技術報告

Development of Cost-Effective In-situ Repairing Using Laser for Aged Power Plant

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(April 13, 2005)

Repairing of cracks in nuclear power plants is an important issue to be solved. An extremely small heat input is also essential to the prevention of SCC in austenitic stainless steel welds. In the present paper, patch-repairing utilizing a thin metal sheet for the prevention of burn-through in storage pools and pipes was investigated using micro-keyhole type welds produced with Yb disk laser of high quality. A feasibility of patch repairing was demonstrated and confirmed.

Key words: laser, repair, welding,power plant, keyhole, disk laser, fiber laser

1. Introduction

Some of the oldest nuclear power plants in Japan have been used for more than 30 years, which is close to their designed lifespan. The Rules on fitness-for-service for nuclear power plants issued from JSME in May 2000 define allowable crack size, which realizes cost-effective nuclear plants maintenance keeping conservative safety[1]. The rules were revised to add the guideline in in-situ inspection in Oct. 2002. Therefore, in-situ flaw seizing and repairs are urgently required. And laser inspections and laser repairing were developed due to their advantage of easy access[2)-4)]. In the present paper, patched repair of thin sheets for storage pools and pipes was investigated using 300 W Yb:disk laser.

2. New Rules, In-Situ Inspections and Repairs

The Rules on fitness-for-service for nuclear power plants issued in May, 2000 by JSME (JSME S NA1-2000) updated nuclear plant maintenance policy from no acceptance of any flaws to allowance of flaws within an allowable size. In the standard, a component that has a flaw within the allowable size range can continue to be operated. The allowable flaw size varies with the type of material (austenitic stainless and ferritic steel), the thickness, and flaw configuration and shape proportion. The assessment and maintenance should be followed by the flow chart shown in **Fig. 1**[1]. These policies are a drastic improvement in the previous maintenance policy for nuclear power plants, and the standard will realize very acceptable, cost-effective and reasonable plant maintenance. However, application of the standard requires accurate and acceptable inspection methods for measuring flaw sizes[8]. Furthermore, in-situ plant repairing is required with minimum heat input in welding to avoid the SCC sensitization. New repairing performed under allowable crack size should be cost- and time-effective.

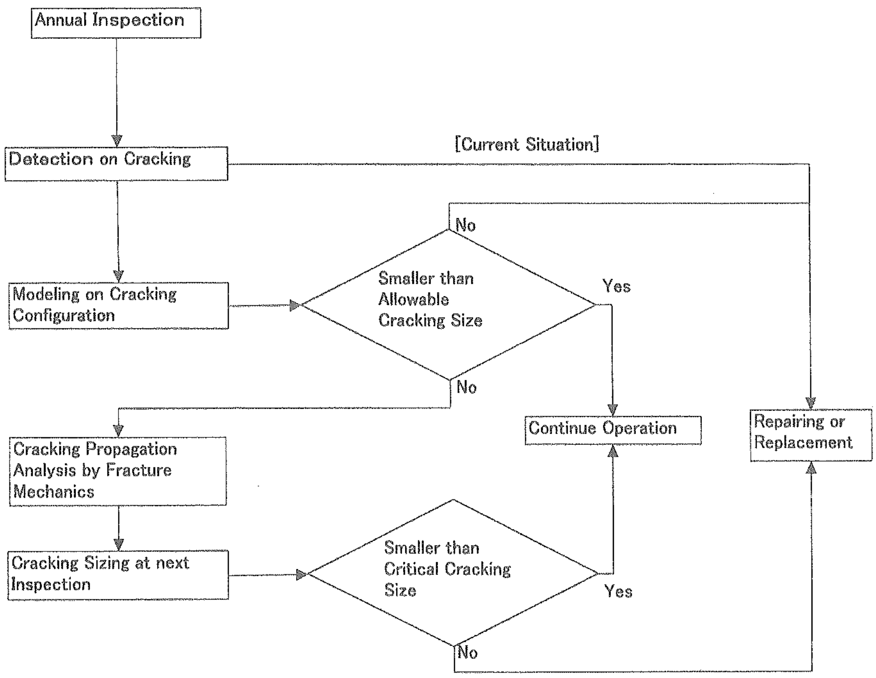


Fig. 1 Flow chart of "Rules on fitness-for-service for nuclear power plants [1), 3)]"

