

Comparison of Inductive Thermography and Computer Tomography Results for Short Surface Cracks [†]

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Abstract: Inductive thermography is a non-destructive testing method, whereby the workpiece to be inspected is slightly heated by a short inductive heating pulse. An infrared camera records the surface temperature during and after the heating pulse. As defects influence the induced eddy current distribution and the heat flow, they become highly visible in the evaluated infrared images. The deeper a crack is, the greater the obstacle it represents. In Inconel welded samples, short surface cracks (length 0.3–2 mm) were created using a so-called Vastrestraint test machine. The samples were inspected via inductive thermography and computer tomography (CT). Additional finite element simulations were calculated in order to model the thermography experiments. The comparison of the thermographic, CT and simulation results shows how the thermographic signal of a defect depends on its geometry. This information can be used for calibration to estimate the crack properties based on the thermographic inspection.

Keywords: inductive thermography; crack detection; crack characterization; computer tomography; finite element simulation



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1. Introduction

In the case of inductive thermography, the workpiece is heated by a short induction heating pulse, usually with a duration between 50 ms and 1 s, and an infrared camera records the surface temperature. As surface cracks disturb the eddy current distribution and also the heat flow, the defects can be well recognized in the infrared images. Therefore, inductive thermography as a non-destructive inspection method is used more and more often in industry in order to detect surface cracks in a quick and contactless way [1–5].

An additional advantage of this inspection technique is that it makes it not only possible to localize the defects but also gives information about depth. In order to prove this statement, additional computer tomography (CT) measurements were carried out on the samples to determine the depth of the cracks. In a further step, the CT results were combined with the inductive thermography results to investigate their crack depth dependency.

2. Finite Element Simulations

Finite element simulations (FEM) were carried out to model the inductive thermography measurements of surface cracks. The multi-physics package of ANSYS was used, which allows the coupled modelling of the electromagnetic and thermal processes. In the first step, the eddy current distribution is calculated around the crack, from which the Joule heating is determined. In the second step, the temperature distribution and the heat flow are calculated [6]. The temperature distribution depending on the time is evaluated using a pixel-wise Fourier transform to a phase image [6]. Figure 1 shows an example for a phase image, calculated for a crack with 0.5 mm depth and 1.5 mm length, after a 100 ms inductive heating pulse. The line of the crack is marked by a red line in the image. At the crack tips, hot spots can be observed as, due to the deflection of the eddy currents, a higher

current density around the crack tips occurs. On the other hand, along the crack line, a lower phase value is visible, as the eddy currents in the vicinity of the crack are deflected from the surface into the body of the workpiece [6]. This typical pattern around the crack can be well used to localize the defect in the infrared images of inductive thermography. The phase contrast, the difference between the phase maximum at the hot spot and the phase minimum along the crack line, is then used for characterizing the defects. Several simulations have been carried out by varying the crack lengths and depths, for which the results are shown in Figure 1b. It is well visible that the phase contrast depends on the crack length and the crack depth [6]. Additional simulations were calculated to investigate how other parameters, such as the shape of the crack, its inclination angle, and the angle between the crack line and the eddy current flow direction, affect the phase contrast [6,7].

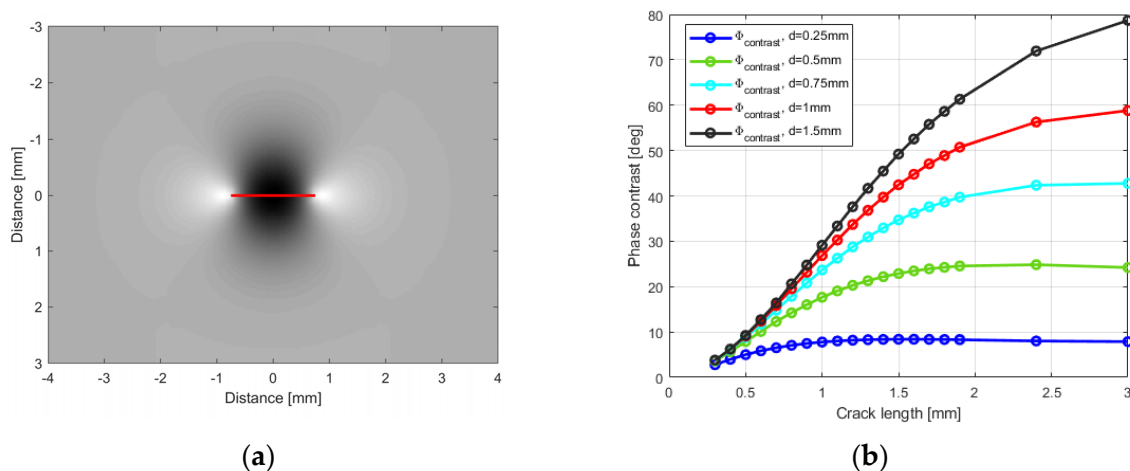


Figure 1. (a) Phase image of crack (depth = 0.5 mm, length = 1.5 mm), calculated via finite element simulations; the crack itself is marked as a red line; (b) simulated phase contrast values depending on crack length and depth.

