Infrared thermography for high-temperature pressure pipe

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High-temperature pressure pipelines are extensively used in petrochemical plant and power stations. Severe pits or wall loss defects can be internally produced after a certain period of time due to media corrosion and cavitation erosion. These defects finally lead to leakage of the pipes. In order to search for a good non-destructive method for these defects, a large pipe testing installation was constructed. A series of infrared thermography testing experiments were performed for four kinds of stainless steel and carbon steel pipes which are drilled with different size holes on their inner-surface. The testing results show that infrared thermography is a very suitable method for non-destructive testing of corrosion pits and wall loss defects in high-temperature pressure pipes. The corrosion pits or wall loss defects that are bigger than 10 mm diameter × 40% wall thickness can be detected by infrared thermography. The testing sensitivity satisfies the requirements for safe operation of pipelines.

1. Introduction

High-temperature pressure pipelines are extensively used in petrochemical plant and power stations. Leakage and explosion accidents often take place after a certain period of time due to media corrosion, cavitation erosion, welding defects cracking, stress corrosion cracking and materials deterioration. According to the statistics from a large number of pipe leakage accidents, media corrosion and cavitation erosion are the main reasons for leakage and explosion accidents. The figure is larger than 50% of the total accidents. In order to ensure the safe operation of the pipes, it is necessary to search for some good NDT methods to assess wall thickness and then replace only critically damaged pipes. X-rays (or γ-rays), ultrasonics, and infrared thermography are useful for such purposes. Infrared thermography testing has the advantages of being non-contact, fast, harmless, useful for either the reflective or transmissive method, and easy to deploy. It therefore has the potential to test the pits and wall loss defects on-line for high-temperature pressure pipes.

The discontinuities in solid materials can change the heat flow condition. The change of the heat flow condition can result in the fluctuation of the temperature on the surface of the materials. Both infrared testing and thermal imaging use this principle to measure the change of the surface temperature and then to deduce the discontinuity condition in the materials.

In non-destructive testing of industrial equipment, infrared thermography is applied to condition monitoring of electrical equipment, power plant machinery and high-temperature equipment[1-3]. In NDT of pressure pipe, only a few papers were found by means of a literature search using INSPEC, EI, ISMEC, METADEX and so on. Almost all of these papers investigated the insulation condition and heat loss for high-temperature pressure pipes[4], heat transfer for heat exchangers[5-7], defects detect for composite pipes[4] , leakage test for underground concrete pipes[8], qualitative and quantitative assessment of steel plates using pulsed phase thermography[9], quality assurance and structural evaluation of GRP pipes[10]. Due to metals having very high thermal conductivity, few people try to test the wall loss defects for steel pipes by means of infrared thermography. Maldague appears to be the only one who performed infrared thermography testing of a small pipe in the laboratory[1, 11]. Two wall thinning defects on an elbow were detected. It has not been established that systemic investigation was performed for different types of pipes with different wall thickness. Nor has the sensitivity of the infrared thermography test for steel pipes with different wall thickness been found.

In order to get solution for such problems, a large pipe testing installation was constructed. A series of infrared thermography testing experiments during heating and cooling were performed for four kinds of stainless steel and carbon steel pipes which are drilled with different size holes on their inner-surface.

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2. Testing equipment and installation

2.1 TVS-2100 thermal video system

All the experiments were performed using a TVS-2100 thermal video system. The infrared camera head of this system is optically mechanical scanning type. The detector is InSb with 10X10 cell arrays. The detecting wavelength is 3~5.4 μm. The operating temperature range is -40~950°C. The frame rate is 30 per second.

2.2 Pressure pipe testing installation

Figure 1 is the pressure pipe testing installation constructed using five different one metre length steel pipes and linking with a 150°C steam pipeline. The 150°C steam and normal temperature water can go into the pipe testing installation according to the testing requirement.

2.3 The preparation of defects inside pipes

First, a 1 metre length of stainless steel pipe and three carbon steel pipes were vertically cut into three parts. Then, a series of different diameter and different depth holes were drilled. Finally, the three

Figure 1. Pressure pipe testing installation for infrared thermography test

parts were welded into a pipe again. Table 1 lists the sizes of all defects in the four types of steel pipes.

