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Detection of Wall-Thinned Defects Using IR Thermography

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1. Introduction

Recently, the number of the life-extended nuclear power plants (NPPs) is increasing. Thus, the degradation can occur in the various structures of the NPP secondary systems caused by the fatigue or corrosion, etc. Among these problems, the wall-thinned defect by the fluids of the inner wall can break the pipe due to the local stress concentrations [1]. This cases have already emerged as an important issue in terms of ensuring the soundness and safety in NPPs. There are many NDT techniques to detect the wall-thinned defect from the inner wall. The infrared thermography which is one of these techniques provides real-time images by scanning the temperature of the target surface and then, converting it to the temperature [2]. This technique can solve the existing problems by identifying the presence or absence of the defect through observation of the temperature difference.

2. Theoretical Background

2.1 Infrared Thermography

When a specific target is heated from the outside, thermal diffusion is interrupted by the defect in the target. The temperature difference occurs on the surface of target by the insulation caused by the defect. The infrared thermography technique is to measure the shape and location of the defect in the target by analyzing the temperature distribution on the target surface.

2.2 Kirchhoff's Radiation Law

If the radiation is passed to the target, images appear in the form of the three ways of the reflection, absorption, transmission by the types of target and surface conditions. These ingredients can be expressed by Kirchhoff's radiation law [3]:

$$1 = \varepsilon + \tau + \beta\left(\varepsilon \le 1\right) \qquad (1)$$

In Eq. (1), ε is the absorptivity, τ is the transmissivity, and β is a reflectance. And it can give the exact values when emissivity is high and transmissivity is low. In case of metals with a low emissivity, it is possible to maintain the emissivity at 0.95 by spraying reflective paint.

3. Experimental Equipment and Methods

3.1 Specimen

In this experiment, the pipe specimen was processed with the defects in pipe inner walls. To perform this study, 4-inch diameter-pipe specimen using the Shc.80 ASTM A106 Gr.B material such as the actual NPP's material was manufactured.

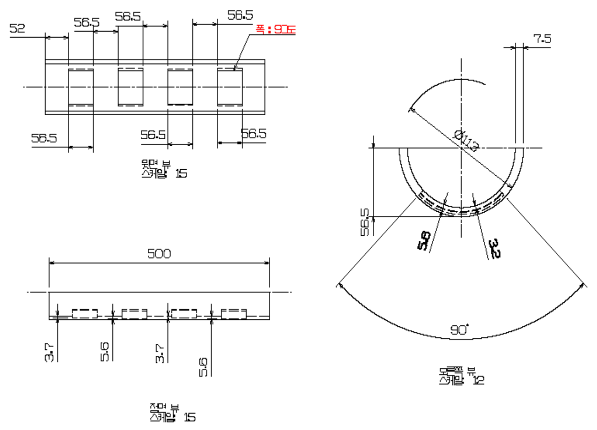

Fig. 1. Specimen

As shown in Fig. 1, the defects that are type of square and have each certain depth are provided artificially to the inner side of the specimen that has size of full-length (l) 500mm, thickness (t) 7.5mm and diameter (D_0) 113mm. The four defects as L/D_0=0.5 (L=56.5mm) are processed in the specimen. The shape of each side defects as shown in Table I.

Table I: Dimensions of defects in the pipe specimen

	Dimensions of defects
Circ. Angle, θ/π	0.25
Depth, d/t	0.5, 0.75
Length, L/D_0	0.5

3.2 Simulation Methods

To carry out this study, the 1kW halogen lamps were chosen as the heating equipment. To find out the optimal experimental conditions and the effect of heating equipment, simulation analyses using the Ansys fluent program were performed. The basic modeling was conducted for the pipe and the lamps in the X-Y-Z coordinate space. The pipe was modeled with the same specimen properties with ASTM A106 Gr.B. And the defects of the same size with ASTM A106 Gr.B were generated artificially. The analysis was performed by adjusting the distance between the lamp and the specimen. And the heat flux of the lamp was adjusted as 50, 60, and 80% of the 1kW halogen lamp.