3. Concept of In-Situ Repairing

As mentioned above, nuclear power plants can be operated continuously if a flaw size in a component is within the allowable flaw size as defined by the JSME standard. Conventional repair methods such as replacing components or completely eliminating flaws are improved rationally under the rules, and new concepts for repairing, such as patched repairs using a thin sheet for cracks of around 100μm in depth, as shown in **Fig. 2,** become available after flaw size assessment[4]. The repairing using micro-keyhole type welding with an ultra high beam quality laser will be possible at minimized heat input compared with any other repairing methods or with other heat sources. The experiment on in-situ laser repairing was carried out as shown in **Fig. 2**.

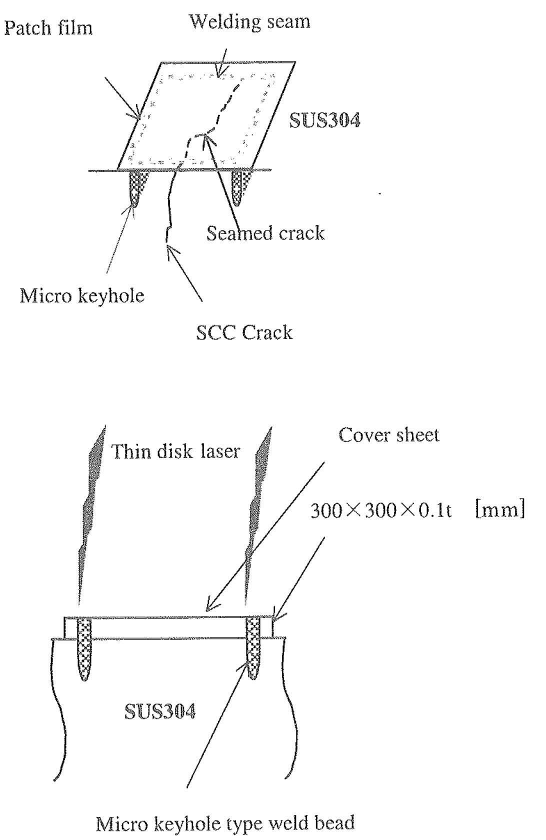


Fig. 2 Thin sheet patched repairing

4. Welding Experiments with Thin Disk Laser

4.1 Specimen

Configurations of specimen, which were decided for obtaining preliminary data in thin disk laser welding satisfy the following requirements:

- The substrate thickness requires more than 5 mm for the construction by micro keyhole welding
- Mechanical flexibility requires patched thin sheet of not more than 200μm in thickness.

To simplify preliminary data, micro keyhole type laser welding was carried out without thin cover sheet. And small heat input allows more than three welded beads on the surface, as shown in **Fig. 3**.

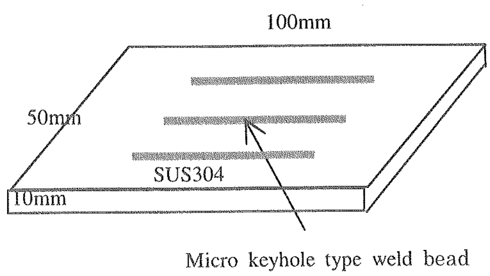


Fig. 3 Configuration of specimen

4.2 Laser welding conditions

For thin cover sheet welding, both substrate surface fitness and shielding stiffness are required. Considering balance in substrate surface configuration fitness and shielding stiffness, cover sheet thickness from 100μm to 300μm will be comfortable, and welding of 100 μm cover sheet was most difficult because of easier formation of burn-through in a thin sheet. In the case of more than 300 μm, weld bead depth required for repair shielding. 300 W was decided as reference CW laser power, and to confirm the micro keyhole formation, the laser power was changed as 500 W to 100 W. The travel speeds were 150 mm/min, 600 mm/min, and 1000 mm/min.

