EFFECT OF ANTI-CORROSION PROTECTIVE PAINT ON THERMOGRAPHIC INSPECTION OF CURVED STEEL TUBE PARTS

[1]Michal ŠVANTNER, [1]Alexey MOSKOVCHENKO, [1]Lukáš MUZIKA

[1]University of West Bohemia, New technologies - research center, Pilsen, Czech Republic, EU,
msvantne@ntc.zcu.cz, alexeym@ntc.zcu.cz, muzika@ntc.zcu.cz

https://doi.org/10.37904/metal.2023.4658

Abstract

The use of anti-corrosion paint coatings on steel pipes is a common practice for their protection against corrosion. However, such coatings may have an impact on the results of the thermographic inspection, which can be used, for example, for their corrosion damage identification. In this study, we investigated the influence of anti-corrosion paint on the thermographic inspection of curved steel tube parts. Long pulse thermography inspection was conducted on painted and unpainted samples, and the results were compared. It was found that the used painting reduced the absorbed energy, however, the contrast of the found defect indications was better on painted samples. The experiments indicated that any inhomogeneity of an inspected surface due to, for example, the painting process, the presence of old painting layers, or the presence of surface corrosion, can cause irregular surface absorption patterns. It can result in signals from this unevenness that can reduce the contrast of the indications of defects. These findings can have significant implications for the use of thermography as a non-destructive testing technique for curved steel tube parts, for example, steel pipes, especially those in operation with correction paint or corrosion layers.

Keywords: Thermography, steel, curved parts, paint, coating, non-destructive testing, defect detection, corrosion protection, thermographic testing, infrared testing

1. INTRODUCTION

Thermographic inspection - Infrared Nondestructive Testing (IRNDT) is a method for near surface defects detection in materials. IRNDT methods are widely described, for example, in the books by Maldague [1] and Meola [2] or in the reviews by Vavilov [3] or Usamentiaga [4]. It is based on an excitation of the tested material by an external source and identification of its response by a thermographic camera. The occurrence of defects or some other discontinuities near the material surface affects the thermal process and this affection can be identified by the thermographic measurement of the material thermal response on its surface. It is a contrast-based identification method. Locations containing defects are indicated by areas with different contrast to the surroundings on the thermographic records. The contrast of these areas, called indications, is mostly increased by additional data processing methods.

IRNDT represents a group of methods, which can be implemented with different excitation sources, inspection procedures and evaluation methods. The often used IRNDT techniques are lock-in, long-pulse or pulsed thermography [5]. In the case of long-pulse thermography, the evolution of surface temperature is monitored during a long-pulse heating and/or subsequent cooling [6]. Lock-in thermography [7][8] is based on periodical heating of the sample, which response is monitored continuously during the excitation process and its amplitude or phase shifts are analyzed. The pulsed IRNDT [9] is based on an excitation with a very short pulse (in the order of ms) and an analysis of the time-temperature response after the pulse. There are different excitation/heating sources, which can be used for the above-mentioned methods. However, currently the most widely used methods are probably illumination-based (IL) methods using halogen and LED lamps (long-pulse, lock-in), flash lamps (pulsed) or lasers (all methods). All these methods also usually use some of the time-temperature data processing methods, which are mostly based on recorded signal smoothing/de-noising, derivation (Time Derivation of Thermographic Signal [10], Thermographic Signal Reconstruction [11]), Lock-in [7] and Pulse-Phase analysis [12] or time transformations.

