Internal Defect Detection of Dissimilar Weld Pipe Using Ultrasonic Infrared Thermography

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Abstract
This study detected internal defects of pipes using the Ultrasonic Infrared Thermography Method and the Lock-In Image Treatment Method among infrared thermography method. An ultrasonic wave generator of 20 kHz oscillation frequency was made utilizing this characteristic and the experiment was conducted with 420 Watt output. For the test specimen, whether defects exist or not was determined by the Ultrasonic Thermography Testing using pipes made by dissimilarly welding STS304 and Inconel 600, and the defects were verified through the Liquid Penetration Testing. According to the experiment result, the defects existing at the heat affected zone (HAZ) of the STS pipes after the weld zone were detected even when inducing ultrasonic waves to the parts of the pipe where the material is Inconel 600 at the pipe weld zone of different materials. By using the Lock in Ultrasound Infrared Thermography Method, the internal defects of dissimilar metal weld joints of pipes used at nuclear power plants could get detected, and the locations and shapes of detects could get determined.

Keywords: Dissimilar metal weld joint, Ultrasonic, Lock in, Infrared Thermography (IRT)

1. Introduction

Safety examination of weld joints of the pipes that are the most fundamental structure to constitute these nuclear development facilities is especially a vital part to consider. Recently dissimilar metal weld cracks were observed at V.C Summer Nuclear Power Plant and other places [1, 2]. Cracks were generated at Inconel Dissimilar Metal Weld Joints and PWSCC (Primary Water Stress Corrosion Cracking) was the main cause for the cracks. PWSCC generates by mutual reactions of three factors such as material sensibility, weld joint residual tensile stress and in-service load while using and corrosion environment [3]. Necessary condition for the generation of SCC (Stress Corrosion Crack) is when the major three factors (tensile stress, sensitive material, corrosion environment) are satisfied. The weld joints of a nuclear power plant are mostly consisted of pipe butt weld joints, and if considering the fact that recently PWSCC is generating at the Dissimilar Metal Weld Joints of PWR (Pressurized Water Reactor), an examination method to detect SCC at the Dissimilar Metal Weld Joints is necessary. Examinations of nuclear power plants so far were to utilize Radiographic Test (RT) at the stage before the installation of a power plant and to utilize the Ultrasonic Test (UT) after its operation, however because power plant facilities are always exposed to radiation and the UT is always conducted in a broad range, many difficulties exist. Especially, the defect detection of dissimilar weld joints has a difficulty in that in many cases, the surface condition is not even and the signal analysis according to the differences of material’s acoustic resistance is not easy, so that its examination time takes longer. As a method to remedy these issues, the IRT (Infrared Thermography Nondestructive Method) was adopted. IRT is a method to detect the infrared energy emitted by all objects above absolute temperature 0 K, create an image that is visible to the test and examine it, which has a merit in examining a broad range within a short time being without making a contact. By utilizing the IRT and attempting the defect detection of weld joints, the IRT’s potential possibilities are examined.
2. Experiment Material and Apparatus

2.1 Experiment Material
The specimen used in this experiment was the specimen prepared by the dissimilar butt weld treatment of STS 304 pipes, and for the defect detection, the pipes with 3 inch diameter and 7.6 mm thickness were cut in the middle in the axial direction as shown in Fig. 1 and the locations and the shapes of the internal defects of the pipes were compared. Chemical components, and mechanical and physical properties are shown in Table 1.

![Fig. 1 Section of a dissimilar weld pipe](image)

<table>
<thead>
<tr>
<th>Materials</th>
<th>S</th>
<th>Si</th>
<th>Mn</th>
<th>C</th>
<th>Ni</th>
<th>Cr</th>
<th>P</th>
<th>Fe</th>
<th>Al</th>
<th>Cu</th>
</tr>
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<tbody>
<tr>
<td>Inconel600</td>
<td>0.01</td>
<td>0.4</td>
<td>0.8</td>
<td>0.012</td>
<td>76.00</td>
<td>15.50</td>
<td>-</td>
<td>8</td>
<td>0.231</td>
<td>0.4</td>
</tr>
<tr>
<td>STS304</td>
<td>0.02</td>
<td>0.9</td>
<td>1.8</td>
<td>0.08</td>
<td>8.00</td>
<td>18.00</td>
<td>0.04</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

