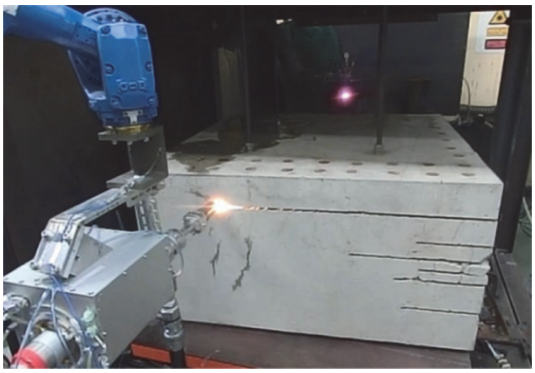
Development of Concrete Building Cutting Technology Using High-Power Laser



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With the increasing power and better quality of laser oscillators, laser processing, which has not been applied to thick concrete, has been increasingly used in recent years. In this report, we describe laser cutting of thick concrete columns (with a maximum thickness of 1200 mm) by using high-power fiber laser of over 20 kW and an ultra-long focus optical system, aiming at establishing a remote demolition technology for nuclear plant buildings that are high radiation areas. This report also describes a new beam laser damper system using water that was developed as a technology for receiving the high-power laser beam passing through a cutting object, which has been an issue in high-power laser processing.

1. Introduction

The buildings of Fukushima Nuclear Power Station of Tokyo Electric Power Company Holdings, Incorporated. are high radiation areas, where it is difficult for workers to be engaged in long hours of demolition work at the site. Therefore, the development of remote demolition technology has been demanded. If machines such as wire saws, which are used in general demolition, are used for the cutting of reinforced concrete in buildings, the wire saws may become caught. As such, it is desirable to use noncontact cutting technology such as laser processing.

The processing ability of laser cutting technology has increased remarkably with the increase in power of laser oscillators. Various concrete cutting methods using lasers have been developed, but there are few reports about laser cutting of thick concrete of over one meter[(1),(2)]. We worked on the development of thick concrete cutting technology by combining high-power laser oscillators and our proprietary optical system (ultra-long focus optical system) and verified the cutting of concrete of 1200 mm in thickness.

On the other hand, in terms of safety, laser cutting needs a beam damper in order to receive the laser beam passing through the cutting object, but there are few reports on the development of beam dampers that can be used for high-power laser beams. Conventional beam dampers usually use a metal plate equipped with a water-cooling system and the metal plate heated with the laser is slowly cooled with cooling water. The metal plate, however, melts from exposure to the high-power and high-density laser before it is cooled, and it is difficult to use them for a long time.

To address this issue, we studied a new concept beam damper that uses water so that the laser power can be reduced before the laser beam is received by the metal plate after cutting the concrete, and manufactured a prototype. Water absorbs infrared light and water mist can scatter it. We confirmed that compared with the conventional beam damper, the new beam damper using

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water could significantly reduce laser power and power density on the metal surface receiving the beam (by about 2%).

This report describes the thick concrete laser cutting technology using a high-power and high-power density laser beam and the new concept of beam damper system using water intended to be used for the demolition of concrete buildings (**Figure 1**).

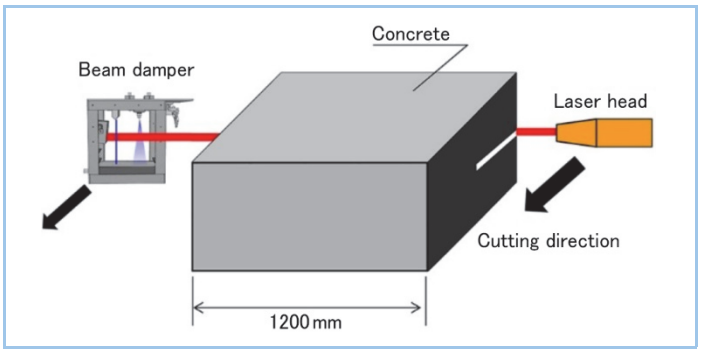

Figure 1 Concrete cutting system using high-power laser

2. Development of thick concrete cutting technology

Laser cutting is a cutting method that melts objects with the heat of a laser beam. Different from plasma cutting and gas cutting, which use the same thermal process, laser cutting has no limitations on the objects it can cut and it can cut metal, ceramics and resin. In addition, the high-density energy of laser cutting also facilitates high-speed cutting.

