The Enhancement of Non-Destructive Testing (NDT) through Active Thermal Infrared Thermography to Identify Internal Piping Failure

By

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Dissertation submitted is partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Petroleum Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

____

(Ir. Dr. Mohd Shiraz Bin Aris)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

SEPTEMBER 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(Mohamad Aliff Muniff Bin Mohd Nasir)

ABSTRACT

Non-Destructive Testing or NDT is an analysis or testing to evaluate the properties of material/component/system without causing damage. In oil and gas industry, the NDT is divided into two which are conventional and nonconventional (Basrawi, et al., 2003). However, there are some problems regarding with conventional NDT which are time consuming, hazardous, complicated and most of it only detect the defects at external surface. The NDT can be enhanced through Thermal Infrared because this Nonconventional NDT can be done safely, easily, non-hazardous and less time consuming. By using infrared camera to detect an internal defect on piping, the experiment was done to enhance the NDT by using thermal infrared method in order to identify internal piping failures, to detect the defects inside a piping by using infrared camera, and to identify the temperature differences between defects and sample. This prediction or assumption is useful in order to enhance the NDT that has been used in oil and gas industry.

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1. INTRODUCTION

1.1. Background of Study

The Non-Destructive Testing or NDT is an analysis or testing techniques to evaluate properties of material/component/system without causing damage. NDT has been used in oil and gas industry since early 1950's and has proven to be a daily routine examination for many in the oil industry (Basrawi, et al., 2003). The conventional such as Radiography (RT), Ultrasonic (UT), Magnetic Particle (MT), Liquid Penetrant (PT) and Visual Testing (VT) are NDT that are frequently used in oil and gas industry to identify the flaws on/in the material (Basrawi, et al., 2003). The nonconventional NDT is a method that is rarely used or never been applied in oil and gas industry. The example for this method includes Electromagnetic Testing (ET), Acoustic Emission (AE), and Thermal Infrared (IR) (Basrawi, et al., 2003). This project mainly concern on piping at the offshore facilities. This kind of NDT will provide the capability to see what is going on within a process system or specifically piping and observe a real-time result if there are any changes during the testing. Infrared camera used in this project detects radiation in the infrared electromagnetic spectrum and produce images of the surface with information about the surface temperatures. Infrared radiation is emitted by all objects; and it depends on its temperature whether the object will emit more or less radiation. The example of thermal image is as shown in Figure 1-1.

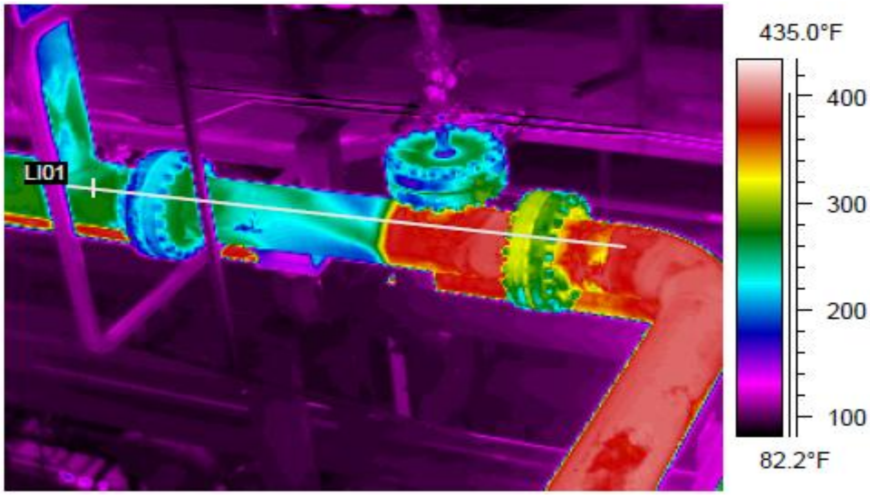


Figure 1-1 Thermal Image

1.2. Problem Statement

Current/Conventional NDT methods which are widely used in Oil and Gas Industry such as Radiography Testing (RT), Ultrasonic Testing (UT), Magnetic Particle Testing (MT), Liquid Penetrant Testing (PT), Visual Testing (VT) has many weaknesses such as time consuming, hazardous, and complicated and most of it only detect flaws at the surface only compared to non conventional Thermal Infrared Thermography (IR).