3. Inductive Thermography Measurements

In Inconel samples, cracks were created using the so-called Vareststraint test machine. During the welding process, pressure is applied to the sample to bend it. This causes small cracks in the welded region [7,8]. Figure 2a shows a photo of such a sample. Afterwards, the samples are straightened again, and inductive thermography measurements are carried out. Figure 2b shows the resulting phase image of the same sample, as shown in Figure 2a. Several small cracks can be well recognized in the phase image.

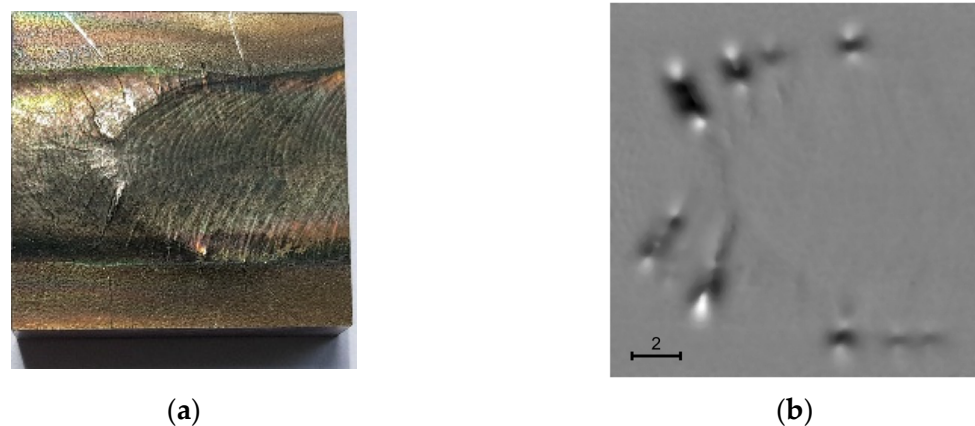


Figure 2. (a) Photo of the Vareststraint test sample AIT_01, where short cracks in the welding region can be observed; (b) phase image of the same sample, obtained via inductive thermography measurement.

4. Computer Tomography Measurements

Additional computer tomography (CT) measurements were carried out on the same samples in order to determine how deep the cracks really are and how their shape below the surface looks. For the evaluation of the CT 3D data, MATLAB routines were developed, localizing and marking the surface cracks. The result for the same sample AIT_01, as already shown in Figure 2, is depicted in Figure 3.

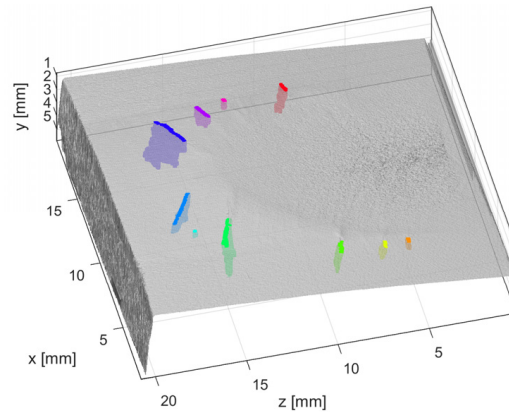


Figure 3. CT results of the sample AIT_01, evaluated by a self-developed MATLAB routine in order to detect and to visualize the surface cracks.

5. Comparison of Inductive Thermography and CT Results

For the automatic evaluation of the phase images, a convolutional neural network (CNN) was developed [8]. This is able to localize the crack regions and to determine the phase contrast of the defect, see Figure 4a. Also, the distance of the two hot spots is marked, which gives crack length, as determined by the inductive thermography measurement. In Figure 4b, the detected cracks in the CT results are displayed on the phase image in order to compare the results of both techniques.