The principle of the laser cutting of concrete is shown in **Figure 2**. Laser cutting is realized by applying a focused and high-power density laser beam to melt concrete and blowing off the molten concrete (hereinafter referred to as dross) by using assist gas. The two main issues in the cutting of thick concrete are as follows:

(1) Securing laser energy required for melting 1200 mm thick concrete through the direction of thickness
(2) Remove dross

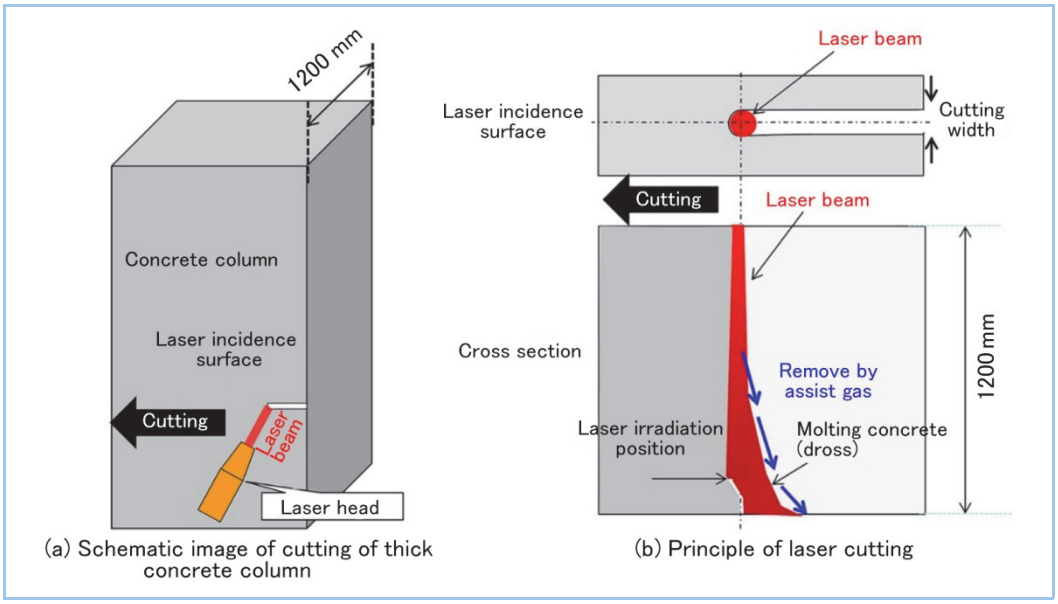

Figure 2 Principle of laser cutting of concrete

Using a condensing optical system with a focal distance of 500 mm, we conducted concrete cutting tests while increasing laser power at constant cutting speeds (6, 12 mm/min) (**Figure 3**(a)). When the laser power was increased from 20 kW to 25 kW, the cutting speed was almost saturated and the cutting thickness of the plate remained about 900 mm. It is supposed that with the conventional laser optical system (Figure 3 (b)), the beam diameter is substantially expanded on the back side of thick concrete, the power density is reduced and the energy required for melting the

concrete cannot be maintained. Therefore, we used an ultra-long focus optical system to form a collimated beam (Figure 3 (c)) so that a sufficient energy density can be obtained even on the back side of thick concrete, and conducted concrete cutting tests. As the laser power increased, the cutting thickness of the concrete increased, and a concrete thickness of 1100 mm could be cut at a laser power of 25 kW (**Figure 4**).

