

技術報告

Newly Undertaken In-Situ Laser Forming Repairs for Aged Power Plants

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Some of the old nuclear power plants in Japan are still running more than 30 years, which are close to their design lifetime. The Rules on fitness-for-service for nuclear power plants, issued in May 2000, proposed to extend the original lifetime of plants. These rules limited allowable flaw sizes in operating plant components. In such circumstances, cost- and time-effective in-situ flaw repairs have been urgently required. Accordingly, laser forming has been investigated as a time-effective repairing of pipe, including computational assessment. The result was in good correspondence with experimental one.

Key Words: Power plant, SCC, Laser forming, Underwater repairs, FEM, In-elastic analysis

1. Introduction

Many laser technologies have been developed in the nuclear and energy industries. The Rules on fitness-for-service for nuclear power plants, issued in May 2000, fundamentally changed maintenance concepts of nuclear power plants¹⁾. The code limited allowable flaw sizes in an operating nuclear power plant components, and under such a rule, time effective and cost effective in-situ repairs are urgently required. In the present work, laser forming of pipe was investigated including computational analysis on forming mechanism by Hitachi as a time- and cost-effective repairing method.

and 40% of electricity is currently generated by nuclear power station in Japan. But a serious economic recession had hit Japan since 1991. It is difficult to be recovered. It arose from the matured economic structure, which provided little chance for further growth. With this in mind, manufacturers of nuclear power plants have been studying the extension of plants' original lifetime using allowable flaw size concept. Some nuclear power plants are already more than 30 years old. JSME issued the Rules on fitness-for-service for nuclear power plants(JSME S NA1-2000) in May 2000, which limits allowable flaw sizes in operating nuclear power plants¹⁾. Cost effective repairing to keep allowable flaw size will be required in accordance with this rule in the nuclear future. Flaws within the allowable size do not require integrity analysis.

2. Background

Commercial nuclear power plants entered commission in 1970

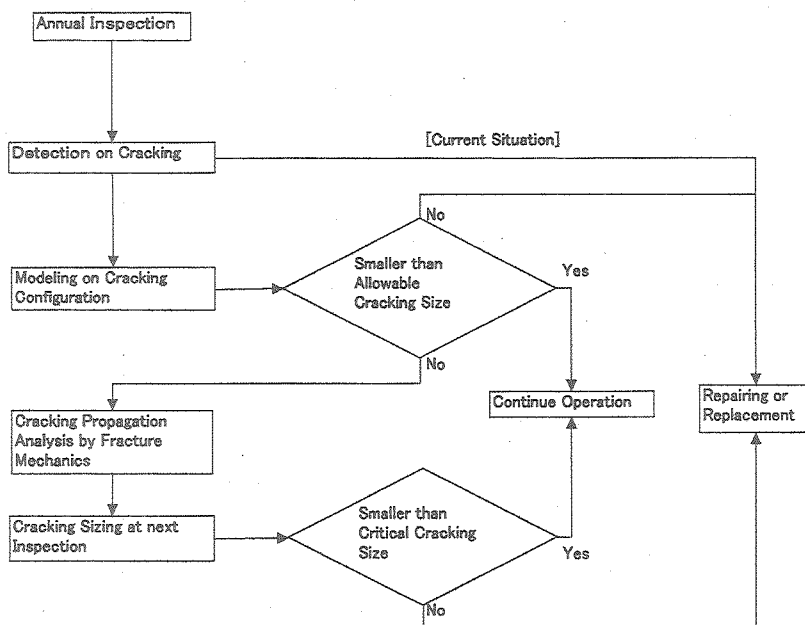


Fig. 1 Flow chart of Rules on fitness-for-service for nuclear power plants²⁾

Necessary repairing should be carried out with low heat input to avoid SCC (Stress Corrosion Cracking), because aged base metal of component are significantly decreased in ductility. Laser forming repair experiments have already been studied since 1997 by authors³⁾. And its forming mechanism was theoretically and quantitatively clarified by computational analysis using in-elastic analysis code MARC. A new laser forming repairing was developed to meet the new Rules on nuclear power plants.

