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Development of underwater laser cutting technique for steel and zircaloy for nuclear applications

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Abstract. In nuclear field, underwater cutting and welding technique is required for post-irradiation examination, maintenance, decommissioning and to reduce storage space of irradiated materials like used zircaloy pressure tubes etc., of nuclear power plants. We have developed underwater cutting technique for 4.2 mm thick zircaloy pressure tubes and up to 6 mm thick steel using fibre-coupled 250 W average power pulsed Nd:YAG laser. This underwater cutting technique will be highly useful in various nuclear applications as well as in dismantling/repair of ship and pipe lines in water.

Keywords. Laser cutting; underwater laser cutting; fibre optic beam delivery; Nd:YAG laser; material processing; heat affected zone; microstructure.

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1. Introduction

Underwater laser cutting and welding has many applications in nuclear facilities and shiping industry and is a promising technique for maintenance/dismantling operations as well as for collecting sample pieces for post-irradiation examination [1–3]. In the field of nuclear decommissioning also, underwater cutting of nuclear facilities is desirable. For such operations, it is highly useful to deliver the laser beam through optical fibre because of its flexibility. During dry laser cutting process, a high-power laser beam is focussed on the job so that the material reaches its melting temperature and a high-pressure active or inert gas is used to remove the molten material. During this process, a considerable amount of energy is conducted into the work piece resulting in changes in the material properties and the microstructure of the material leading to large heat affected zone (HAZ). In addition, debris and metal vapour from the cut kerf is spread in air. In cutting of irradiated material, debris and metal vapour creates airborne activity, which may be harmful for people working nearby, whereas, underwater cutting is advantageous in terms of a narrow HAZ adjacent to the laser cut surface providing better samples for the analysis of irradiated material with minimum thermal damage and effective reduction in debris spread in air. Underwater laser cutting also results in better natural convection than that in air, which results in reduction of the temperature gradient and thermal stress in the material thereby reducing the possibility of crack formation. It also helps in the removal of the debris from the surface and hence results in better cut surface. In this paper, we report the development of an underwater laser cutting nozzle and process for cutting of metals using in-house developed 250 W average power fibre-coupled pulsed industrial Nd:YAG laser. Underwater cutting of 6 mm thick SS304 and 4.2 mm thick zircaloy using air and oxygen as assist gas has been performed along with analysis of HAZ and microstructure near cut surface.

2. Experimental details

In laser cutting experiments, an in-house developed fibre-coupled pulsed Nd:YAG laser with 400 μm fibre optic beam delivery providing an average output power of 250 W with a pulse duration from 2–20 ms and repetition rate of 1–100 Hz has been utilized. The diverging output beam from the optical fibre was collimated and focused using a 1 : 1 imaging optics, which provided a focussed beam diameter of 400 μm. Two samples, one of a 6 mm thick SS304 and the other of the zircaloy were cut in dry air and then underwater using both air and oxygen as assist gases. The gas/air pressure in both the cases was 12 kg/cm^2. The nozzle tip to work-piece distance was 1 mm. Figure 1 shows the experimental set-up for underwater cutting of metal samples. Initially, both the samples were cut in air and then the samples were placed in water jar, which was mounted on an XY-table. The samples were kept at a depth of 100 mm from water surface. While immersing laser cutting nozzle in water to focus the beam on the samples to be cut, about 2 kg/cm^2 gas pressure was maintained through nozzle, so that water would not enter and deposit