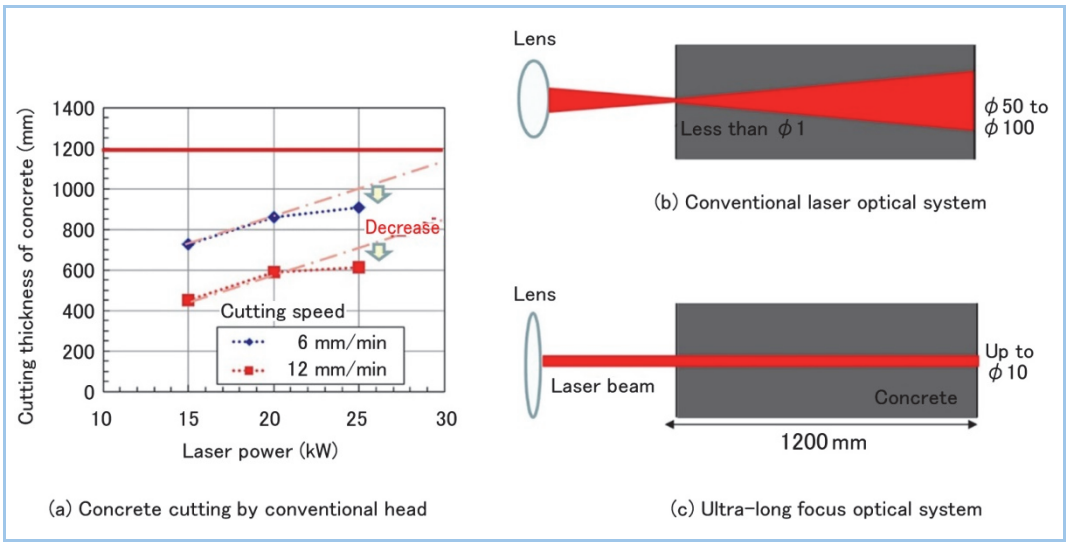

Figure 3 Development of ultra-long focus optical system

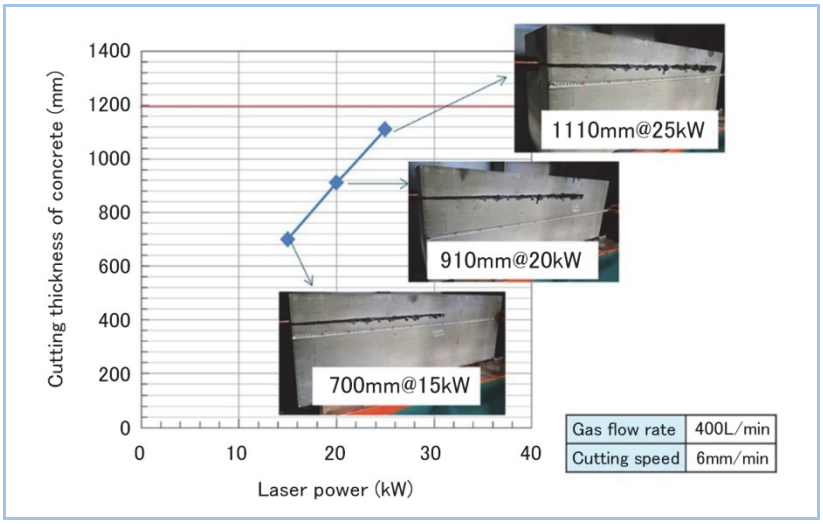

Figure 4 Relationship between laser power and cutting thickness of concrete

Next, to efficiently remove dross, we changed the gas nozzle. With the conventional gas nozzle, as the gas flow rate increased, the cutting thickness of the concrete increased until the flow rate reached 3000 L/min. After the gas flow rate exceeded 3000 L/min, the cutting thickness started decreasing and continued decreasing with the increase in the flow rate to 4000 L/min (**Figure 5** (a)). This is supposed to be because with the conventional gas nozzle (Figure 5 (b)), a gas flow rate exceeding 3000 L/min is the sound speed and the flow speed is saturated, resulting in the molten concrete removing effect reaching its limit, while the temperature of the dross decreased due to the gas cooling and the viscosity increased, resulting in a reduction of the fluidity. We adopted a Laval nozzle (Figure 5 (c)) so that the flow speed could increase over the sound speed with an increasing flow rate. As a result of conducting the cutting tests of thick concrete using the Laval nozzle, we confirmed that concrete of 1200 mm in concrete thickness could be cut at a gas flow rate of 4000 L/min (**Figure 6**). **Figure 7** shows the state of thick concrete (concrete thickness of 1200 mm) being cut at a laser power of 25 kW.

