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Improvement of cutting performance for thick stainless steel plates by step-like cutting speed increase in high-power fiber laser cutting

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ABSTRACT

A study was conducted to improve the cutting performance of a 60-mm thick stainless steel plate using a 6-kW fiber laser. Two techniques for improving the initial cutting performance were evaluated by preheating the work piece with a waiting time and step-like cutting speed increase. Both techniques showed improved cutting results compared to constant speed cutting. Among them, the method with a step-like cutting speed increase showed the better result in terms of cutting performance. As a result, a 60-mm thick stainless steel plate was cut at a maximum cutting speed of 72 mm/min with a preheating cutting speed of 24 mm/min. In order to confirm the effect of preheating, an additional experiment was performed to measure the temperature variation during the cutting process. Through this experiment, preheating temperature conditions were found to allow the specimen to be cut. It is expected that the results of this work will contribute to improving the cutting performance of thick metal structures in various industrial fields, as well as the dismantling of nuclear facilities using lasers in the future.

1. Introduction

Laser cutting technology has been used for material processing in various industrial fields [1]. Recent advances in fiber and disk lasers have resulted in a commercially available laser output within a 1-μm wavelength range of up to several tens of kilowatts [2,3]. As the optical fiber delivery of such a high power laser beam has become possible, the technology development has been actively carried out worldwide to apply the laser cutting to the dismantling of the facility [4–19]. In particular, in the dismantling of nuclear facilities, laser cutting has attracted attention as a next-generation cutting technique which has various advantages compared with the conventional cutting methods such as mechanical cutting, water jet cutting, and plasma arc cutting [4–12]. For application to this field, remote control is essential because workers cannot access the high radioactive work place. Laser cutting with optical fiber delivery is advantageous for remote cutting inside a complex structural space, because only a small laser head is placed in the work place without large electrical and mechanical devices. In addition, laser cutting is non-contact cutting and there is no reaction force, and thus it is easy to control through a manipulator such as a robot arm. Furthermore, the kerf width related to the amount of secondary waste is smaller than that of other cutting methods. Therefore, laser cutting technology is considered as an eco-friendly technology.

In the cutting process, the laser beam is locally focused on a work piece made of metal, and the absorbed power heats and melts the metal. During the cutting process, an assisting gas, such as nitrogen or compressed air, blows off the generated melt at the same time. High-quality cutting is required in the industrial field to avoid secondary processing, but is no longer important in the dismantling field. At this point, the most important thing is to achieve a higher cutting capability, which means cutting a thicker material with a higher cutting speed. Therefore, cutting studies aiming at improving the cutting capability have been carried out in this field. Tamura et al. developed laser cutting technology for application to the dismantling of the Fugen nuclear reactor [7–10]. Recently, cuttings of stainless steel and carbon steel plates of up to 300 mm in thickness were successfully achieved with a 30-kW high power fiber laser [7], and additional studies have been conducted to efficiently cut through a thickness of more than 100 mm [8–10]. In another group, Chagnot et al. cut stainless steel plates with a maximum thickness of 100 mm with an 8-kW Nd: YAG laser and their own developed cutting head [13].

In these works, the cuttings were performed at a constant speed. In the previous results of our studies [16,17], it has been empirically found that a constant speed cutting is not suitable for

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thick steel plates. In the case of thick steel plates, it takes a sufficient time to raise it up to the melting point near the start point. When the cutting was performed at a high speed in one go, the work piece was partially cut by incomplete initial cutting. In order to obtain a complete cutting, the cutting speed should be low enough. However, once the hole was made in the work piece at a distant of a few millimeters from the start point, the cutting was done well thereafter at a high-speed without any problems. Thus, the cutting speed was limited to the initial cutting speed for the case of constant-speed cutting. If only the initial cutting performance could be improved, and it would have been possible to cut thick steel plates at a higher speed. In the previous works, M. Takashi et al. used a 9 kW fiber laser to cut a 100-mm thickness stainless steel plate, which was cut at the beginning with a waiting time [18,19]. Although this method was not described in detail, it was presumed to be an attempt to improve the initial cutting performance. In our group, Shin et al. recently introduced a method with a step-like cutting speed increase for improving the cutting performance, which increases the cutting speed in two or three steps [16,17]. Through this method, they demonstrated that a 6-kW fiber laser can cut 60-mm thick stainless steel at a maximum cutting speed of 72 mm/min. However, sufficient studies have not been conducted on how to improve the cutting performance of thick steel.

For this reason, this work focused on an evaluation of techniques for improving the initial cutting performances when cutting thick stainless steel plates by a laser beam. Both techniques with a waiting time and step-like cutting speed increase were examined. After that, a better way was determined for the cutting of thick steel plates by comparing the results of two techniques. Then, the cutting conditions were optimized for the better method and the maximum cutting speed was obtained. In addition, the improvement of the initial cutting performance by preheating was confirmed once again with an experiment by measuring the temperature variation during the cutting process.

