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Thermographic crack detection by liquid gas in materials with low emissivity

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Abstract

A new approach for detection of cracks in metals with low emissivity was investigated. Liquid gas is sprayed in a linear movement across the test object. The gas propagates into cracks open to the surface by capillary effects and by the pressure of spraying. This causes cooling and subsequent warming up. It was found that the time profiles of the temperature close to the crack have characteristic properties which are different from the time profiles of a pure surface disturbation of the emissivity. Cracks of different depth were investigated in aluminium and steel. An advantage of the technique compared to liquid penetrant testing is the residual-free evaporation of the gas that allow testing in a single step.

1. Introduction and principle of the technique

In automobiles, more and more heavy loaded safety-relevant components are employed that have to be inspected for surface defects like cracks. A standard technique in industry is liquid penetrant testing. The new approach used here is explained in figure 1. Liquid gas is sprayed in a continuous movement onto the surface (figure 1 a). The gas leads to rapid cooling of the outer surface and then causes heat to diffuse from the depth to the surface. Furthermore, moisture from the ambient air may re-sublimate and form a film of frost (figure 1 b). Beyond the known technique of cooling down thermography [1], the effect used here is that the gas penetrates by capillary forces into open cracks or by direct gas pressure (figure 1 c). The temperature distribution at the surface and its behaviour with time are recorded as an infrared camera image sequence. A certain time after the application of liquid gas, both gas and frost evaporate and sublimate, respectively. They leave a clean surface (figure 1 d).

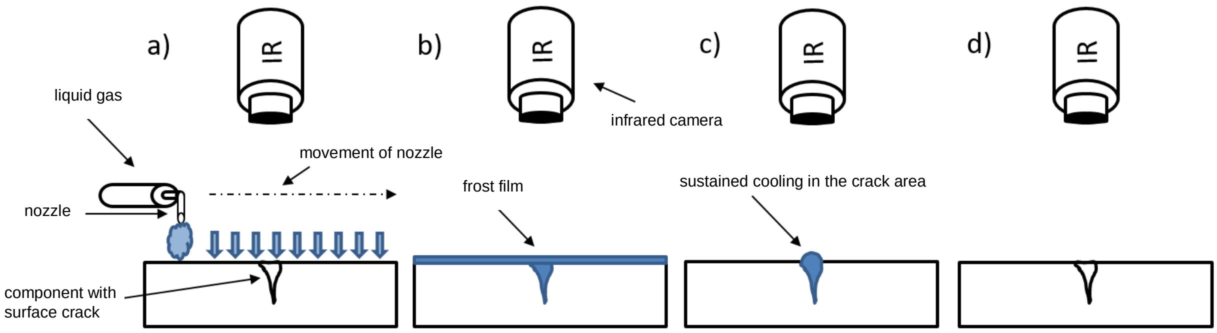

Fig. 1. *Schematic sequence of testing*

2. Experiments on artificial cracks in aluminium

Experiments showed, that a commercial cooling spray consisting of 75-100% tetrafuoroethane and 5-10% dimethylether [2] is a good gas mix for given task. An aluminium plate with long notches serving as artificial cracks with depth from 2 to 4 mm was investigated at room temperature. Figure 2 shows a sample in the clean state. Beside the notches, the aluminium surface was marked with a thin line of black paint in order to simulate an area of increased emissivity. The spay nozzle with the diameter of 0.5 mm covered a test area of approx. 1 cm2 at local impact. The nozzle was moving over the surface at a speed of about 30 mm/s. The process was recorded at 150 frames per second with an infrared camera for the 2-5 µm wavelength range having the detector resolution 320x256 pixels. Some selected infrared images of the sequence are presented in figure 3.