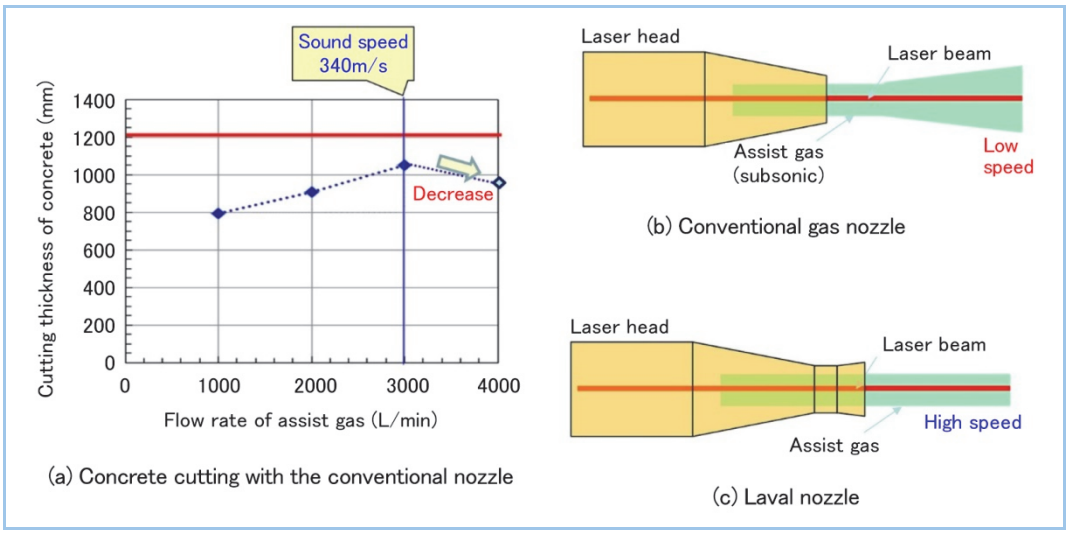

Figure 5 Improvement of gas nozzle

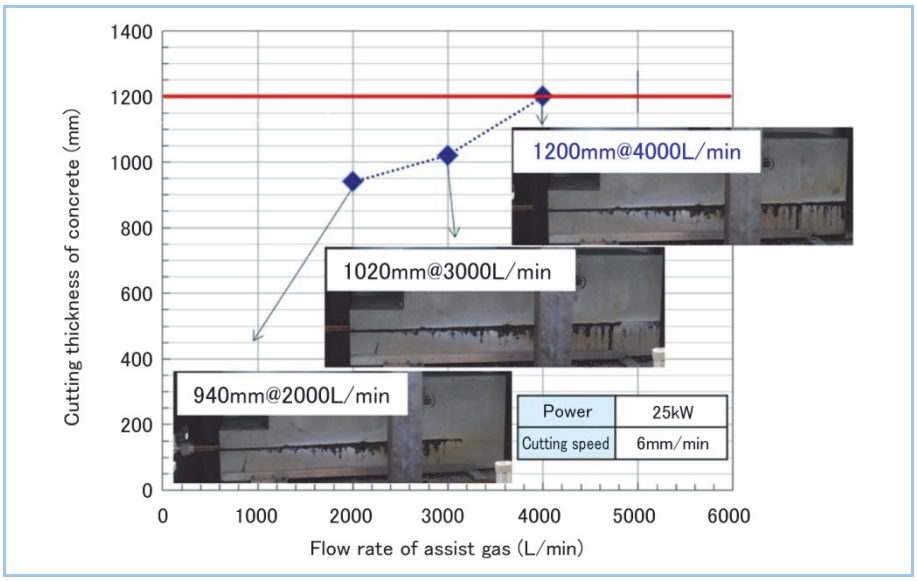

Figure 6 Relationship between gas flow rate and cutting thickness of concrete

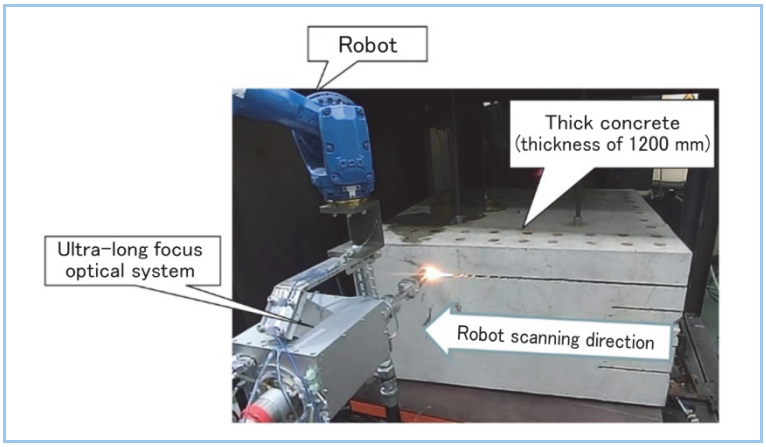

Figure 7 State of laser cutting of thick concrete

3. Development of new concept beam damper technology using water

As shown by the schematic image of a concrete demolition system using a high-power laser in Figure 1, when concrete is cut, the laser beam passes through the concrete. For safety at work, a beam damper needs to be installed to receive the laser beam passing through the concrete. **Figure 8** shows the specification (receivable laser power and power density) map of a commercial beam

