DOF oscillations of the focus position of the laser. With this technology, we expect a smooth cut surface to be realized even in laser machining of a thick plate.

We consider that in-plane, high-frequency orbital oscillation of the laser focus position will form shallower striations with smaller pitch on the cut surface. Fig. 3 is a pictorial representation showing the mechanism by which it is proposed the striations are formed

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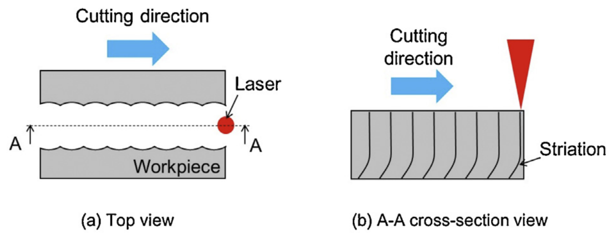

Fig. 1. Striations on the cutting surface.

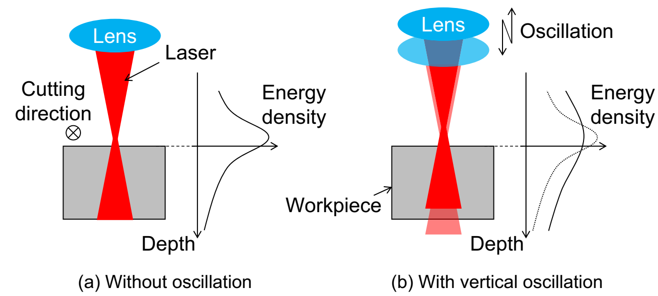

Fig. 4. Assumption of uniformizing laser energy density distribution (side view, time average).

with orbital oscillation of the laser focus position. During the orbital oscillation, the laser focus position moves rapidly around the leading edge. This is expected to increase the frequency of the cyclic oxidization reaction and generate a higher density of striations. The profile of the striations on the cut surface will be almost the same as the trajectory of the laser beam. Therefore, we can form arbitrary striations by tuning the radius and frequency of the orbital oscillation.

Furthermore, we consider that high-frequency vertical oscillation of the laser focus position will also help to generate uniform striations. As shown in Fig. 4(a), the power density of the beam decreases as the distance from the laser focus position increases. In order to realize a cut with a smooth surface, the location of the focus position should be optimized according to the material and thickness of the workpiece [10,17]. However, when cutting into thicker workpieces, the variation in power density on the cut surface increases in the thickness direction and this decreases the quality of the cut. By oscillating the laser focus position in the direction of the beam, the laser power density distribution on the cut surface is expected to be more uniform, as shown in Fig. 4(b).

In order to carry out laser cutting with high-frequency orbital and vertical oscillations of the laser focus position, we manufactured a magnetically levitated lens drive actuator (maglev actuator). The maglev actuator can move the laser focus position by driving the focal lens with positioning ranges of ± 1 mm and ± 5 mm, and bandwidths of 160 Hz and 105 Hz in the horizontal and vertical directions, respectively [18].

In this paper, we constructed a laser cutting system consisting of the maglev actuator and a laser cutting machine. Furthermore, the effectiveness of the orbital and vertical oscillations of the laser focus position on the roughness of the cut surface and the characteristics of the kerf on the top surface (incident surface), such as the kerf width, the height of the serrations and the wavelength of the striations was evaluated by performing laser cutting tests on thick mild steel plates.

2. Laser processing system with a maglev lens drive actuator

The configuration of the developed maglev actuator used to drive the focal lens in the laser cutting machine is shown in Fig. 5(a). The mechanism and magnetic levitation control are described in Ref. [18]. The maglev actuator mainly consists of a lens holder and four electromagnetic driving units. One driving unit generates magnetic forces in the *Z* and either *X* or *Y* directions. Using the four units, the lens holder is levitated without any contact and high-response 6-DOF motion control of the lens holder is realized.

Fig. 5(b) shows a photograph of the prototype maglev actuator. The full size and the total mass are 124 mm × 124 mm × 144 mm and 6 kg, respectively. The positioning performance is summarized in Table 1.

The laser processing system utilizing a conventional laser cutting machine integrated with a maglev actuator is shown in Fig. 6 and a schematic view of it is shown in Fig. 7. The maglev actuator is mounted on the laser head. The position of the laser head (x_h, y_h)

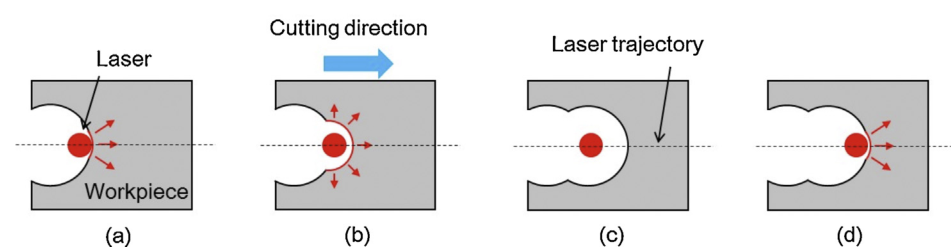

Fig. 2. Striation formation mechanism (top view): (a) laser starts melting workpiece, (b) leading edge goes ahead of laser, (c) melting workpiece stops due to the insufficient temperature on leading edge, (d) laser catches up with leading edge and restarts melting workpiece.

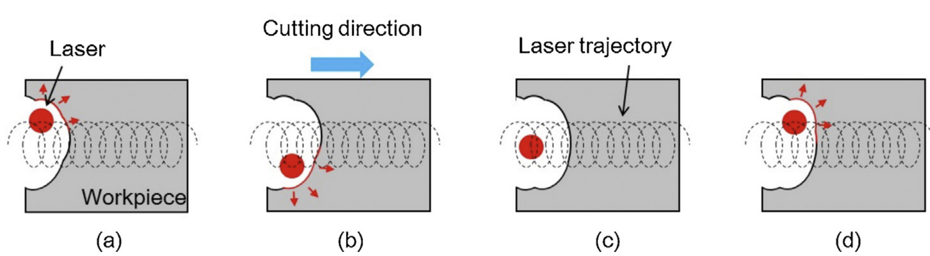

Fig. 3. Assumption of striation formation mechanism with orbital oscillation of laser focus position (top view): (a) melting workpiece starts where laser approaches and a part of leading edge goes ahead of laser, (b) melting workpiece stops where laser leaves due to the insufficient temperature, (c) melting workpiece stops, (d) laser approaches to leading edge and restarts melting workpiece.