Evaluation of pulsed laser irradiation on concrete using a QCW laser system

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Laser irradiation techniques for removing degraded parts of concrete structure such as tunnel's concrete of railways safely and efficiently is an urgent task, since the significant defects in wall concrete have been detected in the JR West tunnels, Japan. Pulsed laser processing of material is an important part of the laser technical application, which include laser drilling, welding, cutting, etc. Advantages include a non-contact processing, a low heat input into the material, accuracy and consistency. An understanding of mechanisms of ejected molten material and characteristic of hole drilled in laser drilling concrete is necessary to enhance the performance for pulsed laser irradiation on concrete.

In this work, the characteristic of hole drilled into concrete and the material removal mechanism corresponding to the temperature of surface concrete during laser drilling were investigated by using high speed camera and thermography, as shown in **Fig. 1**. For requirement of small apparatus with high accuracy, as working in the tunnel transportation, the QCW (Quasi continuous wave) fiber laser system having compact dimensions was used in this experiment, allowing for a maximum peak power of 1.5 kW and average power of 150 W, operating at 1070 nm. Experiments have been performed on two types of concrete sample, such as heavy and real tunnel concrete.

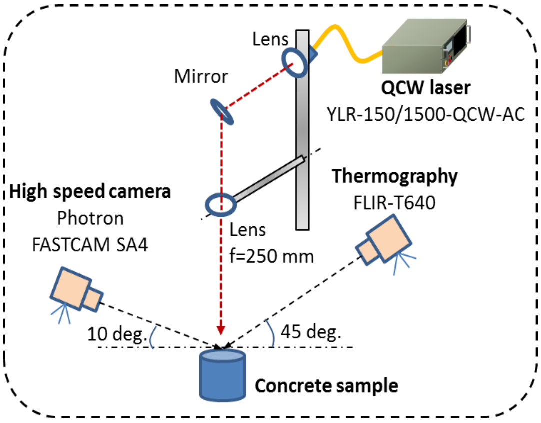

Fig. 1 Experimental setup of QCW laser drilling

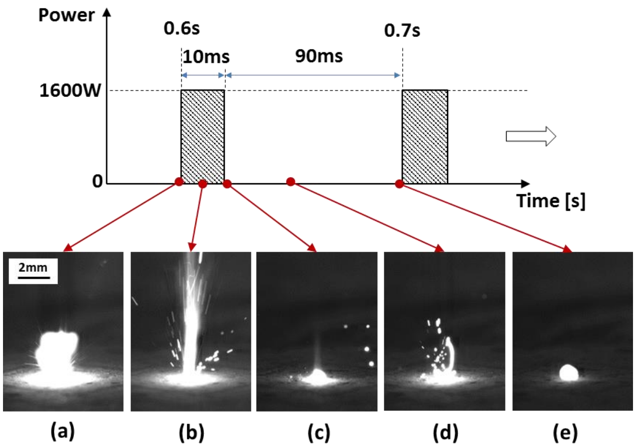

Fig. 2 High speed images of melt concrete ejection

When a laser pulse interacts with concrete, the surface of the concrete is quickly heated to high temperature by the absorption of laser energy causing concrete to melt and vaporize. The result in **Fig. 2** shows the images of melt ejection process by high speed camera at 3000 frames per second for 1600 W pulsed QCW laser with pulse duration of 10 ms and repetition rate of 10 Hz. At the beginning time of pulsed laser drilling process, a vapor plume is created immediately, as shown in **Fig. 2 (a)**. As the surface temperature reaches vaporization temperature, the part of molten concrete is further vaporized by the beam creating a pressure on the surface molten concrete. This vapor or recoil pressure increases with increasing surface temperature and this pushes the vapor away from the molten zone. Also, this pressure expels the molten concrete along the sidewall of the hole until it is ejected. This description, as shown in **Fig. 2 (b)**, clearly indicated that the melt is partially ejected through the vapor plume in the vapor state. After that, the significant melt concrete continuously ejected by recoil pressure even the laser pulse has ended until the temperature under melting point, as shown in **Fig. 2 (d)**. Consequently, the melt concrete is removed from the interaction zone both in vapor (laser on) and melt liquid state (laser off).

As an experimental results, the tendency of penetration depth increase with peak power for both tunnel and heavy concrete. The penetration depth was achieved on 20 mm thick with peak power of 1600 W within 10 s. In addition, the melt concrete expulsion has a significant effect of variation in peak power and pulse duration. This basic study of pulsed laser drilling provides information which can be useful to control and enhance the performance for laser irradiation on concrete. The QCW laser system is recommended for removing the concrete defect in tunnels due to its compact dimensions and responsive performance.