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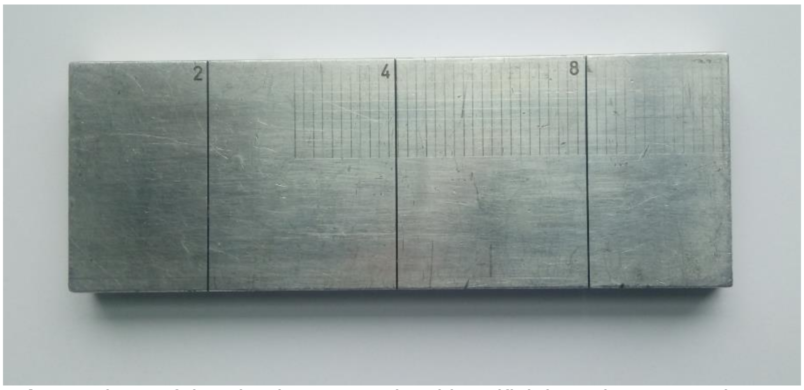


Fig. 2. *Photo of the aluminum sample with artificial notches 2,4 and 8 mm*

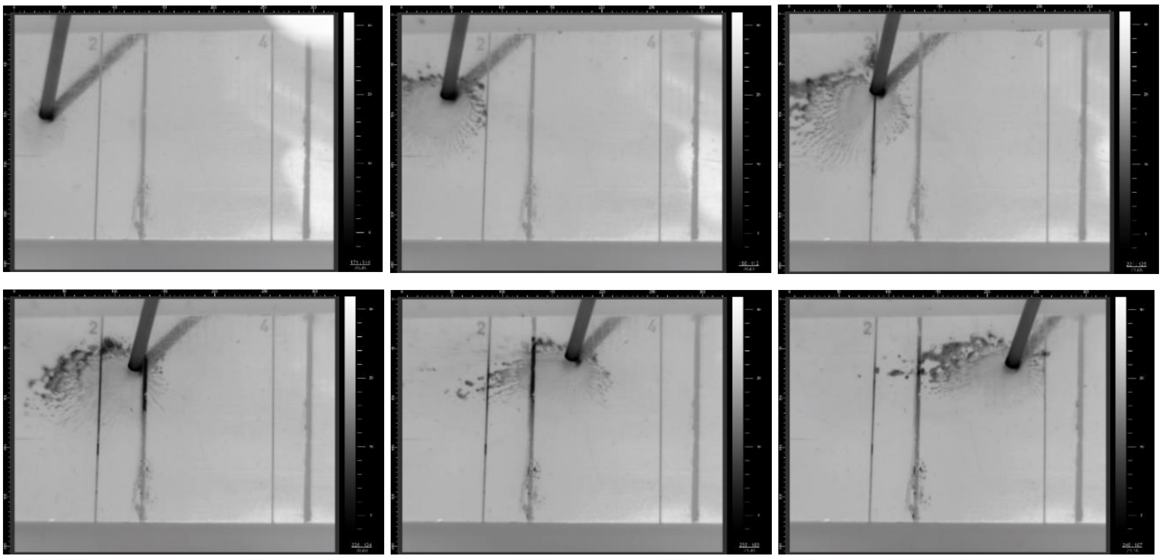


Fig. 3. *Testing of the aluminum sample with the liquid gas, infrared image sequence.*

A thin film of the liquid gas can be easily recognized near the nozzle pin, and some liquid gas drops have wide spreading.

Figure 4 a shows on the left part a frame from the infrared video sequence with the nozzle which was moving from left to right and being just shortly behind a crack. The liquid gas on the surface is visible in darker grey levels, indicating lower temperatures. Two measurement positions, indicated by blue and red crosses, are reference points beside the crack. A further measurement position / green cross lies exactly over the crack. The apparent temperatures at these points as a function of time are plotted in the right part of figure 4 b. For the reference areas, the cooling can be seen when the nozzle passes the measurement positions. It can also be seen that liquid gas droplets from the spray disturb the signal heavily in particular at the begin and the end of the passage of the nozzle. The green curve from directly over the crack shows that the temperature decreases rapidly when the crack is filled with gas, but it recovers with much lower slope when the nozzle has passed the crack. This corresponds to the situation shown in figure 1 c. This asymmetry in the cooling/warming curve is the key criterion to distinguish a crack from a pure emissivity effect, which has steeper flanks and a more symmetric appearance.

