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THERMOGRAPHY ANALYSIS ON WELDING DEFECTS AND INTERNAL EROSION OF CARBON STEEL PIPELINE

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ABSTRACT

Emerging faults are typically associated with excessive heat or heat loss. Capturing these heat images and analyzing them allows a quick solution to be taken. Due to that, thermography infrared is widely used nowadays as a non-destructive testing for a fast detecting variety of defects. In this paper, application of active thermography method for detection of internal pipe defects has been investigated. The main focus of the project is on the identification of two most common defects of pipeline; (i) welding defects, and (ii) erosion defects. Three types of welding defects; crack, undercut and lack of fusion weld and also internal erosion defects with different depth were implemented on an ASTM A53 Gr. B carbon steel pipeline as a prediction model for the experiment. During testing these defects were heated through thermal energy generated by heated water. The result found that with the presence of abnormal feature in these defects, propagation of thermal energy through these defects has directly influenced on the surface temperature of the specimen by inducing a significant thermal contrast between defective and non-defective area. Significant temperature gradient occurred within 35 seconds for 100°C, 90°C and 80°C heated water. The others of 70°C and 60°C were found unstable in producing significant infrared image. The 4mm erosion with 66.67% of penetration depth has always shows the higher temperature. The study concludes that active thermography technique is suitable as a non-destructive method for the detection of internal pipeline defects.

Keywords: Thermography・Non-destructive Test・Welding Defect・Erosion

INTRODUCTION

Pipelines are widely used in the field of engineering such as power stations and petrochemical plant. However, pipeline leakage could take place at any time without awareness of people due to unpredictable phenomenon of internal defects such as media corrosion, erosion corrosion and welding failures [1–3]. According to the statistics of hazardous liquid pipeline incidents, erosion corrosion has rated as the most typical defect which caused the highest number of pipelines failure and explosion accidents, followed by materials or weld failure defects [4].

Erosion defects occurred due to instant impact created by solid particles at the inner surface of pipes, resulting in significant reduction of pipe thickness [5]. For this reason, frequent failures of engineering applications takes place such as pipelines, turbines and heat exchangers. There are two major sources which are mainly affected the rate of erosion; (i) velocity of the solid particles by creating an instant impact at the inner surface of pipes, and (ii) angle of impact in between target surface and the particle trajectory. However, the actual impact velocity carried out by the solid particles is highly depending on the size and shape of particles.

Others factors include the total distance of acceleration take places, where longer acceleration distance allowed solid particles to create higher actual impact velocity, causing significant service life reduction of equipment [6].

In pipeline industry, one of the method to connect each pipe is by using welding. However, there is no weld that is completely perfect. Lack of ability on handling of testing, measurement and control in correct way may cause failure of the weld [7]. Weld defect is defined as the physical discontinuity or absence of homogeneity in the form of mechanical, physical or metallurgical property of the welds.

Cracks occurred in welded joints due to the existence of stress concentration caused by weld shape and weld discontinuities. Cracks can be classified into hot cracks or cold cracks [8]. Cracks occurred in welded joints during solidification process or before the heat of weldment has completely released from the welded joints is known as hot cracking. Low melting impurities that contain in base metal such as phosphorous, sulphur, selenium and boron remain in liquid form even after the solidification process of main metal has completed, causing impurities occupy the grain boundaries. Crack that occurred in the welded joint after the solidification process of weld is completed was known as cold cracking. Three main sources which brings the formation of cold cracking such as existing of residual stresses in the weldment, hardening of the heat affected zone and the presence of the diffusible hydrogen in the weldment [9,10].

In general, infrared thermography techniques can be categorized into two main classes; passive and active thermography. In term of passive thermography analysis, propagation of natural heat in the structure due to its

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normal operation is scanned by infrared camera, whereby no heat source is required [11]. Meanwhile for active thermography, implementation of external energy sources takes place where energy is delivered to the specimen and then propagated through the structure until it encounters a flaw [12–14]. As a result, speed of the propagated thermal energy was influenced by these discontinuities, resulting in either hotter or cooler spot on the surface of the specimen.