damper. A laser power meter can receive a laser power of 30 kW. In that case, however, the power density must be reduced to several kilowatts/cm^2 or less to prevent the laser receiving surface from melting or burning. On the other hand, the ultra-long focus optical system which is used for thick concrete cutting emits a small-diameter beam and the beam diameter at the position of the beam damper is reduced to about φ10 mm. It is expected that the laser beam passing through the concrete has a power of 25 kW at maximum at the beam diameter of φ10 mm and a high-power density of 32 kW/cm^2. Therefore, it is difficult for current damper products to receive such high-power and high-density laser beams. We studied a new concept beam damper using water as a beam damper applicable to high-power laser cutting such as thick concrete cutting (**Figure 9**).

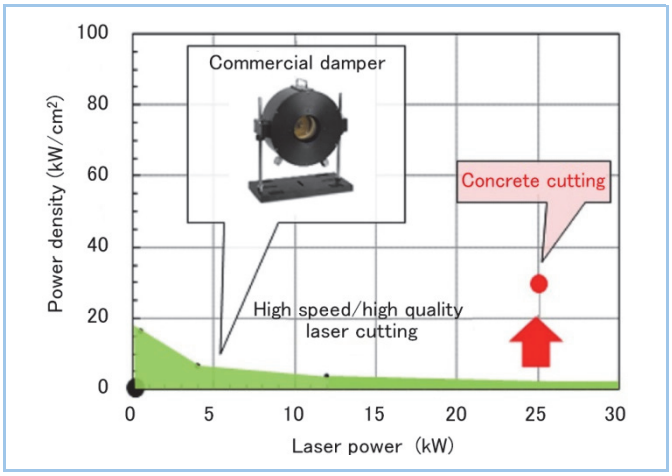

Figure 8 Specification required for beam damper (Power and power density)