2.2 Experiment Method

2.2.1 Weld Condition
Among infrared thermography nondestructive methods, there exist passive methods utilizing only infrared energy and active methods detecting defects by adding energy to the specimen and changing internal infrared radiation energy of the specimen. These active methods mainly include methods using optic wave, ultrasound, vibration, Eddy current, microwave, etc. For this research specifically, the Ultrasonic Infrared Test, which is an easy method for fine crack detection was used. The procedure of Ultrasonic Infrared Test is shown in Fig. 2. If contacting an ultrasonic wave horn to the specimen and inducing 20 kHz ultrasonic wave, the generated ultrasonic wave transfers the specimen to a medium, a vibration generates at the defect detection part and the generated frictional heat gets detected as an infrared camera detects the temperature change [4].

![Diagram of Ultrasonic Infrared Test](image)
3. Experiment

To detect the defects of weld joints of dissimilar metal pipes, it was set up as shown in Fig. 2 and a vibration was induced. The frequency was 50 mHz, 20 KHz ultrasonic wave and 420 Watt acoustic energy were used. Fig. 3 (a) shows the infrared thermography image of the pipe before the inducement of vibration. When using a passive method without knowing the defect part, whether the defect exists or not cannot be determined. Fig. 3 (b) shows the generated pipe image when inducing ultrasonic wave. Unlike the appearance before the vibration inducement, it is observed that a slight temperature change of 0.1°C with the hot spot occurs.

Rough locations and size of defects at pipes can be determined through Fig. 4 where the heat signals are processed into data and clearly listed. In case of ultrasonic testing, as the defect is tested by generating ultrasonic wave and using the modification of the sound wave, the ultrasonic wave operates differently depending on the influence of the medium and it becomes difficult to test the defects, however since the ultrasonic wave utilized in this research is the energy playing a role to generate a vibration, the defects at the part where its energy affect can be defected. For this reason, the parts where the defects detected at the thermography are generated when inducing ultrasonic wave to an Inconel 600 pipe were observed at the heat-affected zone (HAZ) near the weld zone of STS 304, and the defect
shape was appeared as a rounded rectangle at a broad part, not as a circle so that it was predictable that the defects exist as cracks in a broad area than as a single crack. When the internal cracks exist upon the Ultrasound Infrared Thermal Test, hot spots are defected as a shape of a single circle or line. However, in case of Fig. 4, it was determined that the defect existed not as a single part, but covering a broad area.

![Fig. 4 Defect Detection of Pipes Using Lock-In Thermography Method](image)

Fig. 4 Defect Detection of Pipes Using Lock-In Thermography Method

Fig. 5 shows an image of defect detection and an internal image of a pipe. Through the image of internal defect, it was determined that the defect location of the defect detection image tested from outside and the actual defect location inside were identical. By an actual PT test shown in Fig. 5, it was observed that the cracks inside the pipe existed not as a single crack but rather as a multiple cracks within a certain area and generated a hot spot image of a broad area on the thermography image.

![Fig. 5 Defect Detection of Pipes Using Liquid Penetration Inspection](image)

Fig. 5 Defect Detection of Pipes Using Liquid Penetration Inspection

4. Conclusion

In case of dissimilar weld metals, more than two materials are used, and this characteristic of material affects the ultrasonic signals and eventually generates defect detection errors. Also, when the shape or roughness of a dissimilar weld joint surface is irregular or when the contact of ultrasonic probe becomes not easy, the defect detection of Ultrasonic Testing becomes even more difficult. There present difficulties to determine the directional property of an internal crack inside a pipe due to characteristics of Ultrasonic Testing. However, when utilizing the ULT technology, it has an advantage that the defect detection is achievable regardless of axial or circumferential direction.
By using the Lock in Ultrasound Infrared Thermography Method, the internal defects of dissimilar metal weld joints of pipes used at nuclear power plants could get detected, and the locations and shapes of detects could get determined. According to the experiment result, the defects existing at the heat affected zone (HAZ) of the STS pipes after the weld zone were detected even when inducing ultrasonic waves to the parts of the pipe where the material is Inconel 600 at the pipe weld zone of different materials. The shape of pipe defect was observed as hot spot shape. Although it was not easy to determine whether defects exist or not by minor temperature differences at the Thermography that was not treated with image signals, when utilizing the Lock-in method, the defects were clearly observed.

References