Table 1. The size of defects in four types of steel pipes

Type and specification (mm)	Inside defects quantity and size (mm)
Φ114×4 stainless steel	24 defects: Diameter: (Φ2, Φ4, Φ6, Φ10) X Depth: (15%, 25%, 35%, 50%, 65%, 75%)
Φ140×5 20 carbon steel	24 defects: Diameter: (Φ2, Φ4, Φ6, Φ10) X Depth: (20%, 40%, 50%, 60%, 70%, 80%)
Φ168×16 20 carbon steel	12 defects: Diameter: (Φ4, Φ8, Φ12) X Depth: (10%, 20%, 40%, 60%) 12 defects: Diameter: (Φ5, Φ10, Φ15) X Depth: (20%, 40%, 60%, 80%)
Φ180×36 20 carbon steel	12 defects: Diameter: (Φ4, Φ8, Φ12) X Depth: (10%, 20%, 40%, 60%) 12 defects: Diameter: (Φ5, Φ10, Φ15) X Depth: (20%, 40%, 60%, 80%)

3. Infrared thermography for locating internal defects in pipes

3.1 Inside steam heating

The pipe was passed through 150°C steam to heat from normal temperature. The thermal effusivity values were controlled by controlling the steam flux between 0.5 m^3 and 1.0 m^3 per minute. At the same time, the thermal image of the defects was viewed and recorded on the floppy disc and tape recorder. The typical thermal images of defects for four types of pipes are shown from Figures 2 to 5 respectively. Table 2 lists the minimum defects identified using infrared thermography for four types of pipes.

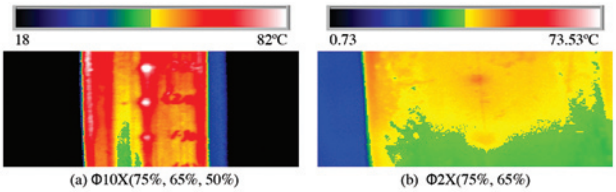

Figure 2. Φ114×1000×4 stainless steel pipe

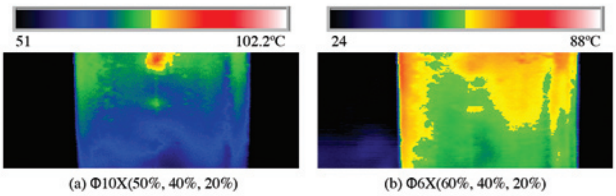

Figure 3. Φ140×1000×5 20 carbon steel pipe

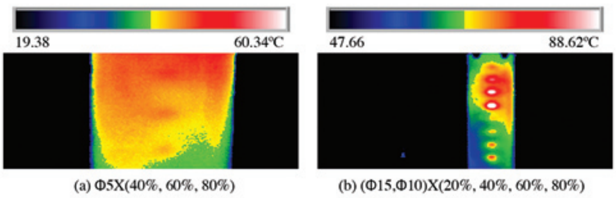

Figure 4. Φ168×16 20 carbon steel pipe

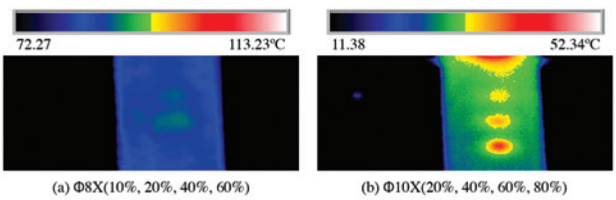

Figure 5. Φ180×36 20 20 carbon steel pipe

Table 2. The minimum defects tested by infrared thermography for four types of pipes

Type and specification (mm)	The size of minimum defects tested (mm)
Φ114×4 stainless steel	Φ10×15%, Φ6×25%, Φ4×50%, Φ2×65%
Φ140×5 20 carbon steel	Φ10×20%, Φ6×40%
Φ168×16 20 carbon steel	Φ10×20%, Φ8×20%, Φ5×40%
Φ180×36 20 carbon steel	Φ12×20%, Φ10×40%, Φ8×60%

3.2 Outside cooling after steam heating

After the pipes are heated for a short time (from 30 s to 5 min), the stationary heat flow condition is constructed. Temperature differences between areas of different wall thickness within a pipe are non-existent. In order to get significant thermal contrasts for the defects, outside cooling is performed to break the stationary heat flow condition. The outside cooling is carried out by means of ice and refrigeration gas. The minimum detectable defect is an internal hole with diameter 6 mm and depth 1 mm for Φ114×4 mm stainless steel pipe and an internal hole with diameter 10 mm and depth 2 mm for Φ140×5 mm carbon steel pipe. Figure 6 shows the instantaneous thermal images of the defects for these two pipes after ice cooling.

