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Quantitative Pitting Evaluation Stainless Steel 304 At Cooling Phase by Active Infrared Thermography With Different Target Angle

Syazwan Haziq Zulkurnain[1], Maznan Ismon[2]*, Suhaimi Hassan[1]

[1]Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussien Onn Malaysia, Parit Raja, Batu Pahat. 86400, Johor

[2]Noise and Vibration Analysis Research Group (NOVIA),
Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

*Corresponding Author

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Abstract: Infrared thermography technique used to inspect various type of problems in engineering field. In this research, active thermography method is applied to overcome the constrain to inspect the pitted location at invisible area. The main purpose of this experiment is to examine the pitted occur behind the stainless steel 304 plate and at the same time to determine the best view angle for thermography inspection. This experiment use heat gun as radiation source to transfer heat energy to the surface of stainless steel plate. The infrared camera used is FLIR T640 will be recording along the experimental process and thermal contras recorded will be analyse by using FLIR Tools software. The experiment testing will be conduct in a closed room. All of data obtain will be interpreted in graph scale by using Microsoft Excel to examine the defect area shown by temperature contras. The experiment conducted will set among 10°, 20°, 30°, 40°, 50°, 60°, 70° and 80° respectively for the view of angle. The finding of this research will determine the best angle for thermography inspection

Keywords: Infrared Thermography, Stainless steel 304, Target angle, Non-destructive test

1. Introduction

Pitting corrosion are declared as frame of corrosion by which cavities or gaps are created within any materials. Pitting considered to be more perilous than normal uniform corrosion because it is more troublesome to identify, foresee and plan against. Little pit contact to metal misfortune can lead to the failure of complete structure system.

Pitting corrosion would act as acceleration to increase those failure compare than any other corrosion such as uniform corrosion and non-uniform corrosion [1]. There are seven type of pitting corrosion

*Corresponding author: maznan@uthm.edu.my

which is narrow deep, shallow wide, elliptical, vertical grain attack, subsurface, undercutting and horizontal grain attack [2]. Infrared thermography applied using two approaches which are active and passive. For active approach, the process is carried out during the same time as external stimulus applied with to the inspected specimen. The approach to ensure thermal contrast on the surface inspected in order to detect the imbalance structure with the existence of defects.

In this study, stainless steel 304 plates is used as a subject while the main tool using in identifying the pitted is FLIR T640. This experiment proposed an active thermography method where 2200W powered of heat gun acting as a heat source transmit to the subject to form thermal difference.

1.1 Infrared Thermography Field

Infrared thermography is well known of non-contact measurement devices resulting from science contribution to the study of thermal Infrared thermography considered as big influenced to be used as inspection method where applied to metallic equipment system such as stainless steel. By using thermography systems, it is possible to determine and localize internal defects to the equipment. This technique is also widely applied in different fields such as military & space, astronomy, environment, medical & life sciences, and commercial applications

1.2 Emissivity

Emissivity of material surface refers to the ability of surface to emit thermal energy called as radiation which depending on temperature. Radiation emits at any temperature above 0 degree on any surface [3]. Mathematically, emissivity defined as thermal radiation ratio to the radiation of ideal black surface. Emissivity can be valued from 0 (shiny mirror) to 1.0 (black body) [4]

1.3 Relationship Angle with Thermography Infrared

In thermography infrared, the uncertainty temperature reflected from emissivity, the angle of infrared detector (camera) and distance. Practically, those are the obstacle for an accurate thermographic inspection [5]. Experimentally the emissivity of any surface could change by viewing angle factor [6]. Few parameters that are directly to determine the emissivity and reflectivity such as spectral wavelength, roughness and angle view. Angle view strongly affect the radiometric data and need to be consider as precaution steps to avoid any problem to spectacular reflection [7].

1.4 Transient Heat

Transient heat refers to temperature of the body change with time. That's mean value of heat energy that enter certain volume will be different to the value of heat energy that exit from those volume. Most work involving to deal with stationary temperature and velocity, but there are small number that deal with time [8]. Different amount of radiance emit by the surface will affect the thermal gradient captured by infrared camera [9].