3. New Rules Required Cost-effective In-Situ Repairing

The Rules on fitness-for-service for nuclear power plants have updated nuclear plant maintenance policy. From that any cracks is not acceptable to allow cracks flaws within an allowable size, and repairing methods guideline was added in 2004. A component that has a flaw within the allowable range can be operated continually. The allowable flaw size varies with the type of materials (for example, austenitic stainless and ferric steel), thickness, and flaw configuration and geometrical proportion. The assessment and maintenance policy are shown in Fig. 1 as the flow chart. These policies are a drastic improvement on the previous maintenance policy for the manufacturers of nuclear power plants, and these rules will realize very acceptable, cost-effective and reasonable plant maintenance^{2), 7)}. Repairing in which crack propagation is minimized to keep in allowable flaw size, operation will be possible. In-situ plant repairing should be performed in radioactive operation spaces, which are much smaller than factory production lines. In such a situation remote processing repairs will be very useful compared with conventional welding repairs^{3), 4)}. Conventional repairing which renews damaged components and welds a new part needs too much time and cost. Laser forming repairing in compliance with new rules will be most required method in such a situation in the near future. In conventional welding process, damaged area is not cut off and is only covered with clamping tube made of rolled plate with laser welding. In addition, cooling water drain and in-situ welding are required after cutting, to minimize heat input.

4. Laser Forming Repairing Method Meets New Rules

Almost of nuclear power plant components such as reactor vessels' inner structures and piping are a cylindrical structure. Laser forming clamp is suitable for repairing such a cylindrical structure. Furthermore, laser forming repairs make minimum heat input on substrate, because SCC often caused by too much heat input during welding. A laser forming of pipe developed by the author, experiments assisted by Kutsuna⁵⁾ using quasi-CW YAG laser. This pipe repairs was an outstanding result in place of a conventional partially exchanging pipe repairs, and this process requires very low heat input for repairing. This method shown in Fig. 2 is time- and cost-effective process with minimum heat input for pipe repairing even underwater⁶⁾.

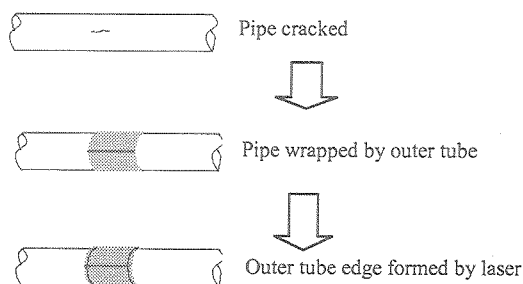


Fig. 2 Concept of laser forming for pipe repairing

5. Experimental Procedures: Laser Forming for Pipe Repairing

In laboratory quasi-CW YAG laser in 50 Hz was used. These experiments were carried out on austenitic stainless steel plate of 0.5 mm in thickness, and pipes of 0.5 mm in wall thickness and 25.4 mm in inner diameter³⁾. The laser bending angle of the plate and deformed pipe hollow depth were controlled by laser power, number of pass, and travel velocity. To clarify quantitative bending force, laser forming experiment were carried out on austenitic planar rectangular stainless steel plate of 0.5 mm×30 mm×70 mm in size. These specimens shown in Fig. 3 were for taking quantitative evaluation coefficient for computational analysis of deformation. Laser forming has been carried out by quasi-CW 300 W YAG laser. Showing pipe repairing concept, austenitic stainless steel pipe of 0.5 mm wall thickness, 25.4 mm inner diameter with 100 mm length were bended shown in Fig. 4 under the laser bending conditions shown in Table 1. 300 W quasi-CW YAG laser was used to planar rectangular specimen under the same conditions.