The main advantages of the IL IRNDT methods are that they are noncontact, non-destructive, area-based, can be used on a wide range of materials and the inspection is relatively fast. The methods are often used, for example, for detection of delaminations (composites, coatings), voids (metals, plastics and others) or cracks. The IRNDT methods can also be efficient for an inspection of thickness, thickness changes, thickness reduction or operating damage of functional coatings [13] or paints [14]. Another application of IRNDT methods, which this contribution is related with, is a determination of hidden/internal corrosion of steel components [15]. It is a usual problem of, for example, technical water pipes or thermal exchanger parts in power industry. Corrosion damage (through holes, wall thickness reduction etc.) occurs at inner or hidden side of a component's wall or under a protective coating. Thus, it is difficult to find it out during routine maintenance of the component and it often becomes apparent at critical damage of the components. In this case, the IL IRNDT can be very useful as it allows fast and area-inspection of the components and it can provide input information for some more localized inspection methods (e.g. ultrasound). All such components are in most cases provided with some protective paint, which cannot be removed before inspection. It is obvious that IRNDT is sensitive and can indicate possible damage of the paint or its delamination, because, as it was mentioned above, it is one of the possible applications of the IRNDT. However, this research was focused on the issue, how the paint can affect detection of defects of the material under the paint.

2. EXPERIMENTAL SETUP

The goal of the experimental research was to verify how a protective painting can affect detectability of defects in steel parts using IRNDT. The halogen long-pulse thermographic inspection was provided. The experiments were performed on steel samples, which were parts of a steel pipe with artificial defects on their inner side. The defects simulated a wall thickness reduction of the pipe due to, for example, corrosion damage. Part of the samples were provided with a corrosion protected painting from the outer side and a natural steel outer surface was left for a part of the samples to compare the results.

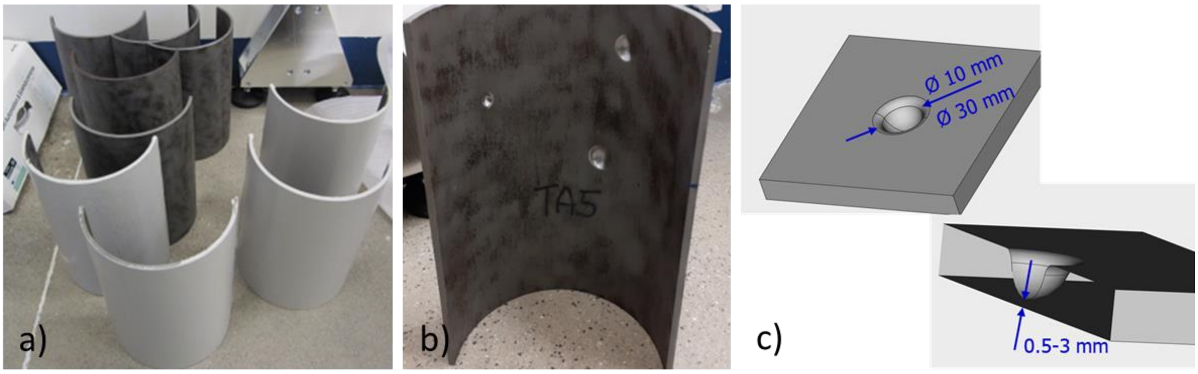

Figure 1 Experimental painted and unpainted steel samples (a), defects on the inner side of a samples (b), drawing of the spherical type defect (c).

The steel (grade 11 steel, unalloyed structural steel) samples had the shape of a circular cross-section half-tube of the length 300 cm, diameter 250 mm and wall thickness 6 mm. There were 2 sets of samples - 5 painted and 5 unpainted as shown in **Figure 1**, each set with identical artificial defects. The Interseal 670HS two component high solids corrosion protective epoxy maintenance coating was applied on the pained samples. The defects were made from the inner side of the tubes. Three types of defects in different depths were manufactured: spherical defect with a diameter 10 mm, spherical defect with a diameter 30 mm and groove type defect of the width 2 mm and length 30 mm. The depths of the defects (the rest of wall thickness between the defect and outer surface of the samples) 0.5, 1, 1.5, 2 and 2.5 mm. That means, each of the 5 samples was provided with 3 different defects (3 types x 5 depths).

A long-pulse thermographic inspection was performed on each sample using one and/or two halogen lamps of the power 2.5-3 kW. The length of the pulse was 15 s and both heating and cooling stages of the pulse were analyzed. The thermal response of the material was recorded by IR cameras FLIR A6751/SC7650 (high-speed cooled detector based IR camera) and/or FLIR A615 (non-cooled micro-bolometer based IR camera) with a 25 mm lens. The recording framerate frequency was 25 Hz and recorded data was processed in the LabIR software developed at the University of West Bohemia. Different processing methods were applied and the results were compared using Contrast to Noise Ratio (CNR [10]) evaluation of indications found, however, the Time Derivation of Thermographic Signal evaluation has proven to be the most effective method in the most cases.