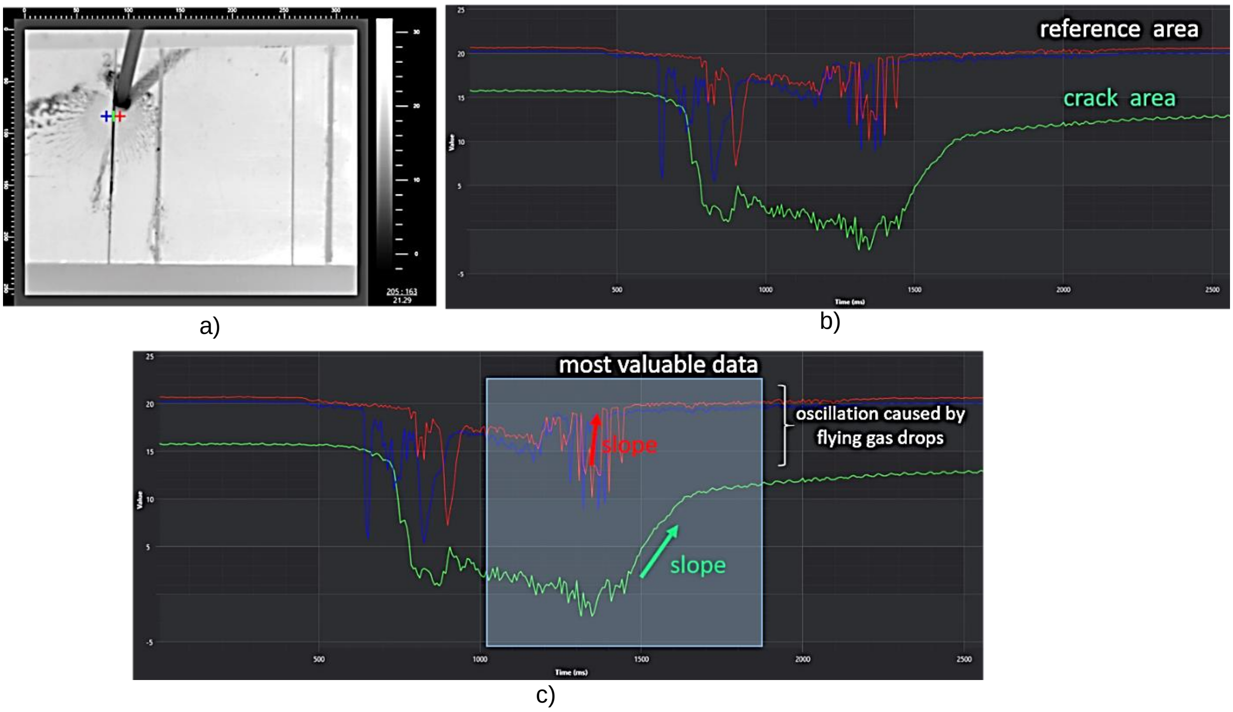


Fig. 4. *a) Infrared image taken from the recorded spraying sequence. The measurement positions are indicated as blue, green and red crosses. b) Temperature-time profiles over the reference positions (red and blue curves) and at the crack position (green curve). c) Slopes of temperature-time profiles over the reference positions (red and blue curves) and at the crack position (green curve)*

Figure 5 a shows the extended analysis. The nozzle was moving from left to right and being just shortly near a coated line (high emissivity). In the following step, the difference between areas of higher surface emissivity and a crack was investigated. The detailed analysis allowed to distinguish some surface contamination or local corrosion from a real surface damages.

Figure 5 b shows the corresponding temperature-time profiles near to the crack (red and blue curves), at the crack (green curve) and at a coated line with high emissivity (cyan). Although the coated line appears wider than the crack in the thermographic image, its width A in the temperature-time profile is smaller than the width of the temperature-time profile at the crack B as shown in figure 5 c. The slopes of the defect-free profiles (red, blue and cyan curves) are steeper except oscillations caused by gas drops. Overall, these are informative features for detailed indication analysis.