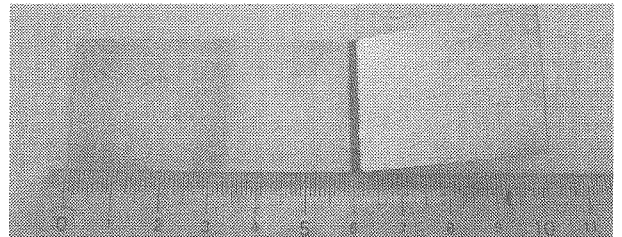


Fig. 3 Photo of plate specimen

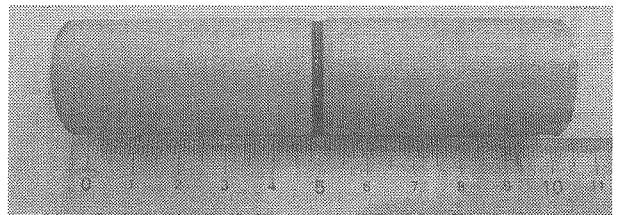


Fig. 4 Photo of pipe specimen

6. Experimental Results in Planar Specimen

The bending angle were controlled by quasi-cw laser power in 50 Hz³⁾, the number of pass, beam spot diameter, and travel speed shown in Table 1. Bending angle is proportional to number of pass, as shown in Fig. 5³⁾.

Table 1 Forming conditions

condition	Spot diameter [mm]	Laser Power [W]	Travel speed [mm/s]
1	3.9	250	30
2	3.9	250	48.5
3	3.9	250	78
4	3.9	310	30
5	3.9	310	48.5
6	3.9	310	78

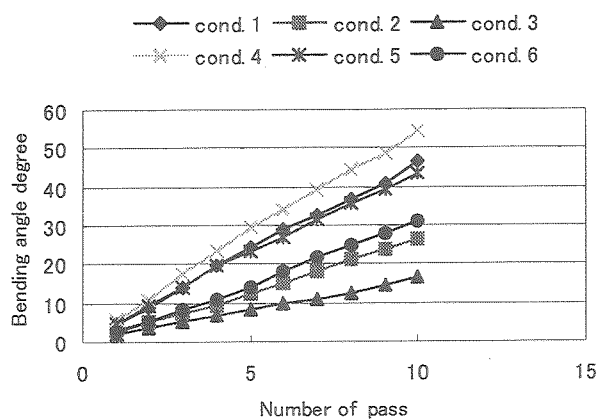


Fig. 5 Bending angle in plate

7. In-Elastic Simulation on Plate Bending

Laser bending of stainless steel plate of 0.5 mm in thickness, 30 mm width, 30 mm length was analyzed using in-elastic 3 dimensional solid model code named MARC. Used FEM model is shown in Fig. 6. The model was symmetrical with beam scanning line, so a half of the plate is simulated.

300 W Quasi-CW YAG laser was irradiated at lower power of 250 W and 310 W in 50 Hz, and heat flux of laser beam can be given as following equation:.

$$q = C \times W / A \quad (1)$$

q: heat flux from beam spot [cal/(mm²·sec.)]
C: absorption rate [%]
W: Laser power [W]
A: laser beam spot area [mm²]

On the beam line, time histories in temperature at the top surface, middle location, and bottom surface are shown in Fig. 7. According to the result, maximum temperature difference in the top surface and bottom surface is more than 600°C, which is bending motive force. Assessment on time history in the residual stress on the top surface, and middle location, and bottom surface, of which direction is symmetric line and perpendicular to symmetric line are shown in Fig. 8 and Fig. 9. Residual stress in symmetric line is strongly restrained by in-plane stiffness, which causes larger residual stress of more than 200 MPa. Residual stress perpendicular to symmetric line is motive force of bending and these stress was smaller caused by bending stress releasing.