NDT method can be enhanced through Thermal Infrared Thermography (IR). By this enhancement, the NDT process can be done by an easy way, less time consuming and safely.

1.3. Objective

- To enhance the NDT (Non Destructive Testing) by using active thermal infrared method in order to identify internal piping failures.
- To detect the defects inside a piping by using infrared camera. But in this project the piping will be replaced by a plate that is made by same material as most of the piping in offshore facilities.
- To identify the temperature differences between defects and host (sample)

1.4. The Relevancy of the Project

The increasingly recognized applicability of infrared thermography has caused development of remote-sensing diagnoses for various engineering applications. A significant advantage of this technique is that we can diagnose invisible defects nondestructively and safely (Inagaki, et al., 1999). This method is important and better than other type of testing which has many weaknesses. Since it is important, this project will be conducted in order to improve this NDT performance.

1.5. Feasibility of the Project

The difficulty level of this project is average. In order to get a best result, this experiment needs to be done in a dark room to avoid from reflection that can be detected by infrared camera. The reflections that appear can cause noisy to the thermal images thus affects result. All objects (even humans) will emit radiation. This radiation can cause reflection and can be detected by infrared camera.

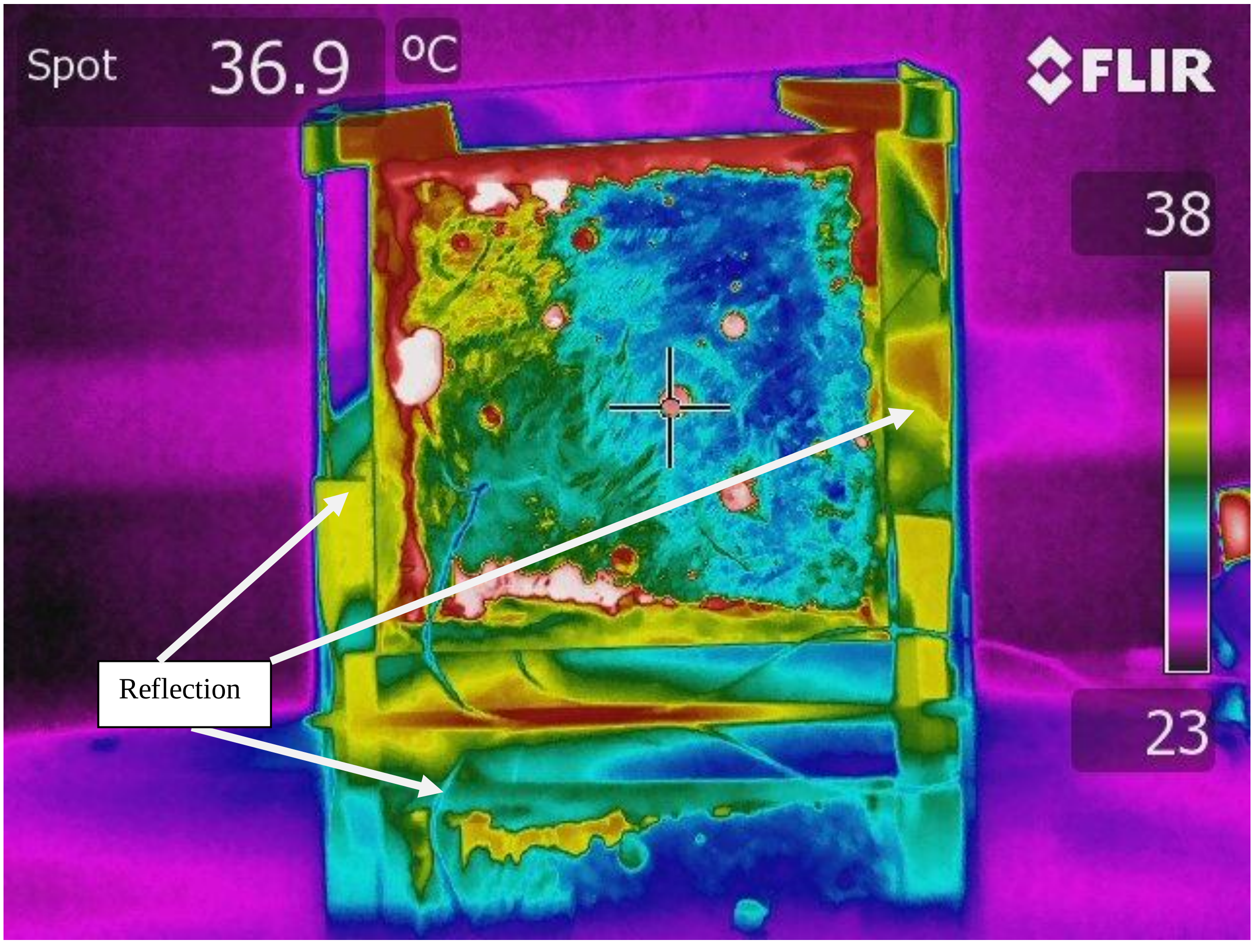


Figure 1-2 Example of noisy thermal images

CHAPTER 2

2. THEORY AND LITERATURE REVIEW

2.1. Non-Destructive Testing

NDT stands for non-destructive testing. In other words it is a way of testing without destroying. This means that the component- the casting, weld or forging, can continue to be used and that the non destructive testing method has done no harm. In today's world where new materials are being developed, older materials and bonding methods are being subjected to higher pressures and loads, NDT ensures that materials can continue to operate to their highest capacity with the assurance that they