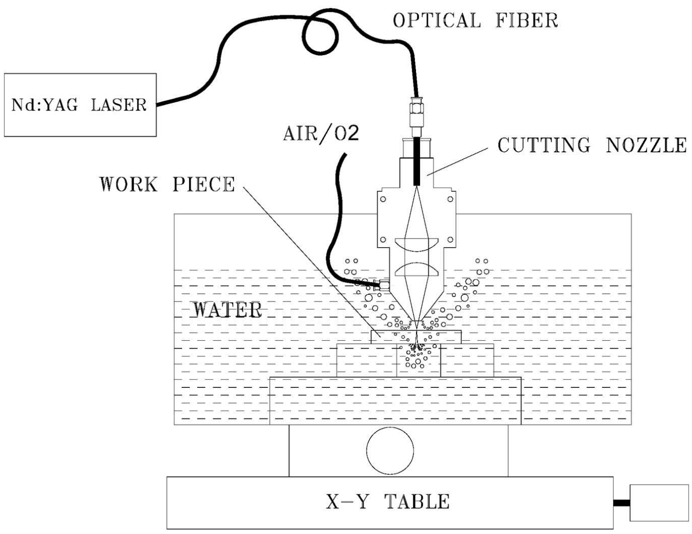


Figure 1. Experimental set-up for underwater laser cutting.

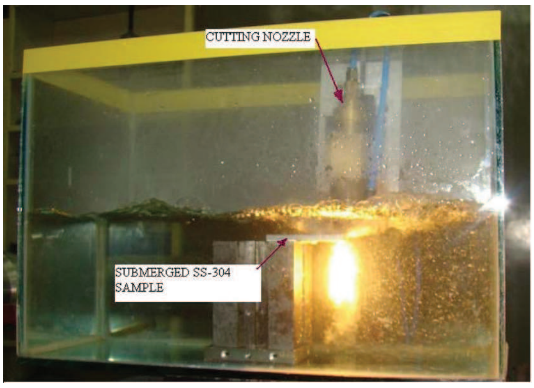


Figure 2. A view of the underwater laser cutting of SS304.

Table 1. Laser cutting parameters for dry and underwater conditions.

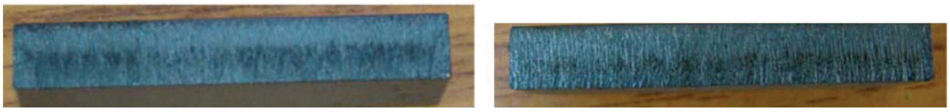
Material	Assist gas	Pulse energy (J)	Pulse duration (ms)	Pulse frequency (Hz)	Speed (mm/min)
SS304 (dry)	Air	33	8	4	16.6
SS304 (dry)	Oxygen	20.3	6	8	33.2
SS304 (underwater)	Air	33	8	4	16.6
SS304 (underwater)	Oxygen	20.3	6	8	33.2
Zircaloy (dry)	Air	18	6	8	33.2
Zircaloy (underwater)	Air	18	6	8	33.2

(a) (b)

Figure 3. (**a**) Underwater laser cut surface of zircaloy using air. (**b**) Laser cut surface of zircaloy in dry condition using air.

on optics through nozzle opening. After focussing the beam, gas pressure was increased to about 12 kg/cm^2 to remove the molten material and XY-table was moved for desired cutting direction.

Figure 2 shows a view of the underwater laser cutting in which submerged SS sample and laser cutting nozzles have been indicated. During underwater cutting a lot of water bubbles are formed. These bubbles burst after coming out on the surface. Water fumes also appear during the process due to heating of water. Table 1 shows a comparison of laser cutting parameters for underwater laser cutting and cutting in dry conditions. It can be seen that energy requirement for cutting with air as assist gas is much more as compared to that with reactive oxygen gas due to energy released during exothermic reaction with iron.



(a) (b)

Figure 4. (**a**) Underwater laser cut surface of SS304 using oxygen. (**b**) Laser cut surface of SS304 in dry condition using oxygen.

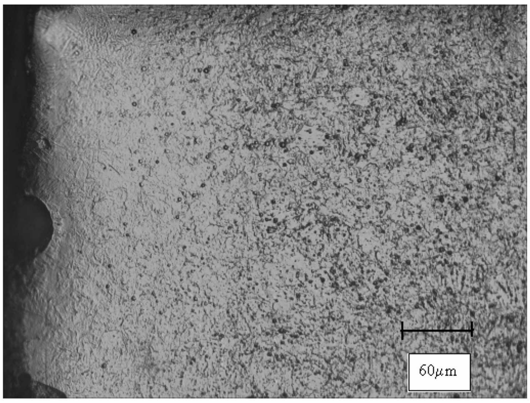


Figure 5. Microstructure in underwater laser cutting of zircaloy using air.