1.5 Stainless Steel 304

Stainless steel 304 provide many uses throughout any application. It is become world famous application materials due to it is good properties such as high corrosion resistance, relative low cost, good formability and weldability [10]. Stainless steel 304 contain the ion composition of Carbon, Manganese, Phosphorus, Sulphur, Silicon, Chromium, Nickel, Nitrogen, and Iron [11]. The composition is shown in Table 1 below.

Table 1 : Composition of stainless steel 304

Composition	Type 304 (wt%)
Carbon (c)	0.08 max
Manganese (Mn)	2.00 max
Phosphorus (P)	0.045 max
Sulphur (S)	0.030 max
Silicon (Si)	0.75 max
Chromium (Cr)	18.00 – 20.00
Nickel (Ni)	8.00 – 12.00
Nitrogen (N)	0.10 max
Iron (Fe)	Balance

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1.6 Previous Research

The previous research is used as a reference and guideline in this study.

1.6.1 Evaluation to Measure Defects in the Invisible Area Using Infrared Thermography

The researchers are using the same concept of active thermography method by using Infrared thermography camera, halogen lamps, and PC were installed to select the reflection plates were required for measuring of invisible area in the plate. For the plate material, they use brass, glass, copper, carbon steel, pure iron and wafer. All of the plate having the same dimensions which are 100 mm x 100 mm with 10 mm thickness. The analysis was based on the rate of heat energy change that absorbed by the plate from the heat energy transfer by heat source. Based on the analysis, pure iron, aluminium, brass and carbon steel because they are considered being able to be used as reflection plate because of high energy absorption by heat source.

1.6.2 Effect of Viewing Angle of IR Thermography Camera For The Detection of Landmine

For this study, it was a research on effect of viewing angle of infrared thermography camera for the detection of landmine. The approached used is to attach the infrared camera to multifunctional quadrocopter to adjust the view angles from the sky. Three type of angle view used which are 90°, 60° and –60°. FLIR-650 SC camera placed 280cm distance from detection surface to snap sequence image at the view angles tested. For the findings, all three angle different of view having little effect towards the effectiveness of inspection. For sure the emissivity are considerably constant between 60° to -60° angle of view.

2. Methodology

This experiment was done at normal surrounding temperature in a closed room. Figure 1 shown the experimental layout for the experiment and Table 2 shown the parameters observed during the experiment

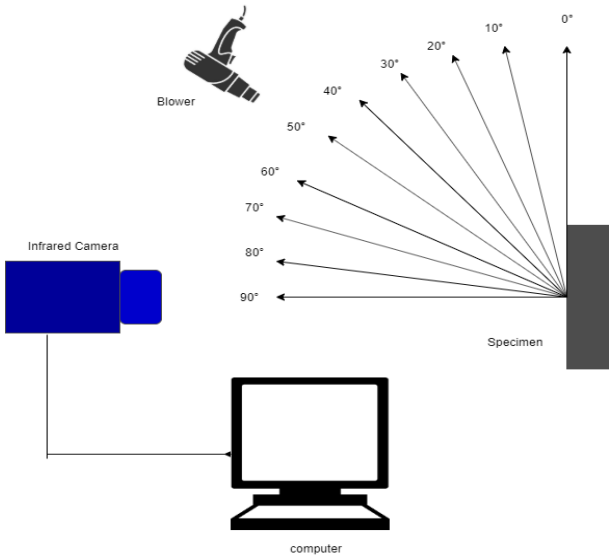


Figure 1: The experimental layout

Table 2 : The parameters observed during the experiment

Parameters	Value
Emissivity of the stainless steel 304	0.95
Atmospheric temperature	28.6
Distance between camera and specimen	1.0 m
Relative humidity	65%
Surface temperature	28.2
Time of heat exposure by specimen	10 seconds

2.1 Experimental procedure

The experiment procedure must be done step by step in order to obtain clear image of pitted.

i. The experiment was set up in closed room
ii. The ambient temperature and the relative humidity of surrounding been measured.
iii. FLIR T640 camera placed 1meter from the stainless steel's plate. The angle view of 10° between camera and plate was set up.
iv. The camera and laptop linked together by using FLIR+ software to record live stream video.
v. Switched on the heat gun and pointed to the plate surface for 10 seconds while FLIR Tools+ are ready in recording mode.
vi. Put away heat gun from experiment zone after settle the heat exposure as precaution for camera from error calibrating.
vii. Camera screen must be monitored along the recording time to observe any suspicious shown.
viii. The recording was stopped after 3 minutes.
ix. The step 1 until 8 was repeated by using 20°, 30°, 40°,50°,60°, 70°, and 80° of angle between camera and stainless steel plate.