will not fail within predetermined time limits. NDT can be used to ensure the quality right from raw material stage through fabrication and processing to pre-service and in-service inspection. Apart from ensuring the structural integrity, quality and reliability of components and plants, today NDT finds extensive applications for condition monitoring, residual life assessment, energy audit, etc. There are many NDT techniques/methods used, depending on four main criteria:

- Material Type
- Defect Type
- Defect Size
- Defect Location

2.2. Other Type of NDT Methods

The Non Destructive Testing methods can be broken down into two main categories: conventional and non conventional. The conventional NDT methods are those that have been in use since as early as 1950's and have proven to be a daily routine examination for many in the oil industry (Basrawi, et al., 2003).

Ultrasonic Testing - UT

A typical UT inspection system consists of several functional units, such as the pulser/receiver, transducer, and display devices. A pulser/receiver is an electronic device that can produce high voltage electrical pulses. Driven by the pulser, the transducer generates high frequency ultrasonic energy. The sound energy is introduced and propagates through the materials in the form of waves. When there is a discontinuity (such as a crack) in the wave path, part of the energy will be reflected back from the flaw surface. The reflected wave signal is transformed into an electrical signal by the transducer and is displayed on a screen. In the Figure 2-1, the reflected signal strength is displayed versus the time from signal generation to when an echo was received. Signal travel time can be directly related to the distance that the signal traveled. From the signal, information about the reflector location, size, orientation and other features can sometimes be gained.

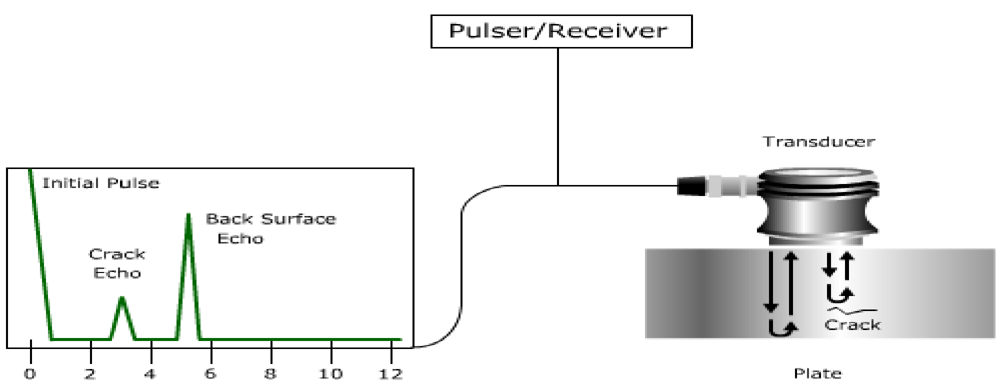


Figure 2-1 Ultrasonic Testing

Radiography Testing (RT)

Radiography Testing (RT) is a nondestructive testing (NDT) method of inspecting materials for hidden flaws by using the ability of short wavelength electromagnetic radiation (high energy photons) to penetrate various materials.

