proceedings

*Abstract*

# Nondestructive testing of joint by active infrared thermography†

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**Abstract:** As part of recent measures to combat global warming, automobiles are required to be electrified and their weight reduced, leading to the advancement of multi-material structures that include aluminum alloys and aluminum die castings. Conventional fusion welding methods for joining aluminum alloys and steel materials have poor joining performance due to differences in thermal conductivity between the materials and the presence of oxide films. Friction stir welding (FSW) has been attracting attention in recent years because they are solid-phase joining methods and can also be used to join dissimilar materials. In this study, three types of FSW overlay joints were fabricated:AA6111, an aluminum alloy, was used for the upper plate, and AA6111, AA6061, an aluminum alloy, and DX30, a die cast material, were used for the lower plate. Non-destructive testing was performed on each joint to instantly inspect and visualize joint defects. In the case of FSW joints, no difference was observed in the heat transfer process when the joint was heated directly, but the location of the hooking could be identified by heating from a distance from the joint. The results of the analysis of the temperature change at the defect location showed a difference in heat propagation.

**Keywords:** nondestructive testing; infrared thermography; FSW

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## 1. Introduction

The automotive industry is aiming to improve fuel efficiency through electrification and reduction of vehicle weight, as well as to improve collision performance in order to comply with stricter collision safety regulations. multi-material structures incorporating lightweight aluminum alloys and aluminum die castings are becoming increasingly common in automobiles. Resistance spot welding employed in conventional joining techniques for car bodies is unreliable for joining dissimilar materials using aluminum alloys due to differences in thermal conductivity between the materials and the formation of brittle intermetallic compounds during joining. Moreover, mechanical joining techniques are also employed, but these techniques require additional materials such as rivets, resulting in an increase in the weight of the car body. Friction Stir Welding (FSW) is a joining technique of dissimilar materials using the frictional heat and plastic flow generated during joining. In the case of overlapping FSW joints for aluminum alloys, hooking occurs inside the joint as shown in Figure 1, the fatigue crack of the joints occurs from this hooking. Thus, it is important to identify the location and shape of the hooking to estimate fatigue damage behavior of the joints. This study proposed an active infrared thermography using the thermal energy of a laser as a heating source to establish a nondestructive inspection method to identify the location and shape of hooking and defects inherent in the joint. Laser heating conditions were employed to consider the high thermal conductivity of aluminum alloys as described later, and the results were compared with the reflection method employed in the conventional active infrared thermography.


(a) Cross-sectional image. (b) Fatigue crack.

Figure 1. Cross section of the fatigued FSW joint.

## 2. Experimental procedure

### 2.1 Materials

This study employed two types of wrought aluminum alloys (AA6111 with a thickness of 2 mm and AA6061-T6 with a thickness of 3 mm). The overlap FSW joints was placed in the upper and lower sheets of AA6111 and A6061, respectively, and the overlap length was 40 mm. The center of the overlapped area was inserted in the FSW tool with a shoulder diameter of 15 mm, a probe diameter of 5 mm, and a probe length of 3.9 mm, after then joined by FSW in length of 270 mm. The advancing side of FSW, where the tool rotation direction coincides with the advancing direction, is the lower sheet side, and the retreating side, where the tool rotation direction does not coincide with the advancing direction, is the upper sheet side.

### 2.2 Nondestructive testing of joints using active infrared thermography

This study was conducted to perform a nondestructive testing using an active infrared thermography with laser heating. This method visualizes the cross-sectional state of the object by irradiating the thermal energy of a laser through the object, resulting in a temperature and phase differences if there are differences in the thermal diffusivity between the sound and defective areas as it passes through the object, and then observing the heat transfer process with an infrared thermography. The active infrared thermography has the advantage of non-contact, easily available measurement of two-dimensional images. Heating methods in active infrared thermography are either reflection methods, in which the measured surface of object is heated directly, or transmission methods, in which the measured object is heated from behind. However, it is difficult to determine the temperature difference in materials with high thermal conductivity, such as aluminum alloys, by the reflection method using flash heating, and to capture the time variation of the heat transfer process with respect to the thickness of the measured object by the transmission method [1]. Therefore, we considered that the location and shape of the hooking could be determined by heating the laser not directly above the joint, but on the lower sheet side of the overlapped joint, as shown in Figure 2, and then capturing the heat conduction process from the lower sheet side. This method is defined as the indirect

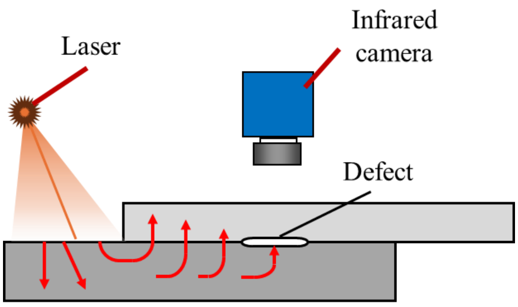
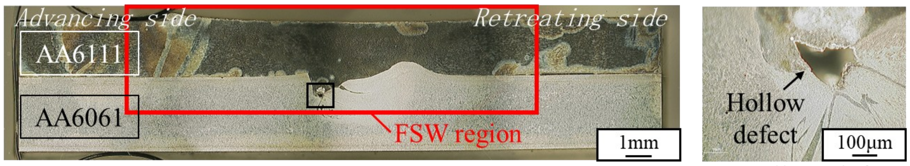



Figure 2. Indirect transmission method.

transmission method, and was compared with the reflection method. Since it is difficult to detect the heat transfer process in detail only by the time-series temperature fluctuation of infrared radiation, we performed discrete Fourier analysis (DFT) on the time-series temperature fluctuation data to evaluate the temperature and phase changes in the heat transfer process after the end of laser heating.