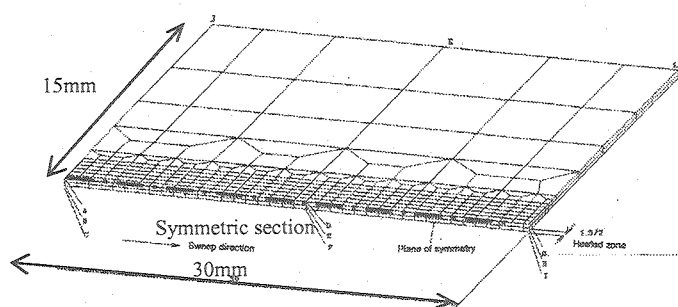


Fig. 6 Plate bending model

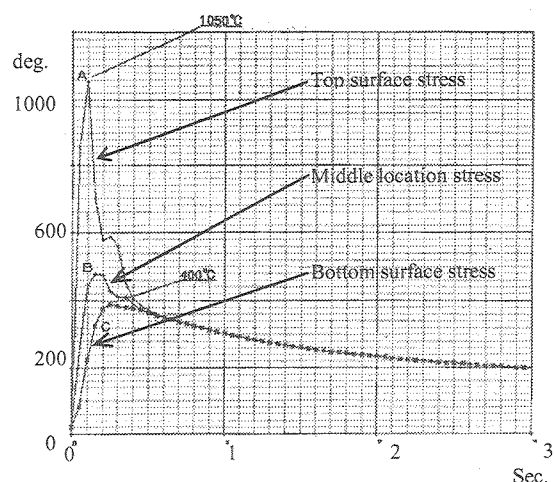


Fig. 7 Time history in temperature

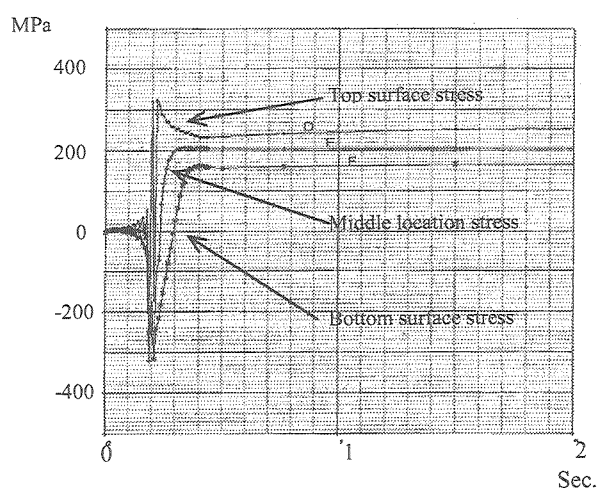


Fig. 8 Time history in stress of symmetric line direction

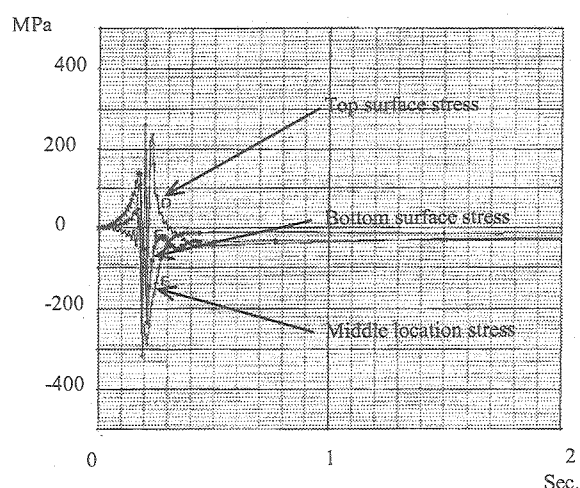


Fig. 9 Time history in stress of perpendicular to symmetric line

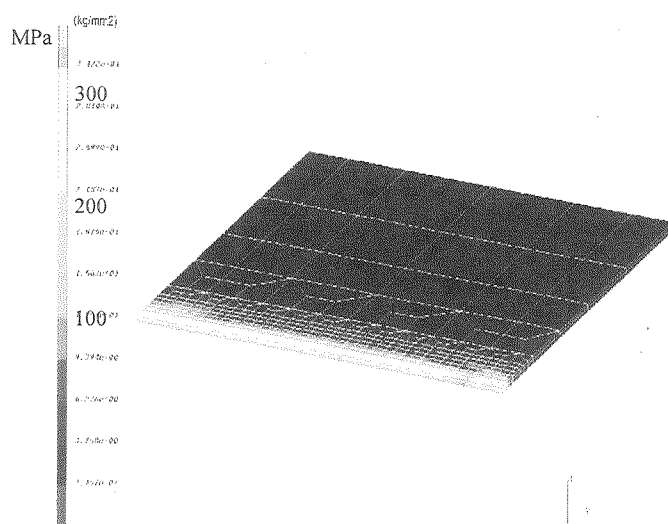


Fig. 10 Analyzed results in plate bending

From experimental bending angle, numerical beam absorption rate was determined as 45% and the accuracy is within 5% on bending angle. Analyzed displacement, bending angle and stress were shown in Fig. 10 as 3 dimensional colored figure.

8. Tubular Experimental Results

Laser bending in stainless steel pipe of 0.5 mm wall thickness, 25.4 mm diameter, 100mm length was analyzed by in-elastic 3 dimensional solid model which is the same as planar model as figured above. Analyzed tubular model is shown in Fig. 11. The model was symmetric with the section figured by beam scanning circle line and axially half of pipe model used in this analysis.

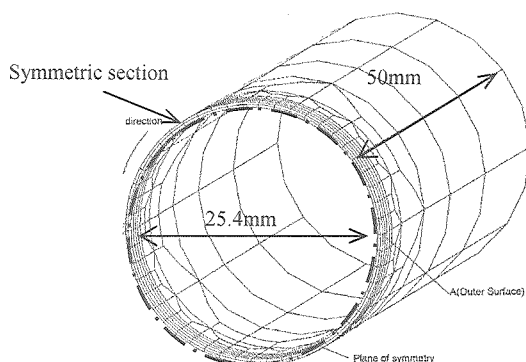


