Fatigue Crack Detection by Ultrasound Infrared Thermography

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Abstract

This paper describes the application of ultrasound excited infrared thermography. In this technique, an ultrasound wave passing through a material with mechanical discontinuity such as a crack or disband causes temperature raise of that due to internal friction or thermo-mechanical effect and the localized heating area is visualized with infrared camera. In this paper, the detection ability of the technique in fatigue damage of metal materials has been characterized according to crack width.

Keywords: Infrared Thermography, Ultrasound, Fatigue crack, Heat generation

1. Introduction

As shown in Figure 1, the ultrasound infrared thermography technology has been used for detecting the defect by measuring the heat source generated in the defective area when injecting the ultrasound with band of 20 ~ 30 kHz on object [1, 2]. This technology enables its user to inspect the defects such as crack or separation with non-destructive, wide area and the real time, so it is highlighted as new nondestructive inspection technology in the automobile industry and aerospace industry. However, the detection ability and heat generation mechanism of this technique is not clearly analyzed [3, 4]. In this study, we investigate relationship between heat

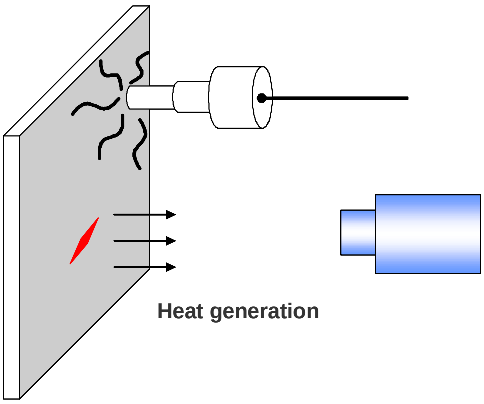

Figure 1. Ultrasound Infrared Thermography

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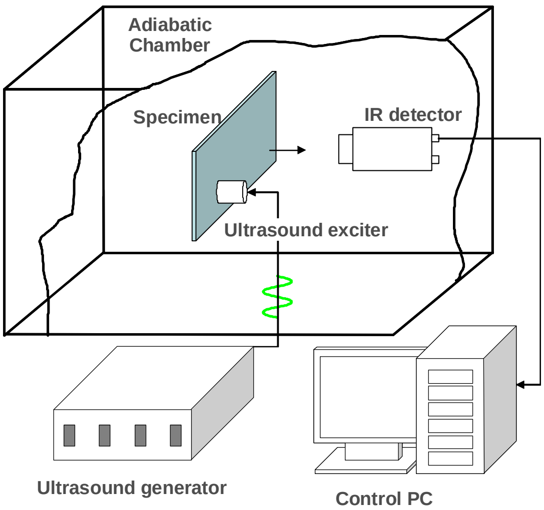
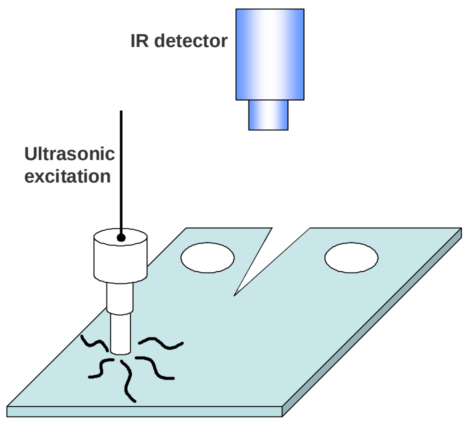
generation and the fatigue crack width, from which the detection ability of fatigue crack is analyzed. Inspection results shows heat generation strongly depends on crack width, which will be a key to understand the detection ability and heat generation mechanism.