Either an X-ray machine or a radioactive source can be used as a source of photons. Neutron radiographic testing (NR) is a variant of radiographic testing which uses neutrons instead of photons to penetrate materials. This can see very different things from X-rays, because neutrons can pass with ease through lead and steel but are stopped by plastics, water and oils.

Since the amount of radiation emerging from the opposite side of the material can be detected and measured, variations in this amount (or intensity) of radiation are used to determine thickness or composition of material. Penetrating radiations are those restricted to that part of the electromagnetic spectrum of wavelength less than about 10 nanometres.

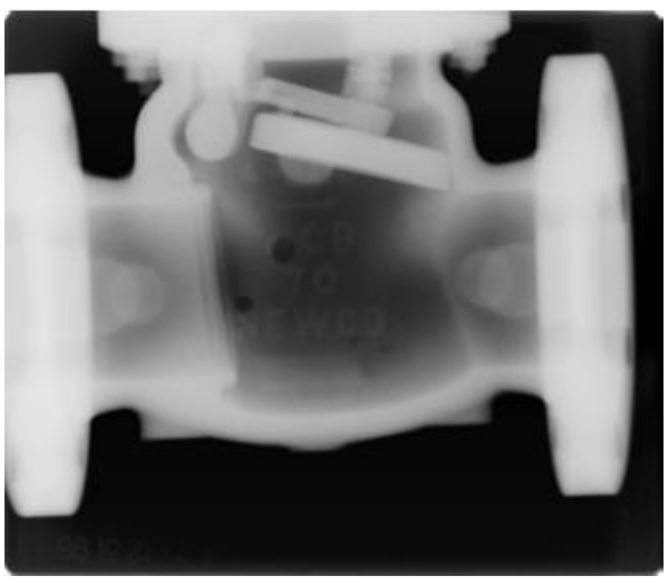


Figure 2-2 Radiographic Image of Valve

Magnetic Particle (MPI)

Magnetic particle inspection (MPI) is a nondestructive testing method used for defect detection. MPI is fast and relatively easy to apply, and part surface preparation is not as critical as it is for some other NDT methods. These characteristics make MPI one of the most widely utilized nondestructive testing methods.

MPI uses magnetic fields and small magnetic particles (i.e.iron filings) to detect flaws in components. The only requirement from an inspectability standpoint is that the component being inspected must be made of a ferromagnetic material such as iron, nickel, cobalt, or some of their alloys. Ferromagnetic materials are materials that can be magnetized to a level that will allow the inspection to be effective.

The method is used to inspect a variety of product forms including castings, forgings, and weldments. Many different industries use magnetic particle inspection for determining a component's fitness-for-use. Some examples of industries that use magnetic particle inspection are the structural steel, automotive, petrochemical, power generation, and aerospace industries. Underwater inspection is another area where magnetic particle inspection may be used to test items such as offshore structures and underwater pipelines.

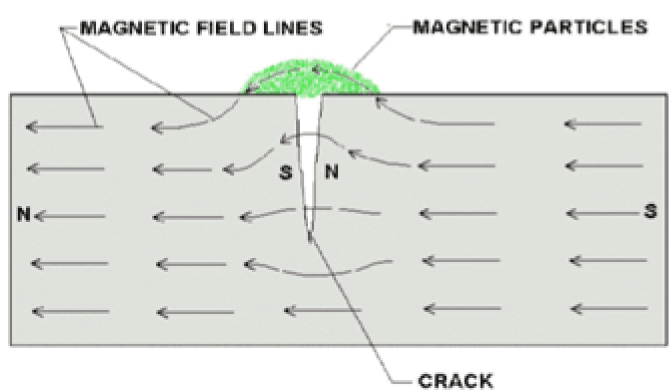


Figure 2-3 Magnetic Particle Testing

Liquid Penetrant (PT)

Liquid Penetrant (PT) is a widely applied and low-cost inspection method used to locate surface-breaking defects in all non-porous materials (metals, plastics, or ceramics). The penetrant may be applied to all non-ferrous materials and ferrous materials; although for ferrous components magnetic-particle inspection is often used instead for its subsurface detection capability. LPI is used to detect casting, forging and welding surface defects such as hairline cracks, surface porosity, leaks in new products, and fatigue cracks on in-service components.