3. RESULTS

Experiments revealed that all spherical defects could be identified if the inspections were focused on a smaller area (about 15x15 cm), examples of the results (defectograms) are shown in **Figure 2**.

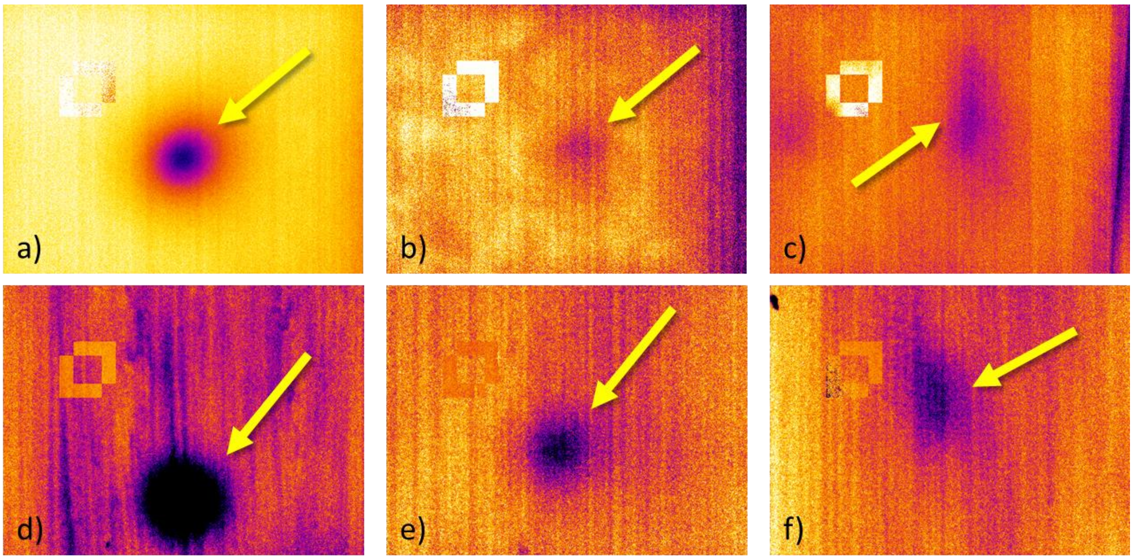

Figure 2 IRNDT results obtained with FLIR A615 IR camera and excitation with 2 halogen lamps, field of view about 15 cm: a) unpainted, phase evaluation, spherical defect 30 mm, depth 1.5 mm; b) unpainted, phase evaluation, spherical defect 10 mm, depth 1.5 mm; c) unpainted, phase evaluation, groove defect, depth 0.5 mm; d) painted, derivation, spherical defect 30 mm, depth 1.5 mm; e) painted, derivation, spherical defect 10 mm, depth 1.5 mm; f) painted, derivation, groove defect, depth 0.5 mm.

Indications of the spherical defects of both diameters 30 and 10 mm can be clearly identified in depths (rest of the material) up to 1 mm. These defects can be also detected in the depths up to 2.5 mm, however, their indications are not too clear and their identification could be more complicated. Indications of the groove defects are more blurry, not too clear and these defects could be certainty detected only in a close proximity below the surface (up to 1 mm). These defects could be in some cases identified in greater depths below the surface (up to 2.5 mm), however, their identification is more complicated and can be covered/hidden by structural or other parasitic features. Structural features made by surface structure can be seen on the defectograms. These features had mostly a longitudinal shape and were caused by a thermal response difference due to the structure of the original surface (production process, oxidation, impurities) or due to the applied painting structure. These features are parasitic indications, which however does not influence significantly recognition of indications caused by the defects. The comparison of the results however showed that indications of the same defects obtained on the painted samples were clearer, as it is also visible in **Figure 2**.