Due to these aforementioned causes of defects in pipeline, active thermography technique was implemented in this study as a non-destructive method for identifying the existence of internal erosion corrosion and three different types of welding defects; crack, undercut and lack of fusion. From the obtained thermal images, propagation of thermal energy through these defects was investigated.

METHODOLOGY

Preparation of specimens

In this research, a 0.4572m (1.5ft) length of ASTM A53 Gr. B carbon steel pipeline was introduced as the prediction model of the experiment. Before welding defects were implemented, normal shielded metal arc weld was conducted on the specimen as a benchmark for the research. Later, three main welding defects such as; (i) crack, (ii) undercut and (iii) lack of fusion weld were implemented on the specimen as shown in Figure 1.

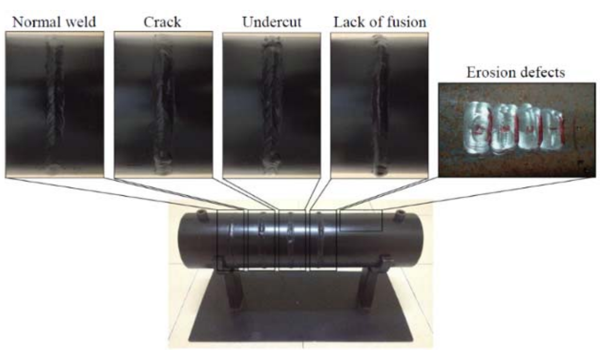

Figure-1. Implemented defects

After welding defects has been introduced on the testing specimen, implementation of erosion defects takes place. Thus, a series of different depth erosion defects were drilled at the inner surface of testing specimen. Table 1 lists the depth of implemented erosion defects. Lastly, testing specimen was covered with flay black paint by obtaining a uniform thermal emissivity on the surface of the specimen.

Thermal imaging process

In term of thermal imaging process, all experiments were conducted through FLIR T640 thermal imaging infrared camera. Operating temperature of the infrared camera was ranged from -40°C to 2000°C with thermal sensitivity less than 0.035°C at 30°C. In additional, the detecting wavelength of the infrared camera is 7.5 ~ 14μm. Periodic image storage processing time of the infrared camera was ranged from 14s to 24 hours per frame.

Table-1. Depth of erosion defects

Measured Point	Length of erosion (mm)	Depth of erosion (mm)	Percentages of penetration (%)
Spot 1	20	4	66.67
Spot 2	20	3	50.00
Spot 3	20	2	33.33
Spot 4	20	1	16.67
Spot 5	20	0	0

Heating process

In this research, heated water was implemented as the main energy sources for all experiments by inducing a thermal contrast between defective and non-defective zones of the specimen. In term of weld inspection, boiled water was injected into the testing specimen. At the same time, thermal image of the welding defects was viewed and captured by FLIR T640 thermal imaging infrared camera in every 5 seconds.

For erosion inspection, a series of different temperature energy sources were implemented. As a result, exposure of thermal gradient across the erosion defects under supplemental of different temperature energy sources were viewed and captured by FLIR T640 thermal imaging infrared camera as illustrated in Figure 2.

Figure-2. FLIR T640 camera

RESULTS AND DISCUSSION

Weld cracking

For weld cracking defect, the result shows that the existence of crack defect at the inner surface of the carbon steel pipe is detectable through infrared thermography technique. With the existence of crack defect at the inner surface of weld, propagation of thermal energy across the flaw has directly influenced on the specimen surface temperature by creating significant higher surface temperature at the middle of the weld. Figure 3 shows the infrared thermal image of weld cracking at t=20s.