Table 1 Laser welding conditions

Laser power [W]	Travel speed [mm/min]		
100	150	600	1000
300	150	600	1000
500	150	600	1000

5. The Experimental Results and Discussion of Weld Penetration

More than 10^6 W/cm^2 power density at around 100μm beam spot diameter was required for micro keyhole formation. In current situation, there are two tooling options: one is thin disk laser[6] and the other is single-mode fiber laser[7]. Thin disk laser was selected because of the availability in the power range of 500 W in CW mode. The focal length of lens was selected as 200 mm for 150μm beam spot diameter at workpiece, and the shielding gas flow rate was 10 l/min. All of the weld runs were carried out as just focus on the specimen surface. From preliminary experiments using more than 1 kW laser, the frequency of acoustic emission from micro-keyhole was much higher compared with conventional one. This was attributed to high frequency vibration of a keyhole. And very small spatters ware generated at a laser power of 500 W. Micro-keyhole type welding was very stable except slight instability at a travel speed of 150 mm/min at 500 W. Laser welding of the cover sheet was carried out, as shown in **Fig. 4**.

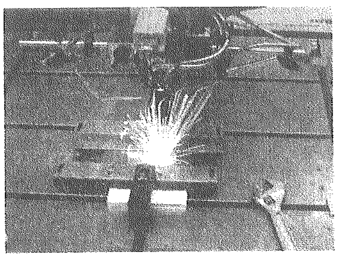
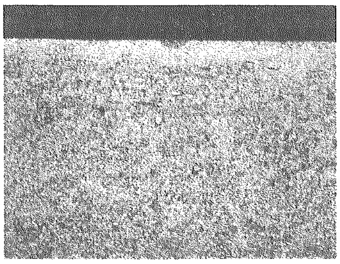
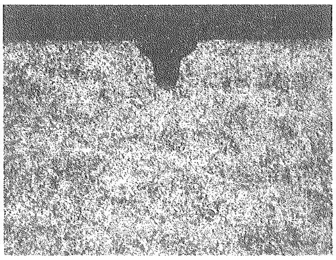


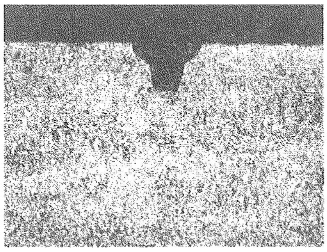
Fig. 4 Laser welding for repairing



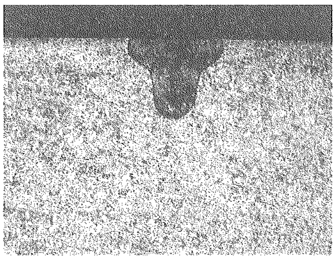
a) Laser power:100 W; Travel speed:1000 mm/min; W=260μm; d=80μm



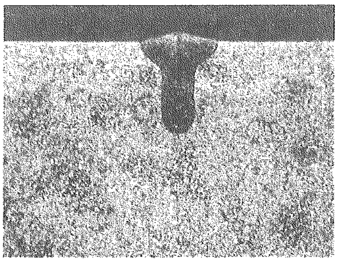
b) Laser power:300 W; Travel speed:1000 mm/min; W=850μm; d=700μm