2.2 Analysis procedure

Specifications and properties of materials, equipment, and other resources used in the current study should be described in this section.

i. One video selected to be put in analysis mode. Played the video to observe the pitted appearance. Once the pitted detected. Add box measurement tools to read the temperature of the surface where pitted detected as Figure 2 below.

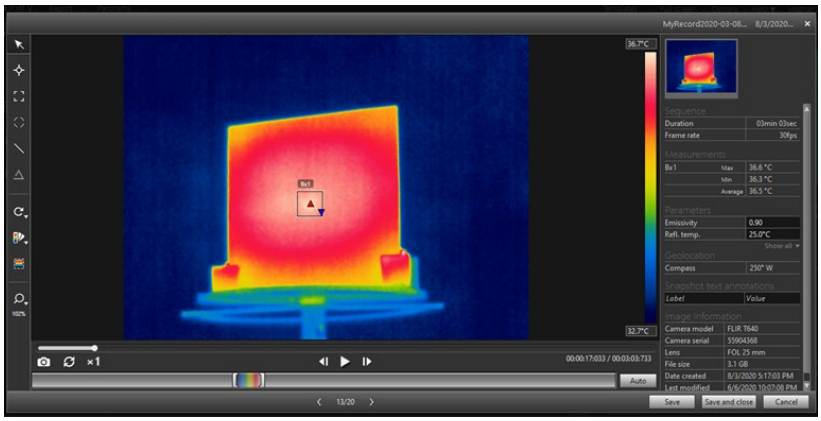


Figure 2 : Pointed Box Measurement of Pitted Detected

ii. Adjusted the temperature range to focus the pitted contrast along the surface. The clear image of the pitted were obtained as Figure 3.

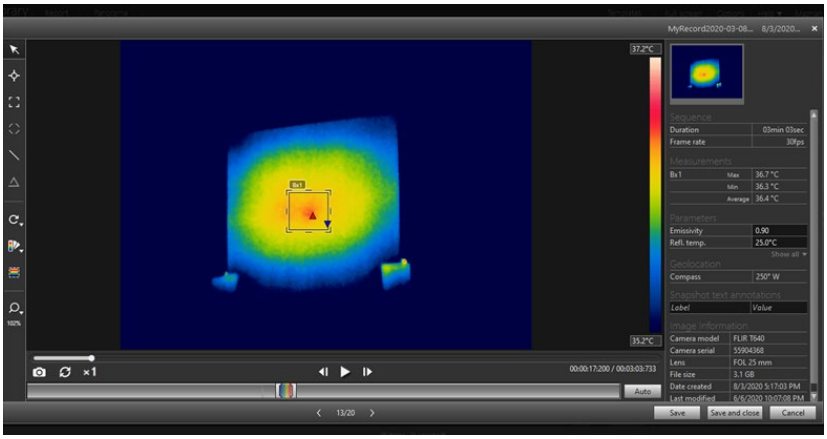


Figure 3 : Adjusted temperature range

iii. The temperature graph of maximum, average and minimum was plotted by using plot figure option on software. Referring to experiment conducted, pitted normally detected exactly on a sudden drop of graph maximum or peak before it goes to achieve condition of thermal equilibrium to the surrounding. The line of temperature reading obtained as Figure 4 below.