The inspection area used to obtain the results described above is quite small, which would require a knowledge of locations of defects or scanning of the bigger samples. Bigger inspection areas (bigger field of view if the IR camera and bigger distance of the excitation lamps) are therefore usually used. **Figure 3** shows example of the results for painted and unpainted sample and the spherical defect of the diameter 30 mm and depth 0.5 mm. Results with the greater field of view showed that, in accordance with **Figure 3**, indications of the same defects were indicated or had better CNR in the case of the painted surface. That means that more defects were found on the painted samples and, in many cases if an indication was found on both samples, CNR was higher for the painted samples.

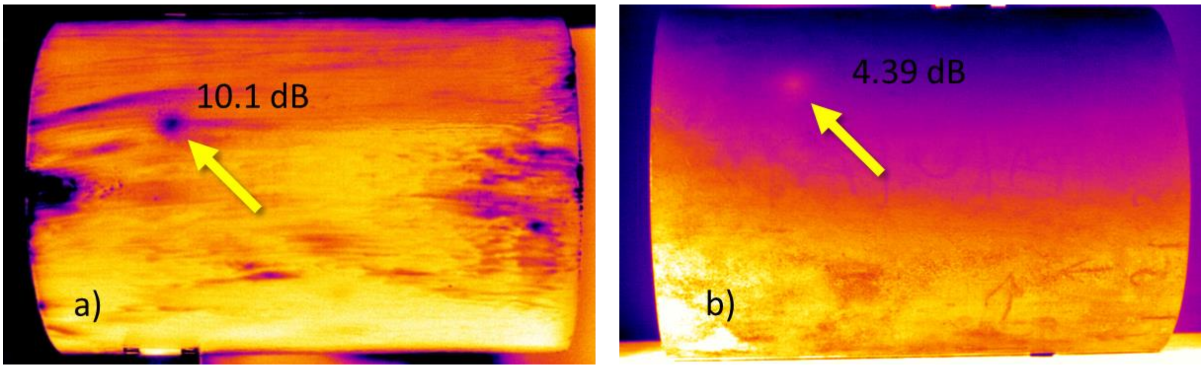

Figure 3 IRNDT results obtained with FLIR SC7650 IR camera and 2 halogen lamps, field of view about 30 cm: a) painted, derivation, spherical defect 30 mm, depth 0.5 mm, CNR of the indication found 10.1 dB; b) unpainted, derivation, spherical defect 30 mm, depth 0.5 mm, CNR of the indication found 4.4 dB.

When the field of view is extended (using the same IR camera), several effects become more significant. The curved shape influence homogeneity of the excitation as well as IR camera depth of focusing. Different view angles of the observation of the samples also increase an effect of possible reflections. Finally, the indications of even large defects are smaller than the parasitic indications caused by surface structure. It results in significantly limited detectability of the defects, when only the spherical defects were indicated in depths up to depth 1.5 mm and 0.5 mm for the defects of diameter 30 mm and 10 mm, respectively.

4. CONCLUSION

The results of the experimental research showed that spherical defects in the curved steel samples (parts of steel pipe) of the diameter 30 and 10 mm and depth of the defects 0.5-2.5 mm can be detected in all cases. The groove defects were also indicated, however, their contrast was worse, and their detection could be, in a non-laboratory application, more complicated or not possible in depths greater than 1 mm. Application of the painting or the use of the cooled/non-cooled IR camera did not play a significant role in the detectability. The use of 1 halogen lamp instead of 2 lamps provided significantly worse contrast (CNR) of the found indications, which was the expected result. If the field of view was extended to the whole sample (about 30 cm), the parasitic indications, curvature of the samples (reflections, limited depth of the focus of the IR cameras), affected in connection with smaller indications detectability of the defects. Only the spherical defects of the diameter 30/10 mm were identified up to depth 1.5/0.5 mm if two halogen lamps were used. The use of one halogen lamp only has not proven to be effective in this case. The type of the IR camera did not influence results significantly, similarly, as in the previous case. However, better performance of the detection was observed for the painted samples, although the used painting does not have ideal properties for thermographic measurement. The results showed that the painting layer had higher reflectivity and lower homogeneity in a comparison with thermographic paintings, which have high emissivity and better homogeneity due to their different composition and different methods of their application. However, it can be concluded, that such a corrosion protective coating does not limit or improve efficiency of the long-pulse IRNDT inspection if the coating or its cohesion with the original surface is not damaged due to its misapplication or degradation in use.