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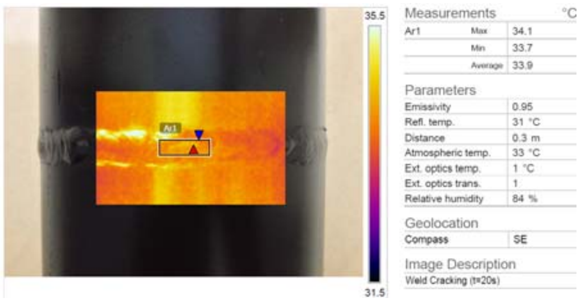

Figure-3. Infrared thermal image of weld cracking

Undercut weld

In term of undercut weld, result shows that the differences of surface temperature in between specimen surface and undercut weld are insignificant due to penetration of undercut defect is relatively low. In this situation, bad formation of metal coalescence during welding process of undercut weld have influence the propagation of thermal energy to tip of the weld causing relatively low temperature was distributed at the tips of the weld as shown in Figure 4.

Figure-4. Infrared thermal image of undercut weld

Lack of fusion weld

For lack of fusion weld, obtained result shows that the existence of lack of sidewall fusion defect could be detected through infrared thermography technique. With the existence of discontinuity in between sidewall of base metal and weld metal, propagation of thermal energy through the weld has directly influenced on the specimen surface temperature by creating significant lower surface temperature at side of the weld. Figure 5 shows the infrared thermal image of lack of fusion weld.

Erosion defects

Through infrared thermography technique, exposure of thermal gradient across the erosion defects at different level of energy sources were viewed and captured by FLIR T640 thermal imaging infrared camera. As a result, variation of surface temperature conducted on each different depth erosion defects over time under supplemental of different temperature energy sources were constructed as shown in Figure 6.

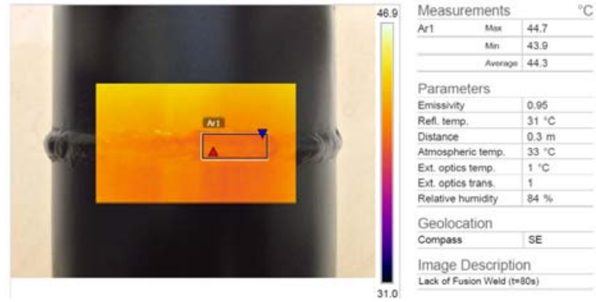

Figure-5. Infrared thermal image of lack of fusion weld

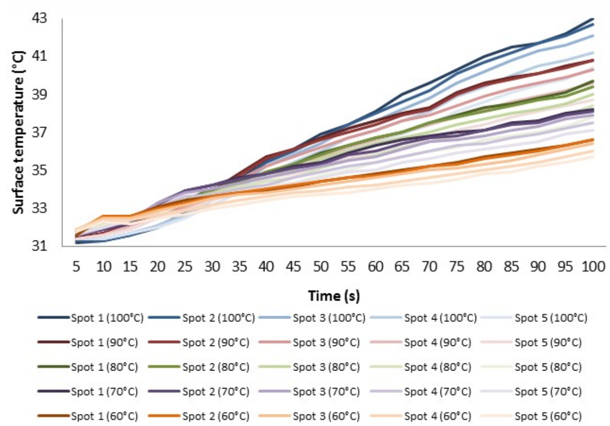

Figure-6. Prediction model of erosion defects at different level of energy sources

Generally, highest surface temperatures were emerged from the obtained infrared thermal image when the penetration of erosion defect is deeper. As can be seen from the graph, differences of surface temperature in between each erosion defects increased significantly when higher level of energy sources was introduced. In this situation, the higher level of energy sources injected into the specimen, the larger scale of thermal contrast between erosion defects and specimen surface were emerged from the infrared thermal image.