## 3. Results and discussion

Figure 3 shows the observation results of the cross- section of the joint. In the FSW area, aforementioned hooking and a hollow defect called a wormhole were generated in the plastic flow area during joining. Figure 4 shows the results of nondestructive testing of the joint. From left to right, the figure shows the results of nondestructive testing by X-ray of the joint, the results of active infrared thermography by the reflection method and indirect transmission method, respectively. In each of the results of active infrared thermography, from left to right are the infrared image at the maximum temperature, and the temperature and phase information analyzed by DFT. First, the location of defects was identified from the X-ray transmission images, but the location of hooking was not yet identified. Secondly, neither the temperature nor the phase of the active infrared thermography using the reflection method showed any difference in the heat propagation due to hooking or defects. On the other hand, the indirect transmission method showed differences in heat propagation due to hooking and defects, from which the locations of hooking and defects could be identified [2].




(a) Cross-sectional image. (b) Hollow defect.

Figure 3. Cross section of defective FSW joint.

## 4. Conclusions

The results of this study show the possibility of using active infrared thermography to identify the location of defects inherent in joints by selecting a heating method that is appropriate for the thermal conductivity and thickness of the material selected for nondestructive inspection of the joints. It was also shown that the inspection accuracy could be improved by selecting the optimum heating conditions.

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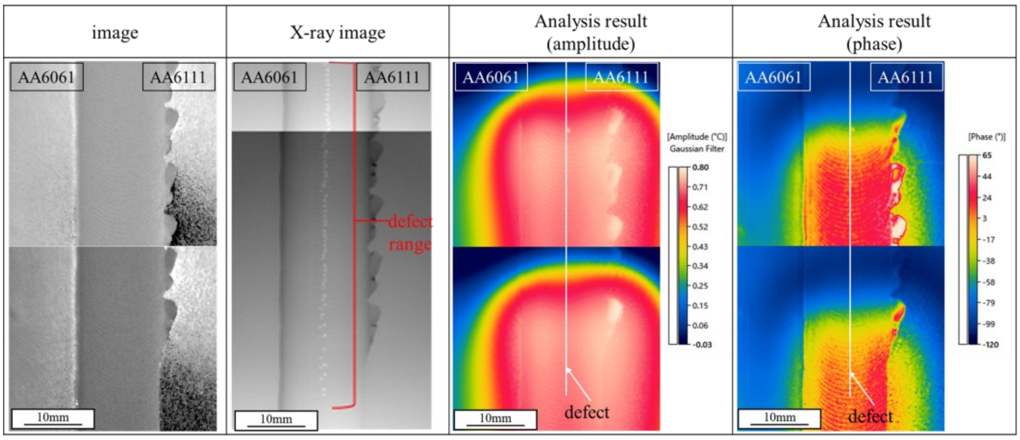
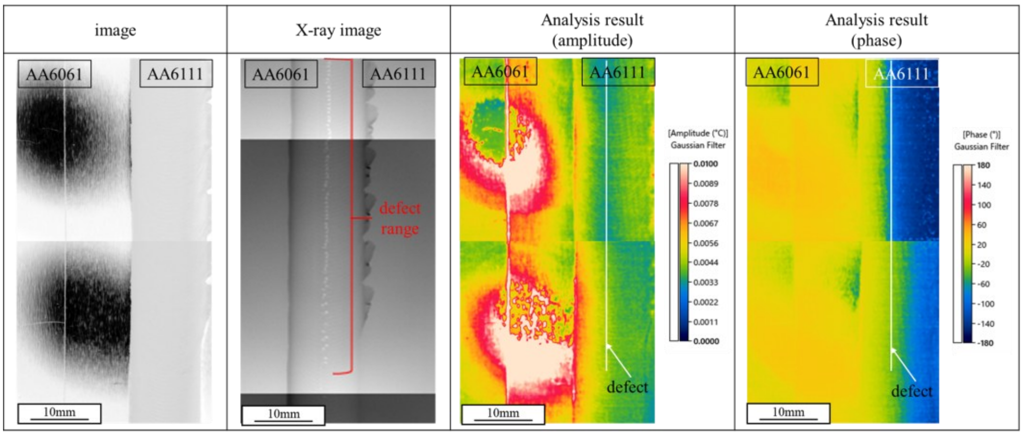



(a) reflection method




(b) transmission method

Figure 4. Nondestructive testing analysis result.

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