ACKNOWLEDGEMENTS

This research was founded by the project SGS-2022-007.

REFERENCES

[1] MALDAGUE, X.P.V. *Theory and practice of infrared technology for nondestructive testing*. Wiley, 2001.

[2] MEOLA, C. *Recent Advances in Non-Destructive Inspection*. Nova Science Publishers, 2011.

[3] VAVILOV, V.P. Thermal NDT: historical milestones, state-of-the-art and trends. *Quant Infrared Thermogr J.* 2014, vol.11, no. 1, pp. 66–83.

[4] USAMENTIAGA, R., VENEGAS, P., GUEREDIAGA, J., VEGA, L., MOLLEDA, J., BULNES, FG. Infrared Thermography for Temperature Measurement and Non-Destructive Testing. *Sensors*. 2014, vol.14, no. 7, pp.12305–12348.

[5] MALDAGUE X.P.V. Introduction to NDT by active infrared thermography. *Materials Evaluation*. 2002, vol. 60, no. 9, pp.1060–1073.

[6] VESELÝ. Z., ŠVANTNER, M. Application of IRNDT method for materials in wide range of thermal diffusivity. In: *Proc. Int. Conf. Quantitative InfraRed Thermography*. Gdansk: QIRT Council, 2016, vol. 22, pp. 895–901.

[7] DUAN, Y., HUEBNER, S., HASSLER, U., OSMAN, A., IBARRA-CASTANEDO, C., MALDAGUE, X.P.V. Quantitative evaluation of optical lock-in and pulsed thermography for aluminum foam material. *Infrared Physics and Technology*, 2013, vol. 60, pp. 275–280.

[8] JUNYAN, L., YANG, L., FEI, W., YANG, W. Study on probability of detection (POD) determination using lock-in thermography for nondestructive inspection (NDI) of CFRP composite materials. *Infrared Physics and Technology*. 2015, vol.7 1, pp. 448–456.

[9] VAVILOV, V.P., BURLEIGH, D.D. Review of pulsed thermal NDT: Physical principles, theory and data processing. *NDT & E International*. 2015, vol. 73, pp. 28–52.

[10] ŠVANTNER, M., MUZIKA, L., CHMELÍK, T., SKÁLA, J. Quantitative evaluation of active thermography using contrast-to-noise ratio. *Applied Optics*. 2018, vol. 57, pp. D49–D55.

[11] BALAGEAS, D.L., ROCHE, J.M., LEROY, F.H., LIU, W.M., GORBACH, A.M. The thermographic signal reconstruction method: A powerful tool for the enhancement of transient thermographic images. *Biocybernetics and Biomedical Engineering*. 2015, vol. 35, pp. 1–9.

[12] MALDAGUE, X., MARINETTI, S. Pulse phase infrared thermography. *J. of Applied Physics.* 1996, vol. 79, no. 5, p. 2694.

[13] ŠVANTNER, M., MUZIKA, L., HOUDKOVÁ, Š. Quantitative inspection of coatings thickness by flash-pulse thermography and time-power transformation evaluation. *Applied Optics.* 2020, vol. 59, pp. E29–E35.

[14] MEZGHANI, S., PERRIN, E., VRABIE, V., BODNAR, J.L., MARTHE, J., CAUWE, B. Evaluation of paint coating thickness variations based on pulsed Infrared thermography laser technique. *Infrared Physics and Technology*. 2016, vol. 76, pp. 393–401.

[15] CHULKOV, A.O., VAVILOV, V.P. Comparing thermal stimulation techniques in infrared thermographic inspection of corrosion in steel. In: *IOP Conference Series: Materials Science and Engineering*. 2015, vol. 81, no. 1, 012100.