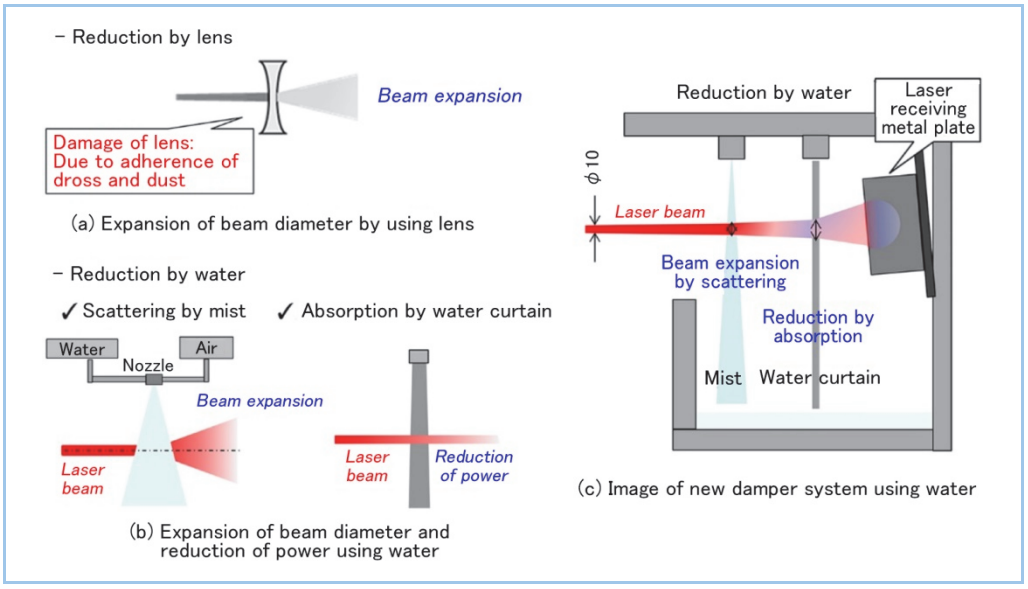

Figure 9 Concept of new damper system using water

In order for metal to receive the laser beam, it is necessary to reduce the power density to several kilowatts/cm^2 or less. One conceivable method for reducing the power density is to expand the beam diameter by using a lens (Figure 9 (a)). However, if dross or dust that was generated in concrete cutting adheres to the lens, it may absorb the laser and damage the lens. Therefore, we studied a method for scattering the laser beam by turning water into mist and forming a mist curtain. With the mist curtain, dross and dust that enter the system can be washed away by water and the system can be used continuously. Infrared light is absorbed by water. We also studied the use of a water curtain that absorbs laser beams to further reduce the power (Figure 9 (b)).

In this study, we conducted the development of the new damper system using a water mist curtain and water curtain in combination (Figure 9 (c)) so that a laser beam with a power of 25 kW and a power density of 30 kW/cm^2 could be received steadily by a metal plate, aiming at reducing the power density to 1 kW/cm^2 or less.

3.1 Absorption of laser beam by water curtain

First, we formed a water curtain and evaluated the absorption rate of the laser beam. A fiber laser was used and the wavelength of the laser beam was about 1 μm. When the water curtain is irradiated with the laser beam, the laser beam is reflected on the water surface, passes through the water curtain or is absorbed by the water (**Figure 10**(a)). The absorption of the laser beam by water is given by the expression (1)[3]. The ratio of the reflections on the water surface is about 1% and the absorption by water depends on the thickness of the water curtain (Figure 10(b)). This shows that when the thickness of the water curtain is 11 to 12 mm, the laser power is reduced to 10% of the incoming beam. In this evaluation, a 100W-class low-power laser beam was used.

$$I/I_0 = (1-I_A)e^{-\alpha z} \quad (1)$$

I : Transmitted light
I_0 : Incident light
I_A : Reflected light (up to 1%)
Z : Thickness
α : Absorption coefficient

For the miniaturization of the laser beam damping system, we examined whether the thickness of the water curtain can be reduced by coloring the water to increase the absorption rate. As shown with the dotted line in Figure 10(b), the use of a colored water curtain increased the laser beam damping ability compared with the use of an uncolored water curtain, and it was confirmed that the colored water curtain with a thickness of about 4 mm, which is one-third of that of the uncolored water curtain, could reduce the power to 10%. The absorption rate of the laser beam by the water curtain can be controlled by the thickness of the water curtain and can be increased by the use of colored water. The coloring material should be selected in consideration of its resistance to laser beams.