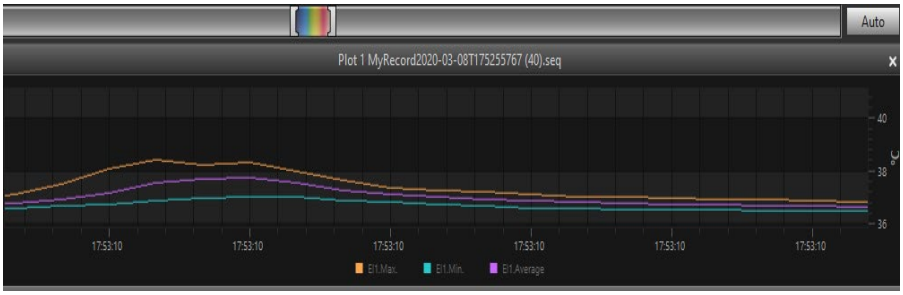


Figure 4: Line of Temperature Reading

iv. When pitted was appeared, click snapshot figure to form a thermogram from recording video. The thermogram that contain of pitted appearance was captured as image then been analysed using Comma Separated Values (CSV). The analysis on box measurement was imported into Microsoft Office Excel in form of temperature data. On the excel, transform all the data into contour graph as Figure 5. The contour graph obtained will exactly present pitted shaped capture by different target angles.

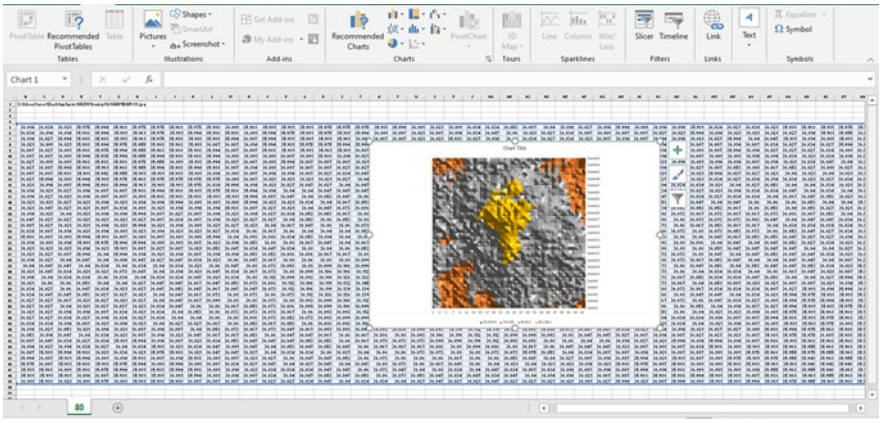


Figure 5: Contour graph using excel

3. Results and Discussion

The evaluation made by using active Infrared Thermography (IRT) method to inspect the pitted behind the stainless steel 304 plate. The experiment is conducted by different target angle which are 10°, 20°, 30°, 40°, 50° ,60°, 70° and 80°. The experiment is done at room temperature surrounding3.1 Results. Heat gun with power of 2200W used to transfer heat by radiation to the stainless steel plate. The time for the exposure to the heat was set up only 10 seconds for each angles. Thermal imaging was recorded and processed by using FLIR T640 infrared camera which is 1 meter from the plate. All the data are obtained converted from the image taken been analyzed until clearest image of pitted detected for every target angle choose by using FLIR Tools + software.

3.1 Data obtained for experiment

The data obtained from this research are tabulated as below. The results are based on different target angle used as variable in this experiment. The data obtained as shown in Table 3 below.

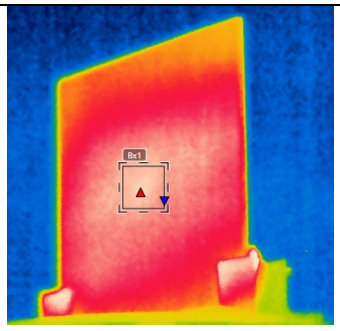
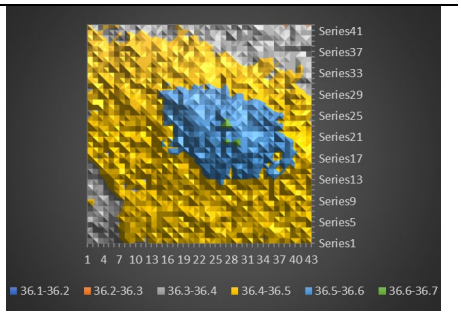
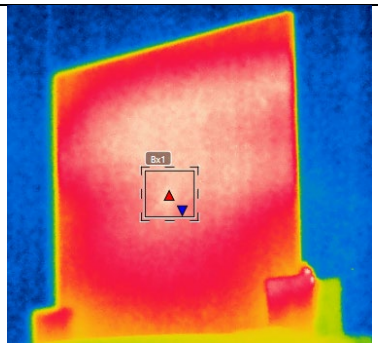
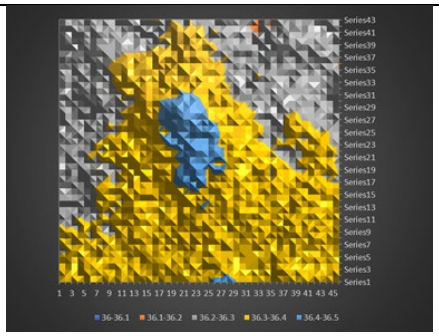
Table 3: Data of time taken to capture pitted image