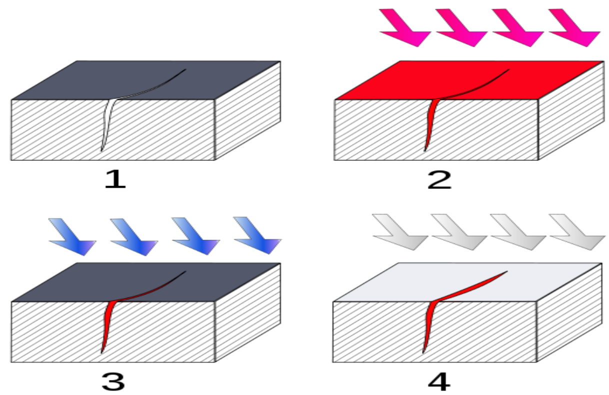


Figure 2-4 Liquid Penetrant Testing

Based on Figure 2.4,

1. Section of material with a surface-breaking crack that is not visible to the naked eye
2. Penetrant is applied to the surface.
3. Excess penetrant is removed.
4. Developer is applied, rendering the crack visible.

Visual Testing (VT)

Visual Testing (VT), the most frequently used and most overlooked conventional NDT method, can be very simple and very complex. Simply looking at a part and identifying areas of concern is the simple part. Remote visual inspection using borescopes, fiberscopes and even robotic video devices is the far more complex part and requires significantly more training and expertise. Both types of visual inspection can be used on virtually any material where access is possible.

2.3. Advantages and Disadvantages of NDT

Table 2-1 Advantages and Disadvantages of NDT

Method	Advantages	Disadvantages
Radiography Testing (RT)	- Can be used to inspect virtually all materials. - Detects surface and subsurface defects. - Ability to inspect complex shapes and multi-layered structures without disassembly. - Minimum part preparation is required.	- Extensive operator training and skill required. - Access to both sides of the structure is usually required. - Orientation of the radiation beam to non-volumetric defects is critical. - Field inspection of thick section can be time consuming. - Relatively expensive equipment investment is required. - Possible radiation hazard for personnel.
Ultrasonic Testing (UT)	- Depth of penetration for flaw detection or measurement is	- Surface must be accessible to probe and couplant.

	superior to other methods. - Only single sided access is required. - Provides distance information. - Minimum part preparation is required. - Method can be used for much more than just flaw detection.	- Skill and training required is more extensive than other technique. - Surface finish and roughness can interfere with inspection. - Thin parts may be difficult to inspect. - Linear defects oriented parallel to the sound beam can go undetected. - Reference standards are often needed.
Magnetic Particle (MT)	- Large surface areas of complex parts can be inspected rapidly. - Can detect surface and subsurface flaws. - Surface preparation is less critical than it is in penetrant inspection. - Magnetic particle indications are produced directly on the surface of the part and form an image of the discontinuity. - Equipment costs are relatively low	- Only ferromagnetic materials can be inspected. - Proper alignment of magnetic field and defect is critical. - Large currents are needed for very large parts. - Requires relatively smooth surface. - Paint or other nonmagnetic coverings adversely affect sensitivity. - Demagnetization and post cleaning is usually necessary.
Liquid Penetrant/Penetrant Testing (PT)	- Large surface areas or large volumes of parts/materials can be inspected rapidly and at low cost. - Parts with complex geometry are	- Detects only surface breaking defects. - Surface preparation is critical as contaminants can mask defects.

	routinely inspected. - Indications are produced directly on surface of the part providing a visual image of the discontinuity. - Equipment investment is minimal.	- Requires a relatively smooth and nonporous surface. - Post cleaning is necessary to remove chemicals. - Requires multiple operations under controlled conditions. - Chemical handling precautions are necessary (toxicity, fire, waste).
Visual Testing (VT)	- Very cost-effective method - It does not require complicated equipment - An ideal first step in the inspection process and can reveal flaws such as surface porosity, undercut, surface cracks and unacceptable bead contour	- The resolution depends on ability of the human eye - It has difficulty determining porosity diameters less than 0.25 mm or cracks less than 0.025 mm wide - Objects closer than 150 to 250 mm are hard to focus on - Lighting conditions must be adequate for good visibility - Surface discontinuities can be detected with this method and the surface must be cleaned of contaminants to prevent masking of those surface discontinuities
Thermal/Infrared (IR)	- A non-contact, non-destructive means of testing - Reduce operating cost - Virtually eliminate unnecessary work	- External factor that might interfere the thermal images such as reflection

	- Reduce unnecessary material expenses - Avoid catastrophic failures - Direct maintenance to the root of the problem - No specific safety required.	