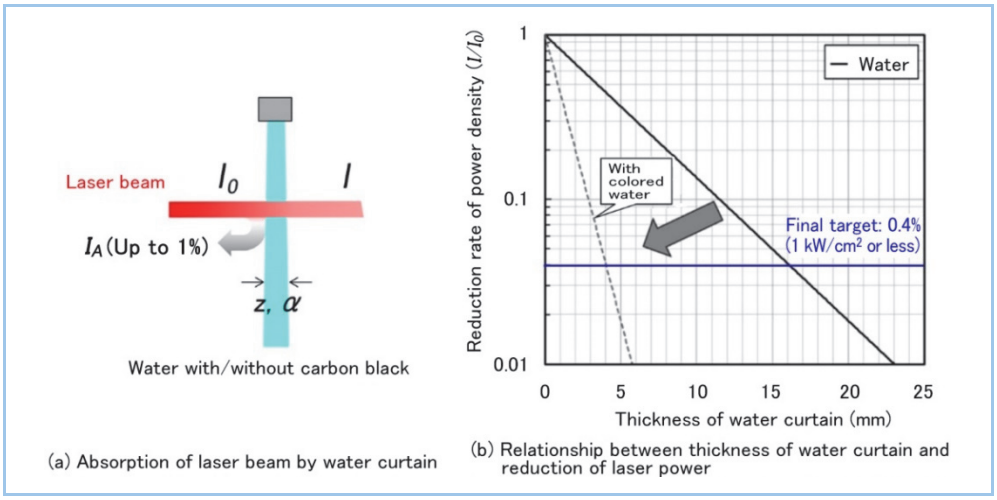

Figure 10 Absorption of laser beam using water

3.2 Reduction of power density of laser beam by mist curtain

Next, we evaluated the laser beam scattering effect of a mist curtain using water mist. **Figure 11** shows the concept of a new damper system using water. Mist consists of minute water particles and air and has a different refractive index profile from that of air. Therefore, when the laser beam passes through the mist, it scatters (Figure 11(a)). It is known that laser beams are scattered more easily by certain particle sizes depending on the wavelength of light, and we examined the relationship between particle size and the reduction rate of power density. Here, we regarded a reduction of power density as the expansion of the beam diameter and calculated the reduction rate of the power density from the measured beam diameter (power density = power/beam area), where a 100W-class laser beam was used.

We controlled the particle size of the mist by changing the nozzle for forming the mist curtain (particle size of mist: 5 to 200 μm). The result showed that as the particle size of the mist became smaller, the power was reduced, and it was confirmed that the power was reduced to 20% with a particle size of 5 μm. The relationship between the thickness of the mist curtain with a

particle size of 5 μm and the power reduction rate showed that as the thickness of the mist curtain increased, the power reduction rate increased. From these results, we confirmed that scattering of the laser beam by mist curtain could be controlled by the particle size of the water and the thickness of the mist curtain.

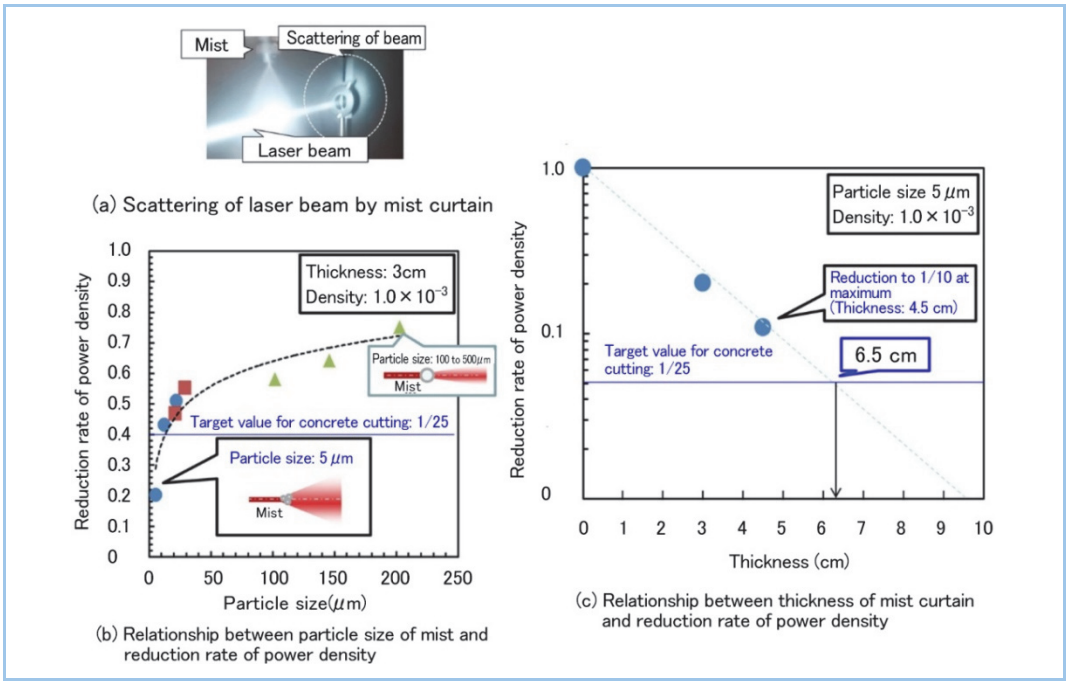

Figure 11 Power density reduction effect of laser beam scattering by mist

3.3 Laser beam damper system with water curtain and mist curtain

As described above, the respective effects of the water curtain and mist curtain were verified. We manufactured a water damper system with a water curtain and mist curtain in combination and examined the power reduction effect of the damper system (**Figure 12**(a)). The mist curtain was set in the forward stage and the water curtain was set in the rearward stage. Laser power of 25 kW was applied and the power and beam diameter were measured to evaluate the reduction rate of power density (Figure 12(b)). As a result, with the mist curtain, the power density was reduced by 70% by the effect of the expansion of beam diameter and with the water curtain, the power density was reduced by 94%. With the combination of the mist curtain and water curtain, the power density was reduced by 98% and the power density of the incident beam of 32 kW/cm^2 (25 kW @ beam diameter of φ10) could be reduced to 1 kW/cm^2 (target value).