3.3 Experiment Methods

The temperature of the piping system maintains the room temperature during the maintenance period (Overhaul) of NPPs. Thus, this experiment was done after checking that the temperature of the specimen was room temperature too.

The experimental equipment consists of the IR camera (FLIR Siver 480M), two halogen lamps (1kW, 2ea) and a PC. This experiment was carried out in the sealed room, and the space temperature and humidity was kept constantly by using the air conditioner.

In the case of the overhaul period replica experiment using the heating equipment, the specimen was set to room temperature, and this experiment was carried out by adjusting the intensity of the halogen lamps. The distance between the specimen and the IR camera was fixed at 1m, and the distance between the halogen lamps and the specimen was fixed at 1m or 2m. The intensity of 1kW halogen lamps were set to 50%, 60% and 80%.

4. Result

4.1 Simulation

Fig. 2 indicates the computer simulation results according to the distance and intensity of the lamps.

The temperature distribution was not clear at the defect depth of d/t=0.5, that is, the first and third defects from the left of each figure. But the shape of defect was shown clearly as the heat flux goes up.

As a result of simulation, the detection efficiency of the defects is expected to be better according as the heat flux is higher and the distance between the lamps and pipe is closer (1m rather than 2m).

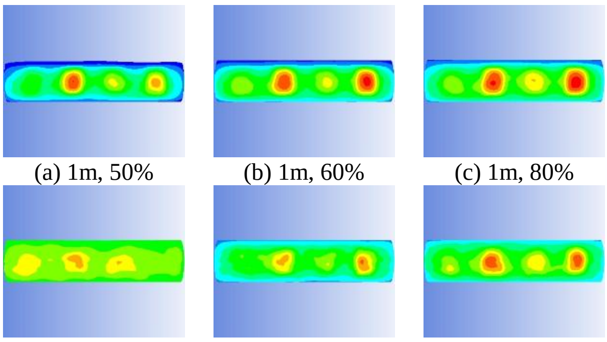
(a) 1m, 50% (b) 1m, 60% (c) 1m, 80%
(d) 2m, 50% (e) 2m, 60% (f) 2m, 80%

Fig. 2. Computer simulation results

4.2 Experiment

Fig. 3 shows the IR images measured in the pipe specimen according to the distance and intensity of the halogen lamps.

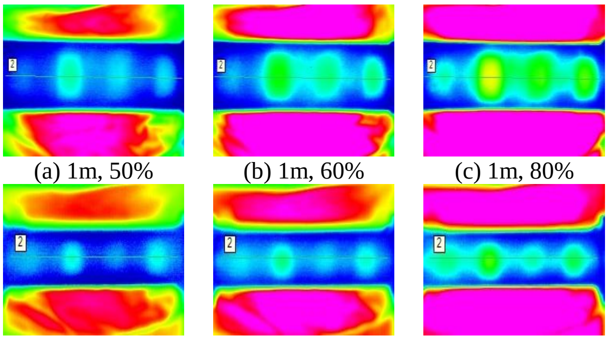
(a) 1m, 50% (b) 1m, 60% (c) 1m, 80%
(d) 2m, 50% (e) 2m, 60% (f) 2m, 80%

Fig. 3. IR images of defective pipe specimen

The defects were identified from all of the test conditions, regardless of the intensity of the halogen lamp. However, the clarity of the defect depth of d/t=0.5 was lower than that of the defect depth of d/t=0.75.

And the defects were clear when the distance is 1m and the intensity of the halogen lamps is above 60%.

5. Conclusions

In this study, the infrared thermography technique was applied to detect the wall-thinned defects. The specimen was produced by processing various types of defects. And the shape of a specimen applied to the experiment is same on the simulation modeling. In result of the simulation, as near as distance between pipe and halogen lamp and as higher as intensity of the halogen lamp, the defects was able to be found easily, and it was proven in the experiment. Also, in the experiment based on simulation results, the defects were identified better when the distance from the lamps was closer and the intensity of the lamps was higher. In case of using the 1kW halogen lamp, the optimal conditions to be applied to the field is that the distance from the pipe to the halogen lamp is 1m and the intensity of the halogen lamp is above 60%.

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