Further experiments with similar results were performed on steel samples with cracks.

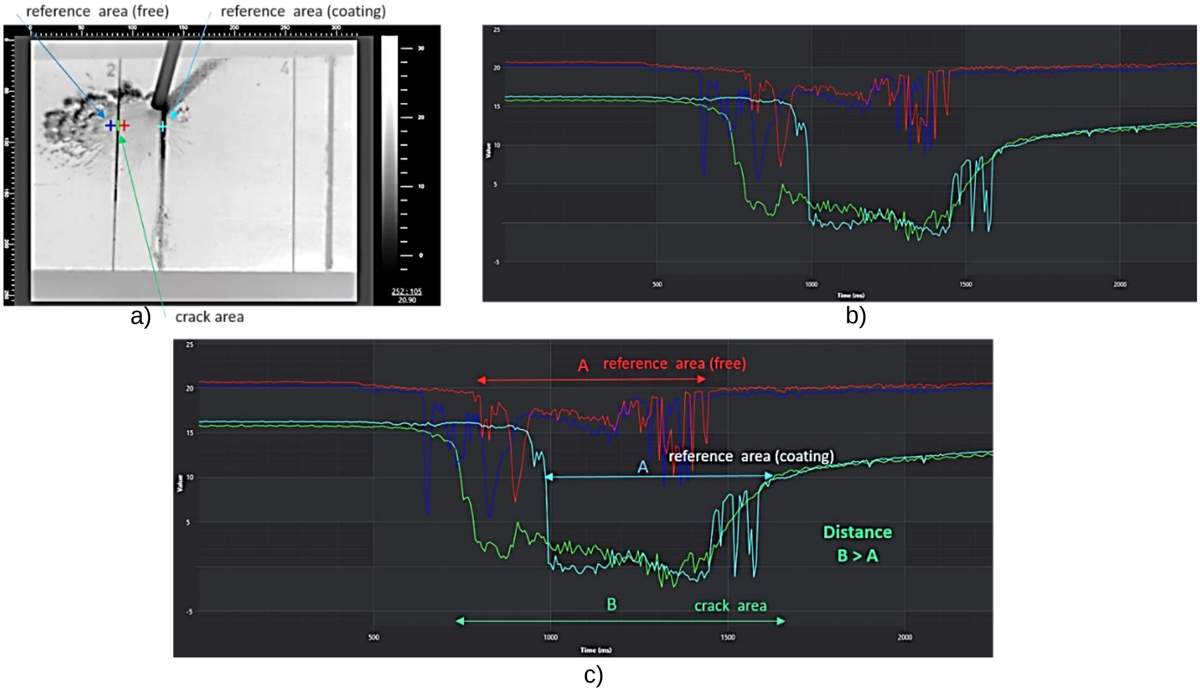


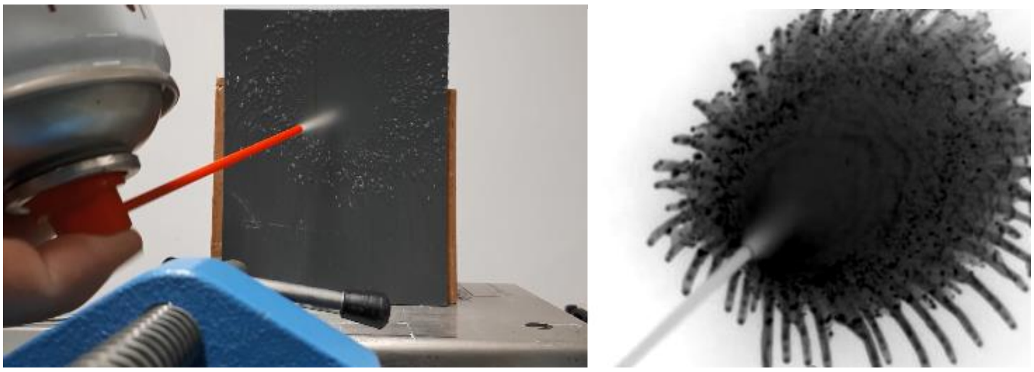
Fig. 5. *a) Infrared image taken from the recorded spraying sequence. The measurement positions are indicated as blue, green, red and cyan crosses. b) Temperature-time profiles over the reference positions (red and blue curves), at the crack position (green curve) and at coated line (cyan). c) Widths and slopes of temperature-time profile indications over the reference positions (red and blue curves), at the crack position (green curve) and at the coated line (cyan curve).*