2. Experimental system

We configure the ultrasound-infrared thermography test equipment as shown in the Fig. 2 (a) for the purpose of performing the fatigue defect test. The test equipment is installed inside the adiabatic chamber to minimize the heat exchange between specimen and external heat source and then perform the test. The ultrasonic excitation system is the DYW-430H Model with output of 400 W and frequency of 30 kHz, manufactured by the Daeyoung Ultrasound Co.. Infrared thermography system is the Silver 420M model (NETD: 20 mK) manufactured by the Cedip, a French company. Fatigue crack of compact tensile specimens is formed by the fatigue testing with aluminum alloy steel and carbon steel. The crack size and width is measured using the optical microscope. The inspection side and excitation side is same for the ultrasound-infrared thermography test as shown in the Fig. 2 (b). The fatigue defect generated in the notch is inspected.



(a) Inspection system configuration



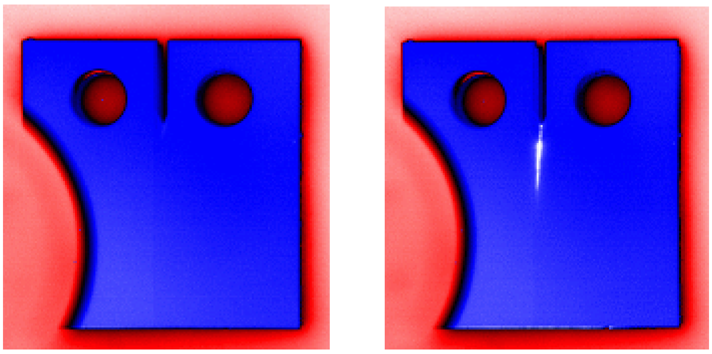
(b) Inspection area

Figure 2. Experimental configuration

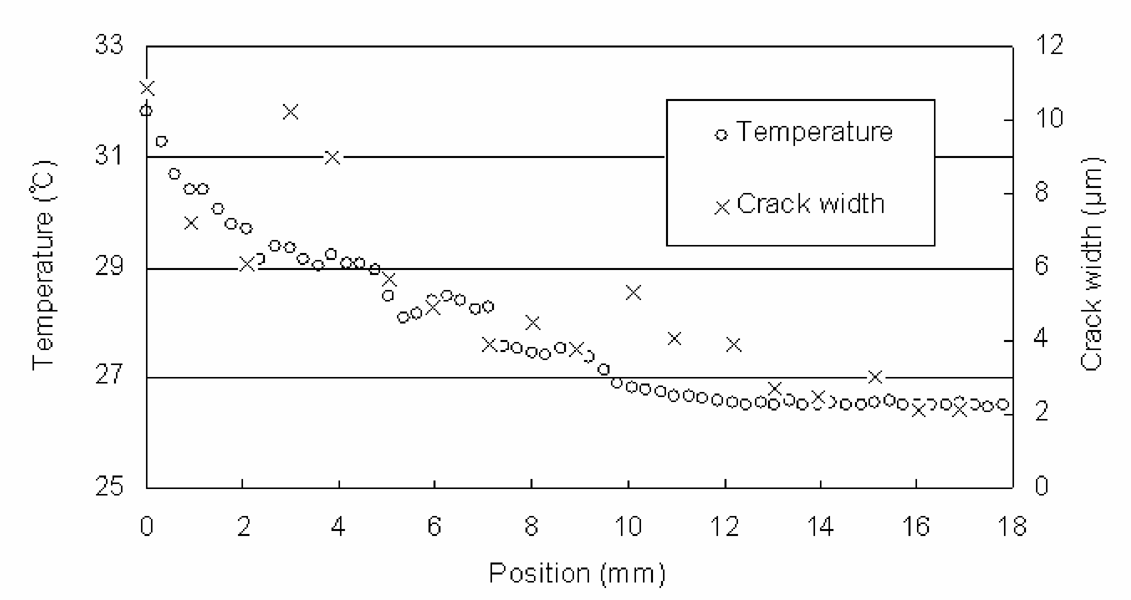
3. Inspection results

3.1 Inspection of aluminum alloy

The fatigue crack of aluminum alloy is inspected for the purpose of defining the relation between the width of fatigue crack and the results of ultrasound-infrared thermography test.



