Detection of Surface Cracks in Welds using Active Thermography

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Abstract
Surface cracks in welds can be detected using several non-destructive testing methods; among the more popular ones are eddy current, penetrant and magnetic particle testing. For an automatic inspection cell, the traditional techniques have limitations. Here we have investigated the possibility of using active thermography for detecting surface cracks in welds. This technique features advantages such as non-contact and high speed. The weld is illuminated using an infrared light source. Due to higher energy absorption in a surface crack, the defect will be identified as a hot spot when imaged by an infrared camera. Artificial weld defects (notches) are investigated by use of active thermography. Results from an inspection of real longitudinal cold cracks in a weld are also presented. The results show that active thermography looks promising for detection of even small cracks and notches, as long as they are open to the surface.

Keywords: thermography, surface cracks, welding, infrared, automated inspection

1. Introduction

Cracks are one of the most serious defects in welds since they tend to grow under stress and eventually lead to failure of the weld. Cracks often originate at the surface, although the opening can be very small. Often cracks can be hard to find using radiography due to their small volume and ultrasound can have problems detecting surface defects. Methods such as eddy current, magnetic particle testing and penetrant testing are instead used for detecting surface defects such as cracks. These non-destructive testing (NDT) methods have their disadvantages. Eddy current requires, in practice, contact with the surface and the results can be hard to interpret. Magnetic particle testing and penetrant testing on the other side both involves liquids and both the testing procedure and the interpretation are difficult to automate.

Thermography is most commonly used for detecting defects in ceramics, plastics and composites [1]. Here we investigate the possibilities of using thermography for detecting surface cracks in welds. Thermography is a relatively novel method within NDT and has the advantages that it is relatively fast, non-contact and provides full field information. This method has been used earlier to detect cracks in concrete [2] and in metal by exciting the crack with either eddy currents [3, 4] or by vibrations [5]. The method used here for exciting the surface cracks is by pulsed infrared (IR) radiation.

2. Theory

The absorption of IR radiation in metals is relatively small, typically 10% or less at a wavelength of 5µm and will generally decrease with increased wavelength. Most of the IR radiation is therefore reflected at the surface. When light enters a crack it is reflected multiple times inside the crack and will deposit a larger amount of energy than at a single reflection, in a similar way as in a blackbody cavity. This can be seen schematically in Figure 1. Furthermore, according to Kirchhoff’s law for a system at thermal equilibrium, the emissivity of a surface equals the absorptivity, although the wavelength of the absorbed and emitted radiation does not need to be the same. Due to these two factors, a crack in a metal plate that
is illuminated by high intensity IR light will absorb and emit more energy than the surroundings and will be visible as a hot-spot if imaged by an IR camera.

![Figure 1](image1.png)

Figure 1. Due to multiple reflections of light in a crack, a larger portion of the energy is absorbed compared to a single reflection at the surface.

The size of cracks that can be detected depends on several factors. To be visible the crack needs to absorb enough energy in order to achieve a temperature that the IR camera can differentiate from the background. Generally the radiation from the background is uneven, because of varying emissivity, and the temperature of a crack therefore needs to be raised above this noise level. How much energy that can be absorbed depends on the width of the crack since a wider crack has a larger area where more light can enter. The width also affects what wavelengths can be absorbed in the crack, since light with a wavelength that is longer than the crack is wide will not enter the crack. Although the wavelength of the radiation will set a limit for which cracks that are detectable, it should in general be as long as possible since that will increase the contrast in absorption between a crack and the surrounding surface. A practical limit to the size of cracks that can be detected is the IR camera. The resolution of the camera together with the choice of lens will determine how small objects that can be detected. The choice of lens is a balance between resolution and field of view. Only the smallest dimension of the crack is of importance when it comes to detection; the length of the crack does not affect this methods ability to detect it.

3. Experimental Setup

The theory presented above was tested using an experimental setup as shown schematically in Figure 2.

![Figure 2](image2.png)

Figure 2. Schematic view of the experimental setup. A heat source, being either a laser or a flashlamp, is used to supply a short pulse of IR radiation and the weld is then imaged by an IR camera.

Two types of IR sources were tested, a laser and a flashlamp. To avoid direct reflections from the IR source in the weld, that would obscure the heat from the crack, both the flashlamp and the laser were pulsed and the camera was triggered to start just after the pulse. The laser used for the notches was a pulsed Nd:YAG laser with a wavelength of 1064nm. This laser
delivered pulses with an energy of 1.54J for 2ms and the beam was spread using a lens to a diameter of 1cm. The flashlamp used delivered a 10ms, broadband pulse with a total energy of 6kJ. The aperture in front of the flashlamp had a diameter of about 4cm and was mounted at a distance of 10cm from the weld. A high speed, cooled, IR camera was used to observe the temperature distribution just after the heat pulse.