Through this development, we anticipate establishing a system that can receive high-power and high-density lasers stably for a long time.

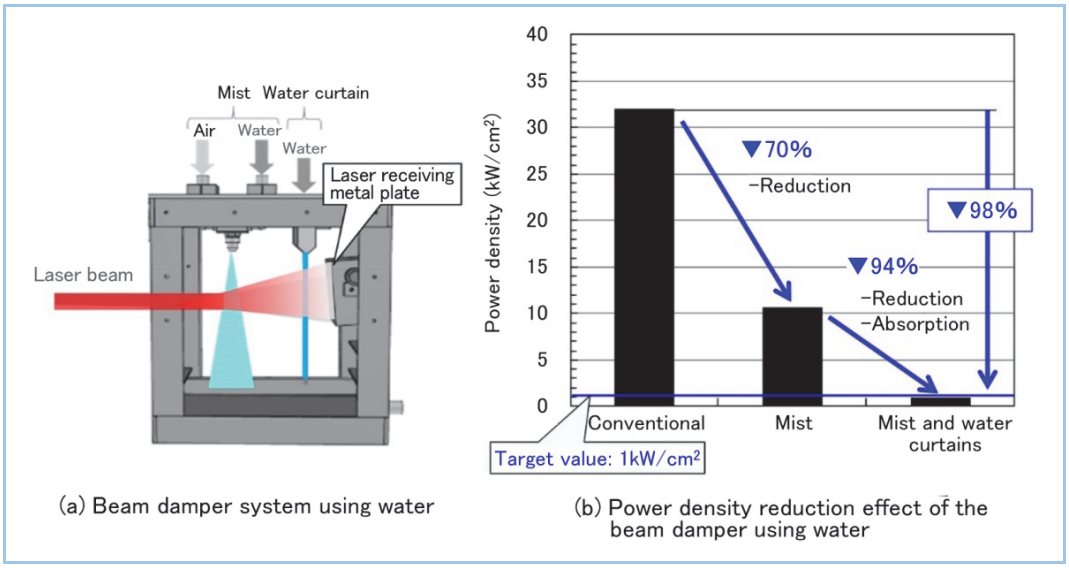

Figure 12 Power density reduction effect by new damper system using water

4. Conclusion

In this study, we developed cutting technology for thick concrete (thickness of 1200 mm) using a high-power laser intended to be used for the demolition of concrete buildings. In addition, as a technology for completing the demolition system, we reported a new laser damper system using water that can receive high-power and high-power density laser beams. In the development of concrete cutting technology, a high-power laser oscillator and an ultra-long focus optical system were combined to form collimated light as an elongated high-density laser that can melt concrete of 1200 mm in thickness. Furthermore, we verified that the adoption of a Laval nozzle allowed for the efficient removal of molten concrete and the cutting of thick concrete of 1200 mm in thickness.

In the development of a beam damper that can receive a high-power and high-density laser beam, we studied a new concept beam damper using water and manufactured a prototype of beam damper with a mist curtain for scattering the laser beam and a water curtain for absorbing the laser beam in combination. The mist curtain scattered the laser beam and expanded the beam diameter, thereby reducing the power density by 70%. In addition, the water curtain absorbed the laser beam, and reduced the power density by 94%. Thus, we verified that the target power density of 1 kW/cm^2 or less could be achieved, and anticipate the benefit of the new beam damper being able to receive the penetrated laser beam stably for a long time.

This technology is applicable to not only the demolition of nuclear plant buildings, but also remote demolition of general buildings and concrete replacement for bridges. Going forward, we will study the application of this technology and make efforts to contribute to our business through the acceptance of orders for demolition work, etc.

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