(a) Before inspection (b) Maximum heat generation



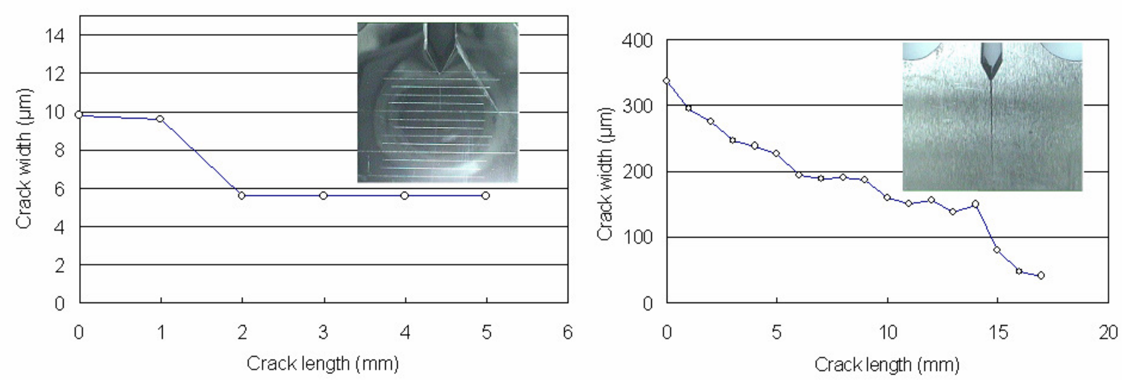
(c) Temperature and defect width along defect length

Figure 3. Fatigue defect inspection of aluminum alloy

The length and width of fatigue crack measured using the optical microscope are 17 mm and 2.1 ~ 10.9 μm respectively, as shown Figure 3(c). The defect is detectable within 1 second after the ultrasonic excitation. Inspection results are compared in position showing the maximum temperature change. Figure 3 (a) and (b) show the thermography image before the ultrasonic excitation and thermography image when the biggest temperature change is measured after the excitation. Figure 3 (c) shows the temperature distribution along the length of defect and results of measuring the width of defect in each position. The width of crack is measured as 10.9 μm and 2.1 μm at start point and peak respectively. The temperature difference between position without defect and position showing the biggest temperature change is measured as 5.1 ℃. The test results show that the heat generates in whole defect. If the elastic effect is functioned or acted as the main cause for the heat generation, heat will be generated at peak of defect. However, the test results show that the biggest heat is generated in position where the widest defect is measured (10 μm) instead of peak of defect. Also, the inspection image of Figure 3(b) shows that the length of defect is 11 mm (size of actual defect is 17 mm). The temperature distribution is measured as 31.8 ℃ and 26.7 ℃ at start point and end point, point of being 11mm away from the start point, respectively. The width of defect is measured as 10.9 mm and 4.1 mm at temperatures of 31.8 ℃ and 26.7 ℃ respectively. This result shows that the sufficient load causing the friction is not transmitted because of narrow defect if the width of defect is less than 4 μm.

3.2 Inspection of carbon steel

Two carbon steel specimens showing the different width of defect are used for the inspection or test. Figure 4 shows the photography on actual crack of each specimen and crack width according to length of defect. The defect length and width of specimen A shown in Figure 4(a) are 5 mm and 5.6 ~ 9.8 μm. The defect of specimen B shown in Figure 4(b) is visually identifiable. The defect length and width of specimen B are 17 mm and 40.2 ~ 337.4 μm.