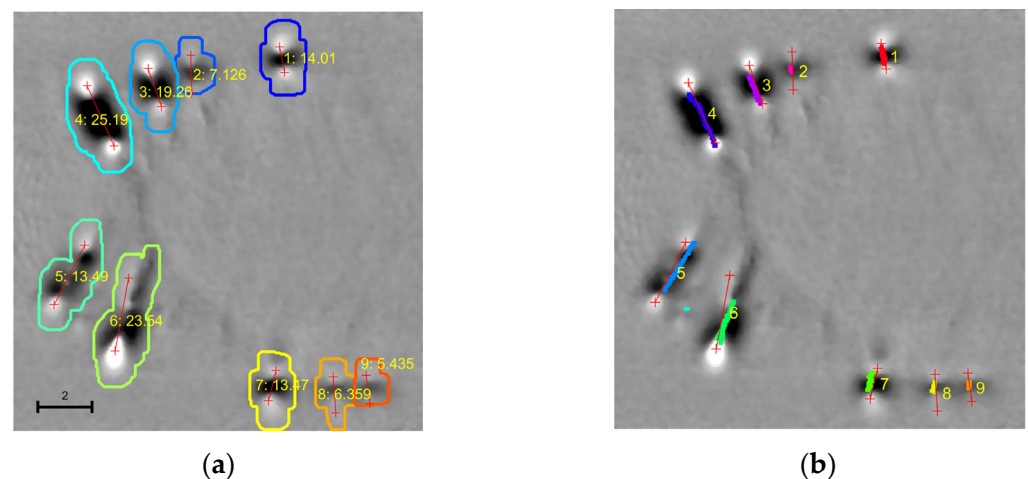


Figure 4. (a) The phase image of sample AIT_01 with the 9 located cracks using a CNN; the phase contrast in degrees is written on each crack; (b) the defects localized in the CT results visualized additionally on the phase image. The crack lengths determined in the phase image are marked in both figures by red lines.

A comparison of both techniques was carried out for three samples, all of them manufactured by the Varestraint test machine. Figure 5a compares the crack lengths obtained from both techniques. Based on this figure, it can be observed that, in most cases, the crack length determined in the phase image is longer than it is determined in

the CT results. This difference is probably caused by the software for evaluating the CT results, which maybe does not recognize the start of the cracks well enough, especially for shallow cracks.

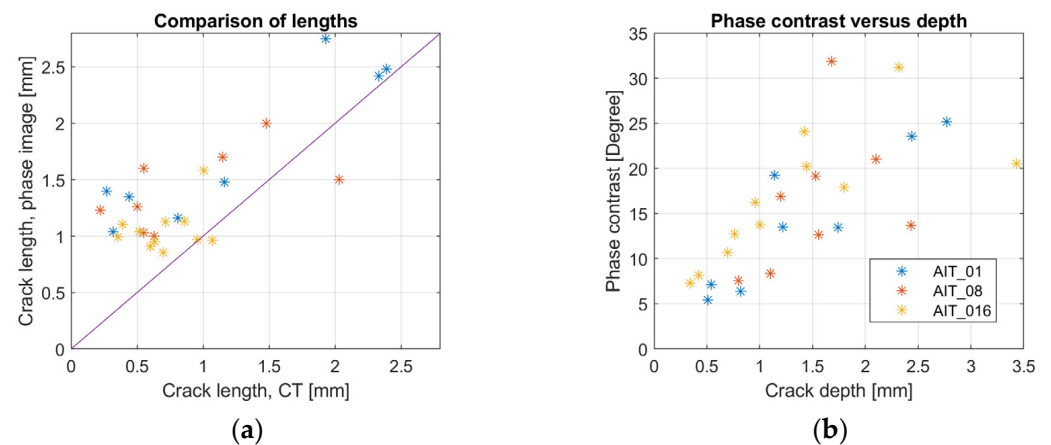


Figure 5. (a) Comparison of crack lengths determined in the CT data and in the phase image; (b) phase contrast from the inductive thermography plotted against the crack depth, determined from the CT measurement. The data are plotted for the cracks localized in three samples.

In Figure 5b, the phase contrast for the cracks in the three inspected samples is depicted with dependency on the crack depth, which was determined from the CT measurements. It is well visible that the deeper the crack, the larger the phase contrast around it, as predicted through the finite element simulations. But, as the simulations also show, the phase contrast also depends on additional parameters, such as crack shape, inclination angle, and the orientation of the crack regarding the induced eddy currents.

6. Summary

Inductive thermography measurements were presented for Varestraint test samples, containing short cracks, with lengths up to 2.5 mm. The goal of these experiments was to show that very small cracks can be detected using inductive thermography. The length of the cracks can be determined by the distance of the hot spots in the phase image, occurring at the crack tips. On the other hand, the phase contrast around a crack depends not only on its length but is strongly affected by its depth. Additional CT measurements were carried out to determine the crack depths. Evaluation of the phase contrast versus the crack depth proves that the deeper the crack is, the larger its phase contrast. This investigation shows the main advantage of inductive thermography. Using this NDT technique, not only the defects can be localized but the phase image can also be used to characterize the cracks, as it gives information about the crack depth.

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Conflicts of Interest: The author declares no conflict of interest.

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