Fig. 11 Pipe model

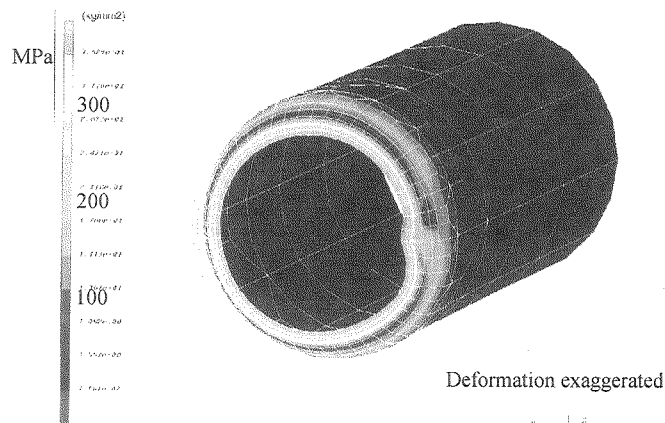


Fig. 12 Analyzed results in tubular forming

Pipe forming analysis is made in the radial direction hollow as well as the experiments. Analyzed radial hollow and stress are shown in Fig. 12 with 3 dimensional figure. Author got accurate radial deformation by defining equivalent beam spot diameter. In this model beam spot configuration is rectangular, which required experimental equivalent spot diameter. Radial deformation was proportional to number of pass, same as plate.

9. Conclusions

In accordance with the Rules on fitness-for-service for nuclear power plants, it is possible to do cost effective and time effective repairing within allowable crack size and laser forming pipe repairing can be realized in minimal heat input repair to prevent SCC. Pipe deformation mechanism and quantitative hollow displacement evaluation was analyzed by in-elastic FEM analysis. As a result, laser forming deforming repairs realize remote pipe repairing and have excellent reappearance in clamping outer tubes' hollow depth.

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