c) Laser power:300 W; Travel speed:600 mm/min; W=1000μm: d=800μm



d) Laser power:300 W; Travel speed:150mm/min; W=1300μm; d=1150μm



e)Laser power:500 W Travel speed:1000 mm/min;W=1100μm d=1300μm

Fig. 5 Macrosections of laser welds

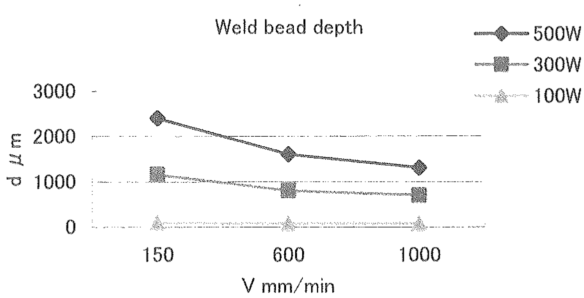


Fig. 6 Travel speed vs. weld bead depth

Macrosections of laser welds are shown in **Fig. 5**.
Relationship between the travel speed and weld bead depth is shown in **Fig. 6**. Keyhole formation is judged to be almost impossible at the power of 100 W at any travel speeds. From **Fig. 5** and **Fig. 6**, at the power of 100 W, the penetration of laser weld was in heat conduction mode and depth were shallower than 100 μm. At 300 W, keyhole formation is possible under any welding conditions, and 700 μm depth was possible even at the speed of 1000 mm/min. At 150 mm/min, the depth was more than 1mm, and around 300 μm depth is enough for thin cover sheet welding. At 500 W, a deeper keyhole was generated, and the weld bead depths were 1.3 mm and 2.4 mm at the speeds of 1000 mm/min, and 150 mm/min, respectively. Consequently, keyhole formation is judged to be almost impossible at any travel speeds at 100 W, while the laser power of 300 W was concluded to be enough for the repairing requirements.

6. Experimental Results of Repair Welding

6.1 Specimen and repairing

Repair welding of cover sheet was demonstrated on a thick austenitic substrate. While the thickness of cover sheet varied from 100μm to 300 μm, and repair welding of 100 μm thickness sheet was most difficult because of easier burn-through formation with a laser beam diameter of 300 μm, as shown in **Fig. 7**. From this result, it was obvious that repair welding of thin sheet is available only by small keyhole at the power density of more than 10^6 W/cm^2. Burn-through is caused by a large joint gap of around 30μm to 50 μm between a cover sheet and a substrate. Thin film burned through at such a lower power density as the formation of heat conduction type weld. An example of successful result is shown in **Fig. 8**, where a weld bead was made at the speed of 3 m/min and 150 W with a laser beam diameter of 150μm. A higher power density was required even for a thinner cover sheet.

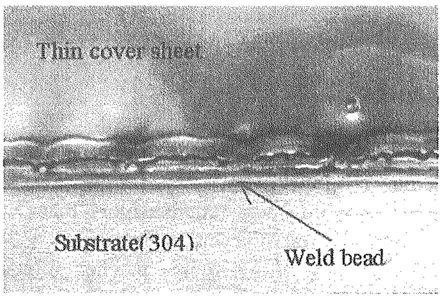


Fig. 7 Burn through in repair welding beam diameter: 300μm

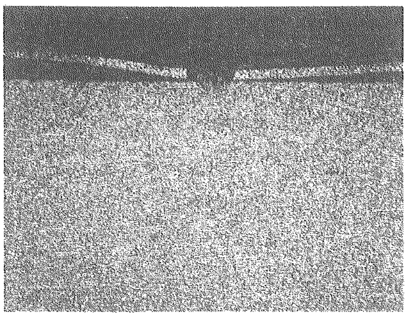


Fig. 8 Macrosection of repair welds by laser

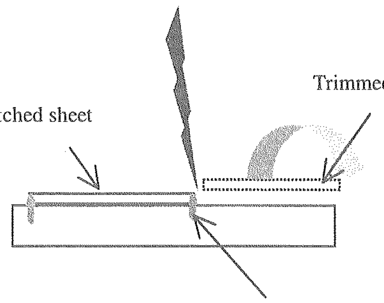


Fig. 9 Edge trimming by laser

6.2 Edge trimming by laser

There is a possibility of crevice corrosion at the edge of cover sheet under water operation. To prevent the corrosion, trimming of cover sheet edge should be required. Edge trimming is easily available by a defocused laser beam. The sheet was melted down outer of the weld bead. An weld bead reacts as a heat sink to prevent over-heating by laser as shown in **Fig. 9**.

7. Conclusions

A micro-keyhole could be generated by high power density of more than 8.5×10^5 W/cm^{2}.

① Both thin disk laser in 1kW and fiber laser in 300W are available in this study, and this study was carried out by 1kW thin disk laser. Under new rules on fitness-for-service for nuclear power plants, laser repair welding concept was developed for time-effective and cost-effective maintenance on aged nuclear components to avoid SCC sensitization. Thin cover sheet prevents SCC propagation.

② This new repair concept was demonstrated in the present work.

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