Two different types of defects were used in the test, artificial defects, in the form of notches, and real surface cracks, see Figure 3. 12 notches were used in the test with sizes between 0.25 and 1.5mm long, the depth were about half the length and the width varied from 100 to 300µm. All notches were manufactured in the weld of a laser welded titanium plate, and one of them can be seen in Figure 3a. To be able to evaluate the method for detecting real cracks in welds it was also tested on two long cracks in MIG welded steel plates. These cracks had widths ranging from 5 and 330µm, measured using an optical microscope. The width of these cracks varies over their length and a detail of one crack can be seen in Figure 3b.

![Figure 3. Micrograph of a 1.3mm long notch a) and a real crack b). The scale below the images is in mm.](image)

### 4. Results and discussion

The method presented above was first tested using notches in a laser welded titanium plate with a Nd:YAG laser as the IR source and the results are presented in Figure 4.

![Figure 4. Results from two of the notches in a laser welded titanium plate with a Nd:YAG laser being used as the IR source. Blue is cold temperature and red is warm.](image)

It was possible to detect all 12 notches that were manufactured in the weld with this method, as long as they were illuminated with the laser. The larger notches were visible in the IR image even without excitation, as faint marks in the weld, but those with a length shorter than
0.5mm were not. This is because the IR camera shows not only the temperature of the plate but also reflections and these are dependent on the surface geometry, just like a regular camera. The result also shows that a small area around the notch had an elevated temperature because of heat conduction from the notch. This makes detection easier since it increases the apparent size of the notch.

The real cracks were tested using a flashlamp instead of a laser to evaluate the flashlamp as a source of infrared radiation for this method. There are advantages in being able to use a flashlamp instead of a laser in terms of cost, safety and portability of the equipment. Results from the tests on a real crack are shown in Figure 5.

These results show that a flashlamp can be a viable IR source for this type of testing. The crack is clearly seen as a line along the weld. In the images some hot spots can be seen, mainly in Figure 5b, these are oxides on the weld that are good absorbers of IR radiation and therefore increase in temperature. The results from this test on a real weld showed that the size limit for detecting surface cracks is about 5-10µm using this setup and equipment. The contrast between the crack and the weld in Figure 5 is not as large compared to the notches in Figure 4. This is due to a longer time delay being used after the pulse to reduce the afterglow of the flashlamp which results in cool down of the crack.

The flashlamp covers a larger area than the laser but also suffers from afterglow, where the lamp is still radiating after the light pulse because it is at an elevated temperature. The result from this will be that direct reflections from the lamp will be seen in the metal plate. The reflections can be seen in Figure 5 as hot areas around the crack and makes the crack harder to detect.

Since only the surface of the plate and surfaces inside the crack are heated, the measured temperature will quickly decrease as the heat spreads into the material. Because of this the material needs to be inspected immediately after the heat is applied, generally within about 50ms, depending on the amount of energy applied. The IR source therefore needs to completely shut off within this time to avoid direct reflections of the source being seen in the metal instead of the surface temperature. A pulsed high power IR laser is therefore the ideal IR source since the pulse can be very short and it can be turned off quickly. Since the flashlamp radiates as a blackbody due to a high temperature it takes a relatively long time to cool down and, in this case, the afterglow lasted about one second and obscured the heat from the cracks. In order to make this method work with a flashlamp it was necessary to direct both
the camera and the lamp in a way that minimised the reflection from the lamp in the weld. This was done by having both the camera and the flashlamp at a high angle of incidence to the weld, from the same side, thereby directing most of the reflections away from the camera.

5. Conclusions

It was shown that thermography can be used for detecting cracks in welds. Tests were performed using both notches and real cracks with either a laser or a flashlamp as an IR source. The smallest crack width that could be detected was about 5-10µm. The preferred IR source for this method is a laser since it can be easily controlled in terms of size of the area that is heated and the pulse length. A drawback with using laser light is that high power lasers are large, expensive and the laser beam can be hard to direct if the wavelength is long and an optical fibre cannot be used. Flashlamps are smaller and easier to move around but suffer from afterglow that will negatively affect the inspection if it is not treated properly. A flashlamp can be used if precautions are taken in order to avoid reflections from the afterglow. One way of avoiding afterglow could be by using a mechanical shutter, LCD shutter or a rotating mirror that blocks all radiation after the main pulse. A continuous laser source can be used if the laser light is not detected by the IR camera due to its wavelength, this can increase the inspection speed.

Since thermography offers non-contact, fast inspection with a good ability for finding even small surface cracks it is suitable for automated inspection and could be used as an alternative to eddy current, penetrant and magnetic particle testing.

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