No	Target angle	Pitted image captured	Time taken for defect start to appear (s)	Surface temperature while image captured (°C)	Total time for the defect appearance (s)
1	10°	No	-	-	-
2	20°	No	-	-	-
3	30°	Yes	0.97	36.0	2.53
4	40°	Yes	0.47	36.6	8.47
5	50°	Yes	0.80	36.4	6.87
6	60°	yes	1.23	36.4	3.17
7	70°	Yes	1.40	36.6	6.57
8	80°	yes	1.53	36.1	4.90

From Table 3, no defect detected by infrared camera for 10° and 20° as target angles. Otherwise, pitted were detected for certain amount of time for 30°, 40°, 50° ,60°, 70° and 80° as target angles. Both 40° and 50° of target angle showing the longest total time for the defect appearance in seconds in this experiment and shortest is at 30° as target angle.

To analyse more precise data, the image captured for all different target angle and all of the heat contrast changes are recorded for about three minutes. The contrast is then analysed by converting to contour graph using Microsoft Office Excel. Table 4 shows the graph contour of the pitted shown by 40° and 50° of target angles.

Table 4: The graph contour of the pitted shown by 40° and 50° of target angles

Target angle (°)	Total time for the defect appearance (s)	Image captured	Contour graph of the defect
40°	8.47		
50°	6.87		

3.2 Comparison of the result

The comparisons done in order to get the best view of angle to obtain the most significant image appeared. There two main focus in discussion which are comparison time of image appear shown by Graph of Time of Pitted Appear (s) Against Target Angle (°) and secondly is comparing for total time for the defect appearance shown by Graph of Total Time of Pitted Appearance (s) Against Target Angle (°).

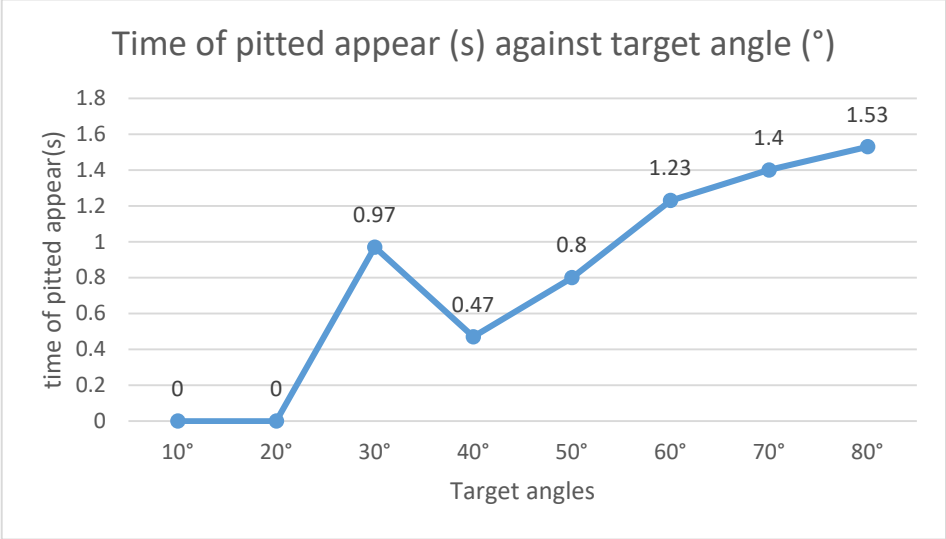


Figure 6: Graph of time of pitted appear (s) against target angle (°)