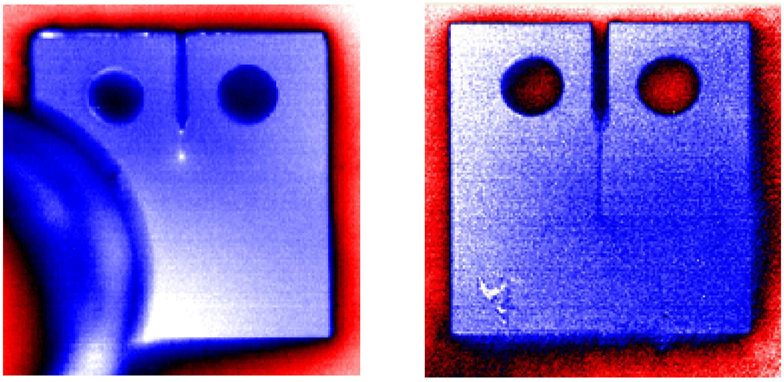


(a) Defect width of specimen A　　　　(b) Defect width of specimen B

Figure 4. Fatigue crack specimen of carbon steel

Figure 5 shows the results of ultrasound-infrared thermography inspection. While the results of test performed against the specimen A show that the heat is generated at defect, results of test performed against the specimen B show that no heat is generated at defect before and after the ultrasonic excitation. This result shows that no heat is generated because the contact force is not sufficient when the defect width is wide. Also, while Figure 5(a) shows that the biggest heat is generated at peak of defect, Figure 5(b) shows that no heat is generated at peak of defect. This result shows that the heat resulted from friction is mainly contributed in the fatigue crack.

Figure 6 is a graph showing the temperature change along the crack length. The average temperature of surface is measured as 21 □. This result shows that the temperature is 1 □ increased at defect. If the distance between 2 peaks is presumed as the length of crack in the temperature distribution, the length of defect is measured as about 5 mm when measuring the length of defect using the ultrasound-infrared thermography. This result is same as the one measured using the optical microscope. These results show that the heat generation characteristics are excellent if the defect width is between 5 ~ 10 μm.



(a) Carbon steel specimen A (b) Carbon steel specimen B

Figure 5 Thermography inspection results

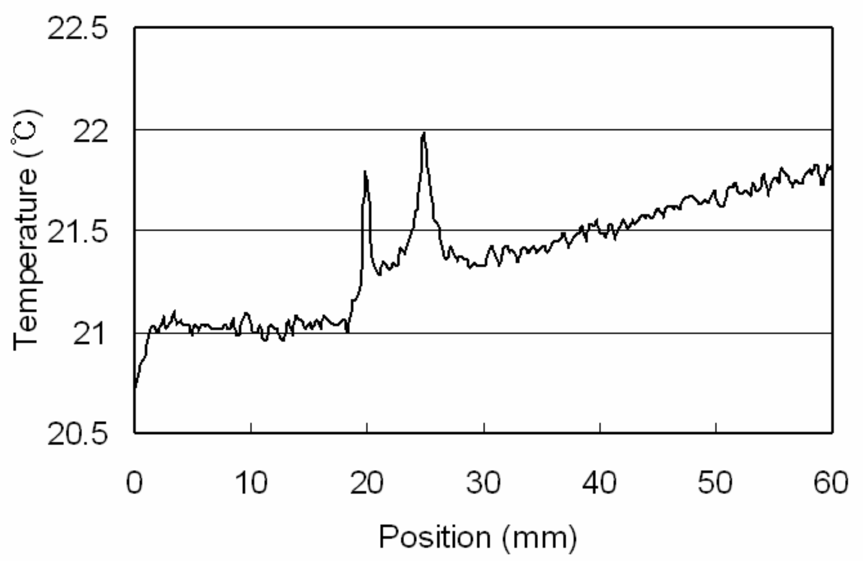


Figure 6 Temperature variation of specimen A along defect length

4. Conclusion

This paper describes the application of ultrasound excited infrared thermography to the fatigue crack of aluminum alloy and carbon steel CT specimen. Our experiment shows the detect ability of this technique is highly dependency on crack width, which related with frictional force.

Considering that heat generation mechanism, the thermal radiation resulted from friction is mainly contributed in the detection of the fatigue crack. These results would be a key to understand the detection ability and heat generation mechanism.

Acknowledgment

This work was in part supported by the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea government (MOST) (No.2008-00467)

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