3. Formation of frost

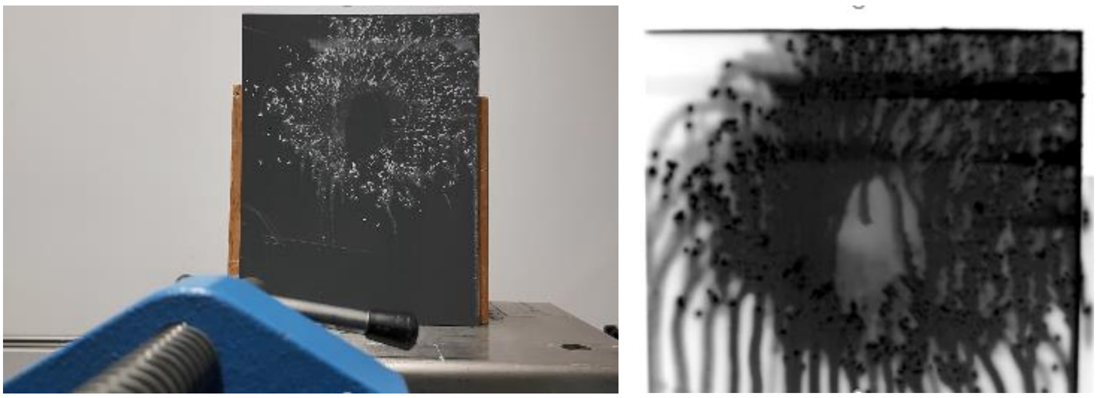
Cooling spray was applied to various technical materials. A video image in the visible spectral range and an infrared image sequence were recorded simultaneously. The investigations on a PVC sample are presented in figure 6.

The main results of these investigations are:

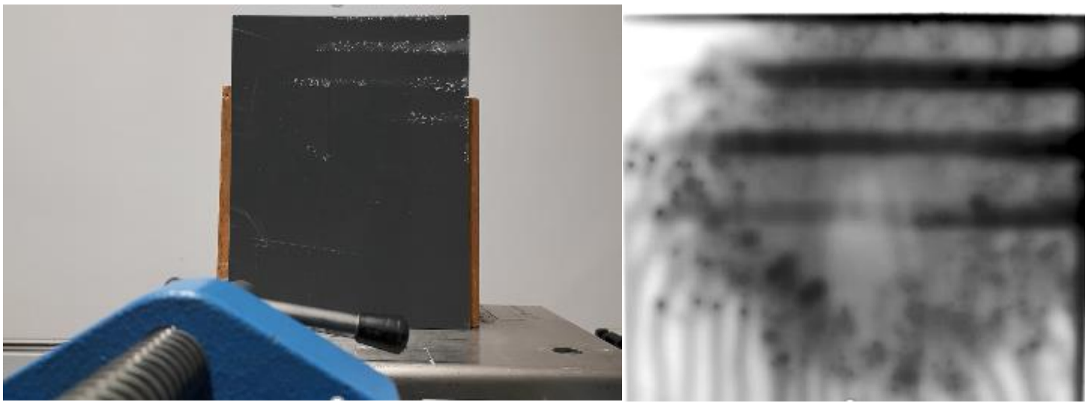
- The frost is usually not forming as a homogeneous film, but often in islands of frost surrounded by remaining liqud gas.
- The duration of the frost depends strongly on the thermal properties of the material. It was >20 s for PVC, 10 s for CFRP, 3 s for zirconia, 1 s for a ceramic coated turbine blade and <1 s for ferritic steel.
- For aluminium, the lifetime was so short, that it was not helpful for testing. Although the emissivity of the frost layer is higher than that of aluminium, this is scotched by the low temperature of the frost.