From the obtained infrared thermal images, exposure of thermal gradient across the erosion defects under supplemental of different temperature energy sources began from t=30s to 50s were constructed as shown in Figure 4.8. As we can see, significant reduction of thermal contrast between erosion defects and carbon steel pipe takes place when the level of implemented energy sourced is decreased constantly. From Figure 7, it is clear that the exposures of erosion defects from the obtained infrared thermal images under supplemental source of heat from 70°C water or below are relatively low.Through application of FLIR ResearchIR software, post-processing thermal images of erosion defects under supplemental of heat from 5 different levels of energy sources was constructed as shown in Figure 8. As can be seen, exposure of thermal gradient across the erosion defects was significantly enhanced through filtering

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Defect	Water temperature (°C)	Time sequences (s) 30	35	40	45	50
Erosion defects	100					
	90					
	80					
	70					
	60					

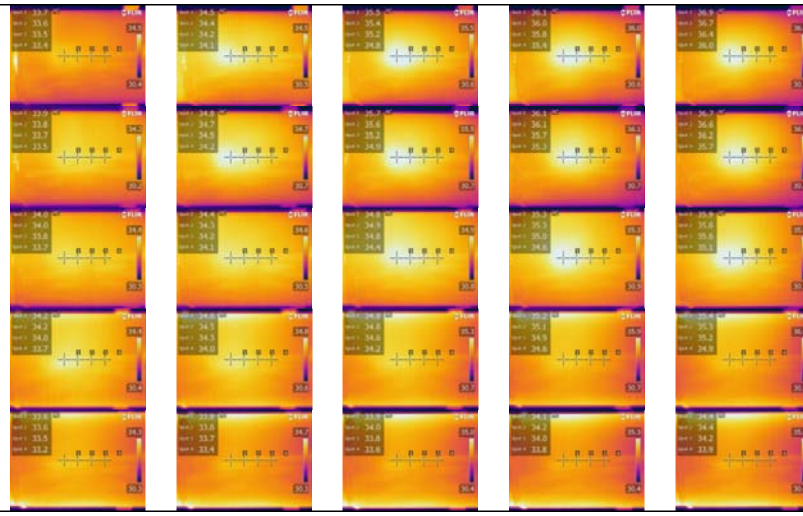
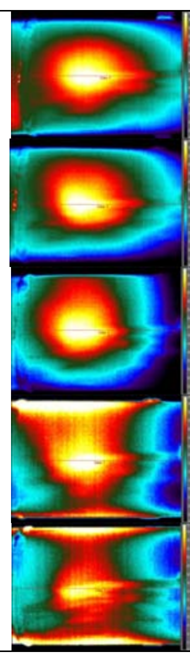


Figure-7. Surface temperature variation of erosion defects from t=30s to 50s

process. With application of line ROI (Region of Interest), graphs surface temperatures versus pixel were generated. As a result, variations of surface temperature across the erosion defects are similar even if the implemented energy sources are different. At this point, result verified that significant decrement of surface temperature was present in the specimen when the depth of the depth of erosion defect was reduced constantly although exposure of erosion defects from the obtained infrared thermal images is nearly invisible for experiment under supplemental of

Defect	Water temperature (°C)	Time sequences (s)	Post-processing of infrared thermal image	Temperature (°C) versus pixel
Erosion defects	100	45		
	90	40		
	80	50		
	70	50		
	60	20		



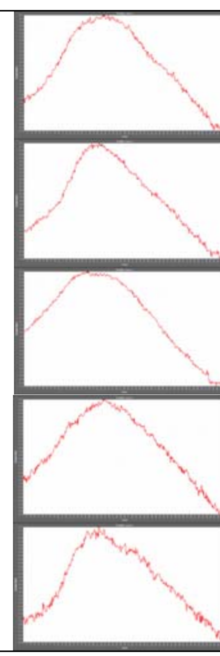


Figure-8. Comparison of post-processing infrared thermal images lower energy source.

CONCLUSIONS

In this research, infrared thermography technique was introduced as a non-destructive testing (NDT) method for welding failure and internal erosion defects. In term of welding failure, results show that the existence of internal weld defects such as weld cracking and lack of fusion weld are detectable through active thermography technique. For erosion defects, result shows that highest surface temperatures were emerged from the obtained infrared thermal image when the penetration of erosion defect is deeper. Thus, the larger scale of thermal contrast between erosion defects and specimen surface were emerged from the infrared thermal image when higher level of energy sources was injected into the specimen. In conclusion, experiment results show that infrared thermography is a reliable non-destructive method by detecting internal pipe defect caused by erosion defects and weld failures.

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