2. Experimental procedure

Fig. 1 shows a view of the laser cutting experiment. A high-power ytterbium-doped fiber laser (IPG Photonic Corp, YLS-6000) with a wavelength of 1070 nm and a maximum power of 6 kW was used as the laser source of the cutting system. The laser beam was emitted through a feeding fiber with a core diameter of 50 µm, and was delivered by a process fiber with a core diameter of 100 µm with the aid of an optical fiber coupler. It entered the cutting head, which was mounted on the X-Y-Z stage device after a distance of 25 m through the process fiber. The laser cutting head consisted of a collimator (Model: D50-F160 WC, IPG Photonics Corp.) with a focal length of 160 mm, and a reflective focusing optical system with a focal length of 600 mm. It was previously developed in our group to effectively cut thick steel at a high speed. Its structure, such as an optical arrangement, is described in our previous paper [16]. Thus, a detailed description of the cutting head is omitted in this paper. When the laser beam was focused by this cutting head, the spot diameter was measured to be 374 µm and the beam parameter product (BPP) was measured to be 3.4 mm·mrad.

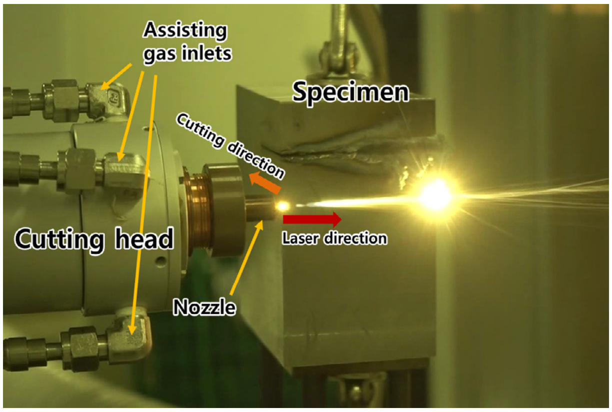

Fig. 1. View of the laser cutting experiment of stainless steel plates. When the cutting process was started, the laser beam was irradiated onto the specimen and the assisting gas blew the melt out of the specimen at the same time. At this time, the cutting head was moved from the right side edge to the left and cutting of the specimen proceeded.

When the cutting process was started, the laser beam was irradiated onto the specimen and the assisting gas blew the melt out of the specimen at the same time. At this time, the cutting head was moved from the right side edge to the left and cutting of the specimen proceeded. The cutting speed was determined based on the moving speed of the cutting head. For safety, the remaining laser power used for cutting was absorbed by the beam dumper with a graphite plate. The generated fume during the cutting was gathered in the dust collector through the duct.

During the cutting tests, the laser power was set to be 6 kW. And 60-mm thick stainless steel (SUS304L) plates were used as the specimens, considering that the typical laser cutting capability was known to be 10 mm per kW [13]. The whole size of the specimen was 100 mm (height) × 100 mm (width) × 60 mm (thickness). Compressed air with a gauge pressure of $\sim$1 MPa was used as an assisting gas. In this case, the gas flow rate expressed under ANR (Atmosphère Normale de Référence) conditions (20 °C, 101.3 kPa, 65% relative humidity) was measured to be 470 L/min with a conical nozzle with exit diameter of 2 mm. The stand-off distance, which means the distance from the nozzle exit to the surface of the specimen, was set to 1 mm. The focus of the laser beam was set to be placed just on the front surface of the specimen. In order to obtain the data under the same conditions as at the initial temperature, each cutting test was performed after the specimen was completely cooled down after the previous cutting. For each cutting line, a length of 40 mm was cut from the right side edge of the specimen. Cutting was performed with different speed conditions for each cutting line. After cutting process, cutting lines were observed whether or not the cutting was done well.

The cutting tests were conducted using the following three methods. First, the performance for a constant cutting speed was evaluated as a reference. Second, the method for cutting with a waiting time was applied to improve the initial cutting performance by preheating of the specimen. In this case, the laser beam was placed on the right side edge of the specimen and irradiated for a certain period of time. Then, the head was cut at a constant speed after that. The period for preheating was defined as the "waiting time." Finally, the method for cutting with a step-like cutting speed increase was evaluated. In this method, the cutting is performed at a low speed for the initial preheating section, and then increased to the final cutting speed for the remaining cutting section. The cutting speed for the initial preheating section was defined as the "preheating cutting speed" and the final cutting speed was defined as the "cutting speed."

3. Results and discussions

3.1. Cutting with a constant speed

Table 1 shows the cutting conditions and the corresponding results of constant-speed cutting. In this case, the maximum cutting speed was 30 mm/min. For a cutting speed of above 30 mm/min, the specimen was not able to be completely cut. Fig. 2 shows