Based on the Table 2-1, Infrared Thermography has been chosen because Infrared Thermography method is assures quality, reduce operating cost, increase efficiency, non-contact and non-destructive, fast and effective, real-time and subjective.

2.7. Thermal Infrared Thermography

Bodies emit thermal radiation as a consequence of their temperature. While thermal radiation is transmitted by most gases, including atmosphere, it is blocked by most liquids and solids. All the bodies emit and absorb thermal energy besides reflecting a part of the incident energy. The thermal radiation emitted by the bodies depends on their temperature basically, surface condition and thermal properties of the material. A black body absorbs all the radiant energy (coefficient of thermal absorption = 1.0), and emits 100 percent of its energy (Rao, 2008). Such an ideal body does not exist in reality, but the concept is useful in comprehending the concept of thermal radiation. By paint the surface with black color, this will increase the emissivity up to 97 percent. The radiation of body is partly absorbed, transmitted and reflected (Rao, 2008). The exitant radiation from the surface of a body comprises component of energy emitted, that reflected from the surface and the energy transmitted through the body by a source behind it. The component of exitant energy depends on the emissivity and refelectivity of the surface, and thermal properties (specific heat and conductivity) of the body (Rao, 2008). Steel elements have uniform temperatures because of high conductivity, while temperature on a concrete element is likely to vary over its surface (Rao, 2008).

The infrared camera senses the exitant (radiated, reflected and transmitted) thermal energy from the body, converts into temperature and displays thermal images (Meola, 2006). Thermal images provide useful data.

Infrared camera senses only the radiant energy received from the surfaces, and not the visible light reflected from the surfaces. Thermal images and visual images are different and thermal images do not require visible light.

Sources of radiation on the body should be shielded from the objects for valid results. It is advisable not to take thermal images in bright sun or when the body is exposed to radiation from any source of heat (glowing light) (Rao, 2008).

The bright region in a thermal image indicate high temperatures, while the dark region indicates low temperature and the intermediate regions are marked by colours ranging from white to black through yellow, orange, red and indigo. The exitant energy from the surface of a body depends primarily on its temperature. The quality of thermal image depends on the variation in surface temperature; the greater the contrast in temperatures, the better will be the images (Inagaki, et al., 1999).

Thermal images can usually be obtained under ambient conditions (Rao, 2008). When the body is heated by ambient conditions (solar radiation), it implies passive thermography (Meola, 2006). Sometimes the body is heated by an external source to obtain temperature contrast. Such process is known as active thermography (Carlslaw, et al., 1959).

It should also be emphasized that the images represent the surface temperature influenced by external factor (ambient conditions and distance from camera) as well as surface conditions (emissivity and coatings). The ambient conditions such as temperature, radiation from surroundings and the time of the day affect the apparent surface temperatures significantly. Thermal images do not always represent the surface temperatures but the values of the apparent temperatures processed from the radiation received by the camera. Further, surface paintings and clutter may camouflage the actual temperature and lead to incorrect conclusions. Thermal images can be processed to obtain actual temperature. (Rao, 2008).

Rate of heat flow is disturbed around the defect, that is, the rate of heat flow is lowered around the defect that having low heat conductivity or thermal diffusivity. (Inagaki, et al., 1999). Surface temperature of the defect becomes low compared with the surrounding but it can be high if the thermophysical properties of the defect are larger. (Meola, 2006). Basically, the temperature between the defect and host will be difference. Theoretically, the defect will visible if the minimum temperature difference between the defect and host is 0.2 K (Inagaki, et al., 1999). The detection of a defect depends on three factors, which are a geometrical factor (Diameter and Thickness of defect), thermal factor (Thermal conductivity, Thermal Diffusivity, Thermal Effusivity), detection/measure factor (The influence of instrumentation - Infrared Camera) (Meola, 2006). The infrared camera senses the exitant (radiated, reflected and transmitted) energy from the body, converts into temperature and displays thermal images (Meola, 2006). The quality of thermal image depends on the variation in surface temperature. The greater the contrast in temperature, the better will be the images (Meola, et al., 2004). The defect in the piping will be clearly visible if the defect has a larger diameter and a larger depth. This always can be seen in the elbow of the piping.