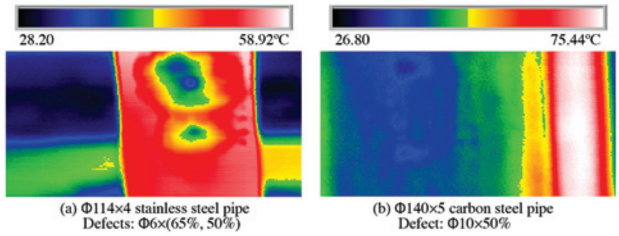

Figure 6. Thermal images of defects after steam heating and ice cooling

4. Analysis

Through viewing the whole infrared thermal imaging process and analysing the testing data listed in Table 2, a series of phenomena and laws are found as follows:

1. Comparing the minimum detectable defects of Φ114×4 stainless steel and Φ140×5 carbon steel, it can be found that the testing sensitivity of stainless steel is much higher than carbon steel. For a Φ10 mm opening hole defect, the duration time is about two minutes from emerge to disappear of the defect on thermal image for stainless steel pipe, but it is just 30 s for carbon steel pipe. The reason is that the thermal conductivity of stainless steel is 15 W/(m.°C) and carbon steel is 48 W/(m.°C). That is, the thermal conductivity of materials is a key factor affecting the sensitivity of the infrared thermography test. The lower the thermal conductivity, the higher the sensitivity and the longer the duration of defects emerging.
2. For defects of different diameters in the same pipe, the detectable depths of the defects are different. These phenomena show that the size of defects is another key factor affecting the sensitivity of the infrared thermography test. The larger the area of defect, the higher the sensitivity of wall loss.
3. Comparing the testing results of three types carbon steel pipes with different thickness, it was found that the thinner the wall, the smaller the size of detectable defects. However, the thicker the wall, the longer the duration of defects emerging. For a Φ10 mm opening hole defect, the duration time is about 30 s for Φ140×5 pipe; 120 s for Φ168×16 pipe, and more than 200 s for Φ 180×36 pipe. Thus it can seen that the thickness is also a key factor affecting the sensitivity of the infrared thermography test. The thicker the material, the lower the testing sensitivity but the longer the duration of defects emerging.

4. Comparing the testing results of inside heating and outside cooling, it was found that the detecting sensitivity of inside heating is higher than outside cooling. The detecting sensitivity of refrigeration gas cooling is higher than ice cooling.
5. Assuming that the operation pressures of the four types of pipes in Table 2 all are 3 MPa, fracture mechanics calculation shows that a 10 mm diameter and 80% wall loss defect is safe for all the four pipes. That is, the sensitivity of infrared thermography test is much more than the accepted defects for safe operation of the pipes.

5. Conclusion

The testing results show that infrared thermography is a reliable non-destructive method for detecting wall loss defects produced by corrosion and flow erosion of high-temperature pipe. The sensitivity of the infrared thermography test is much higher than the accepted defects for safe operation of the pipes.

The disadvantage of this method is the need to heat the pipes to change the temperature during testing. Wall loss defects cannot be detected at steady temperature.

References

1. Nondestructive Testing Monographs and Tracts, Vol 7, Infrared Methodology and Technology, edited by X Maldague, Gordon and Breach Science Publishers, 1994.
2. Nondestructive Testing Handbook, Vol 9, Special Nondestructive Testing Methods, eds: R K Stanley, P O Moore and P McIntire, American Society for Nondestructive Testing, 1995.
3. T-M Liou, C-C Chen and T-W Tsai, 'Heat transfer and fluid flow in a square duct with 12 different shaped vortex generators', Transactions of the ASME. Journal of Heat Transfer Vol 122, No 2, pp 327-35, May 2000.
4. R N Wurzbach and D A Seith, 'Infrared monitoring of power plant effluents and heat sinks to optimize plant efficiency', Proceedings of SPIE – The International Society for Optical Engineering Thermosense XXII, Orlando, FL, USA, 24-27 April 2000.
5. R Rozenblit, M Simkhis, *et al*, 'Heat transfer in horizontal solid-liquid pipe flow', International Journal of Multiphase Flow, Vol 26, No 8, 2000.
6. S Yamawaki, T Yoshida, *et al*, 'Fundamental heat transfer experiments of heat pipes for turbine cooling', American Society of Mechanical Engineers, (Paper), Proceedings of the International Gas Turbine & Aeroengine Congress & Exposition, Orlando, FL, USA, 2-5 June 1997.
7. Y Qin and N Bao, 'Thermographic nondestructive testing technique for delaminated defects in composite structure', Proceedings of SPIE – The International Society for Optical Engineering Thermosense XVII, Orlando, FL, USA, 1995.
8. K R Maser and M S Zarghamee, Proceedings of the Speciality Conference on Infrastructure Condition Assessment, Boston, MA, USA, 25-27 August 1997.
9. C Ibarra-Castanedo, N P Avdelidis and X Maldague, 'Qualitative and quantitative assessment of steel plates using pulsed phase thermography', Journal of Materials Evaluation, 63(11), pp 1128-1133, 2005.
10. M Wright, 'Sure2Grip-Quality assurance and structural evaluation of GRP pipes', in the 9th European Conference on Non-Destructive Testing, Conference Proceedings, Berlin, 25-29 September 2006.
11. X Maldague, 'Pipe inspection by infrared thermography', Materials Evaluation, Vol 57, No 9, 1999.