From Figure 6, there are ascending pattern line graph from 40° to 80° of target angles. The peak of the graph hold by 80° of target angle at 1.53 seconds and the lowest at 0.47 seconds for 40°. For 10° and 20°, there are no pitted identified by infrared camera along the recording time. Fluctuate pattern were discovered from 30° to 40° and then after that, the graph continuing to show an ascending pattern to the end.

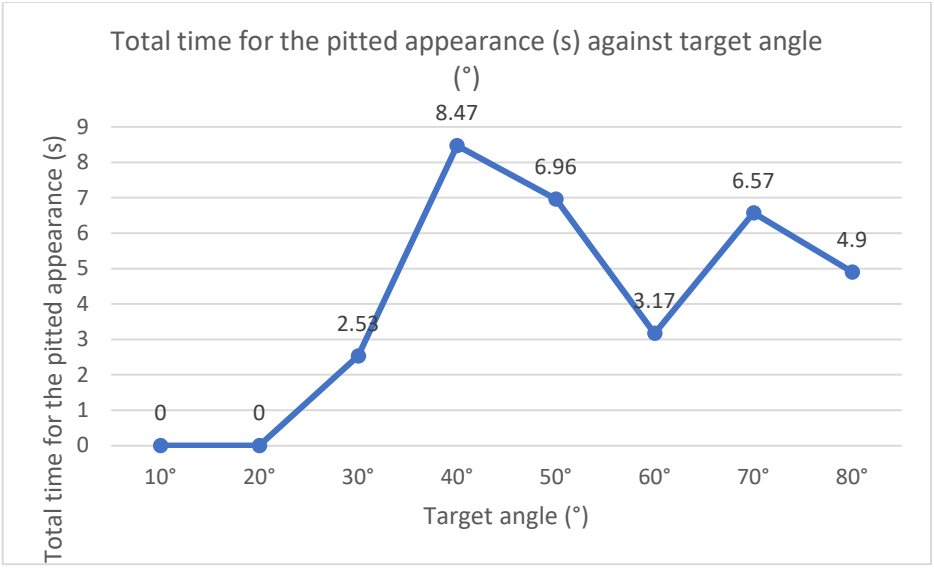


Figure 7: Graph of total time of pitted appearance (s) against target angle (°)

From Figure 7, the peak shows the longest time recorded for pitted appearance is 8.47 seconds for 40° as target angle. For the second highest at 50° of target angle which is 6.96 seconds. There are no pitted detected by infrared camera for 10° to 20°. The shortest time recorded for pitted appearance is 2.53 seconds for 30° as target angle. The pattern of the graph in ascending pattern from 30° to 40°. After reach the peak, the graph pattern fluctuated to 3.17 seconds at 60°. Then, it climbs back to reach 6.57 seconds for 70° and descending to 4.9 seconds for 80° as target angle.

4. Summary and conclusion

The research is focussed by analysing the time taken for pitted to appear and total time for the defect appearance based on different target angles. Infrared camera FLIR T640 were used throughout the experiment which play the important role to record the experiment conducted. The heat was supplied heat gun throughout whole of stainless steel plate surface. After complete heat exposure, the heat source must be taken away from the recording scene in order to avoid any unnecessary error because the slightest difference in temperature would affect the thermogram captured. The infrared camera is connected to laptop by using FLIR Tools software for every test involving different target angles. The analysis was made through the FLIR Tools+ software by analysis the graph of maximum, minimum and average temperature of the full-length video. The defect is then, represented into contour graph by extracting all the data from radiometric image. The experiment come out with pitted detected for 30°,40°,50°,60°,70°, and 80°. The longest time recorded for the total time of the pitted image detected observed is 40° for 8.47 seconds. For the second longest held by 50° of target angle which is 6.96 seconds. In conclusion, it is approved that 40° and 50° the best target angle in evaluating pitted corrosion on stainless steel 304 by infrared thermography method.

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