a) Spraying on the luquid gas (t=1,75 s), left: visual image, right: infrared image



b) Formation of frost layer on the surface, left: visual image, right: infrared image



c) Sublimation of the frost layer, left: visual image, right: infrared image

Fig. 6. *Formation and sublimation of the frost layer on a PVC sample*

4. Investigation on porous ceramic

Besides liquid gases, a similar approach can also be to use volatile organic liquids. Figure 7 shows a part of the surface of a porous alumina ceramic in the visible and the thermal infrared (figures 7b and 7c) form. A drop of isopropanol has then been applied to the marked position. Due to evaporation cooling the moistened spot appears colder than its surroundings. The diffusion of the liquid into the depth is disturbed by a sub-surface defect, probably a metallic inclusion. After a short time, this is visible for the infrared camera. After longer time, the isopropanol evaporates completely without leaving residues.

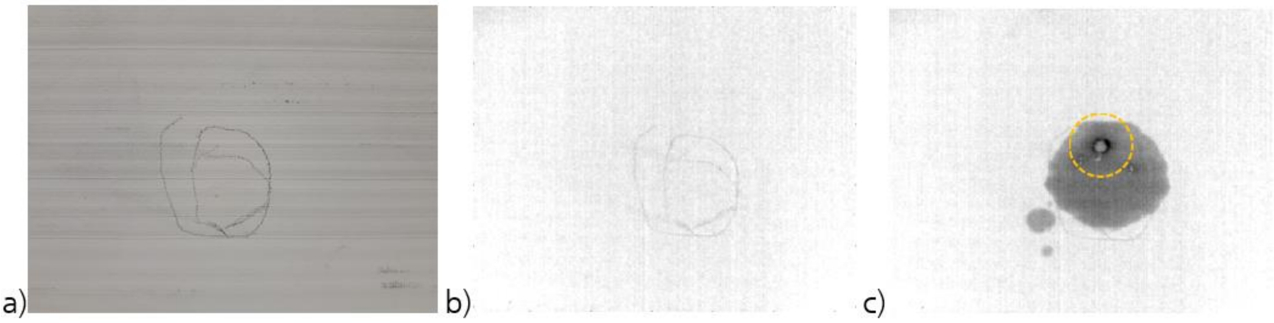


Fig. 7. *Detection of a hidden defect in porous alumina ceramics. a) Photo of the sample surface (about 40 mm x 50 mm). b) passive infrared image. c) infrared image a time after applying a drop of isopropanol.*

5. Conclusion

A new approach for the detection of surface cracks in metals with low-emissivity has been presented. A liquid gas is sprayed under a pressure in a linear motion over the test object, penetrating the crack by capillary effects and causing cooling and subsequent warming up. It was found that the temperature time profile of a crack have characteristic behaviour different to the time profile of pure emissivity disturbances. Cracks of different depths in aluminium and in forged steel were investigated experimentally. Spray can gases like KÄLTE 75 have demonstrated good results in the experimental application. The formation of a frost layer is less important to crack detection as it occurs either in the form of individual islands or in only short-lived areas. In porous ceramic, hidden defects have been detected using highly volatile liquids. A major advantage of the presented approach in comparison to penetration testing is the automatic, residue-free evaporation of the gas or liquid so the inspection can be conducted in a single step.

REFERENCES

[1] Danesi S, Salerno A, Wu D, Busse G, Cooling down thermography: principle and results for NDE, Proceedings of SPIE - The International Society for Optical Engineering (March 1998), DOI: 10.1117/12.304736

[2] Safety data sheet “Kälte 75”, CRC Industries Europe bvba, www.crcind.com