3. Results and discussion

Figures 3a and b show a view of the cut surface of zircaloy underwater and in dry conditions, respectively using air as assist gas. Figures 4a and b show laser cut surface of SS304 underwater and in dry conditions respectively using oxygen as assist gas. It can be seen that in both zircaloy and SS304, adhesion of dross is less in underwater laser cutting compared to that in dry laser cutting. The heat affected zone was about 210 μm in underwater cutting of zircaloy and about 270 μm in cutting in dry condition. Figures 5 and 6 show the microstructure near the cut edge for zircaloy in dry and underwater conditions, respectively. Figures 7 and 8 show microstructure near the cut edge for SS304 in dry and underwater conditions, respectively. It can be seen that there is a change in the microstructure near the cut edge in the HAZ. It can also be seen that dross adherence is less in underwater cutting compared to dry cutting. Further experiments for underwater laser cutting of SS up to a thickness of more than $1/2''$ is under progress.

4. Conclusion

We have developed underwater laser cutting technique for metals using our home-built fibre-coupled pulsed industrial Nd:YAG laser. Using this technique, we have carried out underwater cutting of 6 mm thick SS304 and 4.2 mm thick zircaloy samples. We have also analysed HAZ and found that heat affected zone is less in

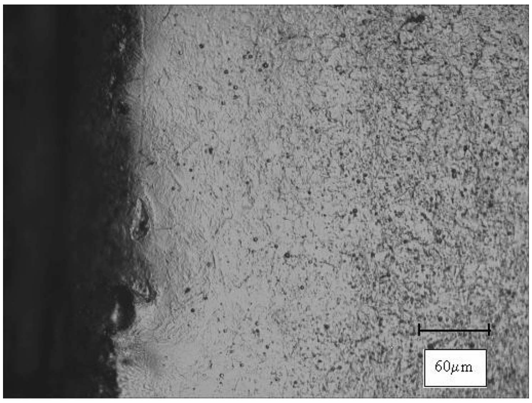


Figure 6. Microstructure in dry laser cutting of zircaloy using air.

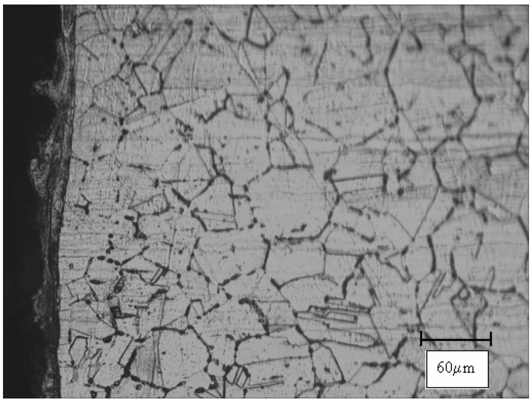


Figure 7. Microstructure in underwater laser cutting of SS304 using oxygen.

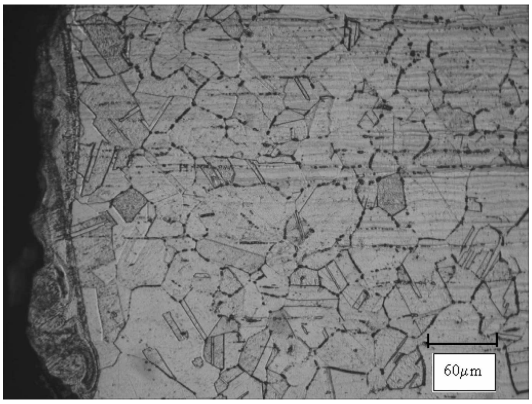


Figure 8. Microstructure in dry laser cutting of SS304 using oxygen.

underwater cutting compared to dry cutting. This underwater cutting technique will be highly useful in nuclear decommissioning and maintenance operation of nuclear power plants.

References

[1] Arvi Kruusing, *Opt. Lasers Eng.* **41**, 329 (2004)
[2] N Morita *et al*, *Appl. Phys. Lett.* **52**, 1965 (1988)
[3] Xudong Zhang *et al*, *J. Laser Appl.* **15**, 279 (2003)