2.8. Corrosion/Defects inside Piping System

Piping is a system of pipes used to convey fluids from one location to another. This project is mainly focus on offshore facilities piping. Facilities at the offshore include well testing facility, water treating facility, power generation facility, and Enhanced Oil Recovery (EOR) facility. Each of the facilities is transporting fluids (water, gas) through piping. Generally, most of the piping is made of steel.

Corrosion causes gradual decay and deterioration of pipes. I can reduce the life of a pipe by eating away at the wall thickness. Under certain conditions, the time for the decay to cause the pipe to fail is as short as five years. Corrosion can also result in encrustation inside the pipe, reducing the carrying capacity of the pipe to a point that it has to be replaced to provide the flow needed.

The property of the fluids passing through the piping system greatly affects the corrosion rate of the material. These effects can be explained in terms of electrochemical theory. The water properties that affect corrosion include the concentration of dissolved oxygen, the temperature, the velocity of the fluids, and the concentration of the chloride ions.

The concentration of dissolved oxygen is one of the most important factors influencing the rate of corrosion for all metals. At ordinary temperatures, the absence of dissolved oxygen will greatly slow corrosion of ferrous metals. Oxygen is a direct participant in the corrosion reaction, acting as a cathode-accepting electron. The level of oxygen concentration increases as the rate of the electron transport increases. As a result, the rate of corrosion for most metals increases with any increase of dissolved oxygen.

Corrosion represents a particular group of chemical reactions. The rate of any particular chemical reaction will increase with a rise in the temperature and decrease with a drop in the temperature. Changes in temperature can influence the chemical composition and physical properties of the water, the character of any scales formed on the metal, and the nature of the metal itself. Temperature affects the solubility of many gases, such as oxygen, that are important to the rate of corrosion. With any increase in temperature, an increase of corrosion activity is expected.

The velocity of the fluids in the piping system is important to the rate of corrosion. If the fluid is flowing fast and is also hot and soft, the rate of corrosion of copper can be extremely fast. The critical velocity is considered to be greater than four feet per second. This type of corrosion is called erosion corrosion and involves the removal of dissolved metal ions. It is typically characterized by grooves, gullies, or waves on the inside of the pipe, especially near points of turbulence. Tees and elbows are often the first to fail when excessive velocities occur.

Microorganisms can play a part in the corrosion of pipe materials. Bacteria have the ability to form microzones of high acidity and high concentrations of corrosive ions in a pipe. The most common bacteria involved in the corrosion reaction are sulfate producers, methane producers, nitrate reducers, sulfur bacteria, and iron bacteria. The greatest possibility for this type of reaction occurs in dead ends where the water becomes stagnant. The conditions favorable to bacterial growth could be a decline of the chlorine residual and a lack of scouring velocities in the pipe. This is more common where there pitting action has been started, resulting in additional areas for the organism to become attached to the pipe. This corrosion could cause an increase of the number of main breaks.

CHAPTER 3

3. METHODOLOGY

3.1. Research Methodology

This project is an experiment-based project. An experiment is conducted by using steel plate that represents piping at offshore facilities. This is because the sample has a same material as the most of the piping used in the offshore. There are several thicknesses of piping in the industry but in this experiment the thickness of the sample is about 10 mm or 1 cm. The thickness plays an important role because the heat transfer through a material is affected by the thickness. The higher the thickness the slower the rate of heat transfers.

The experiment has been done by using steel plate as a sample. The defect or pitting has been applied at the backside of the sample which represent the defects at the internal of the piping. The sample has been heated by using heater mat that was attached at the backside of the sample in order to apply “Active Thermal Infrared” which needs external heat. The higher the heat supplied, the higher the temperature, thus the higher the radiation emission. This will give a clear thermal image of the sample and the defect. Besides that, in the industry, when the oil flows inside the piping, the temperature can reach to around 200 ^{O}C. So, the heating of the sample is tally with the actual thing in the oil and gas industry.

The setup of the experiment is as shown Figure 3-1

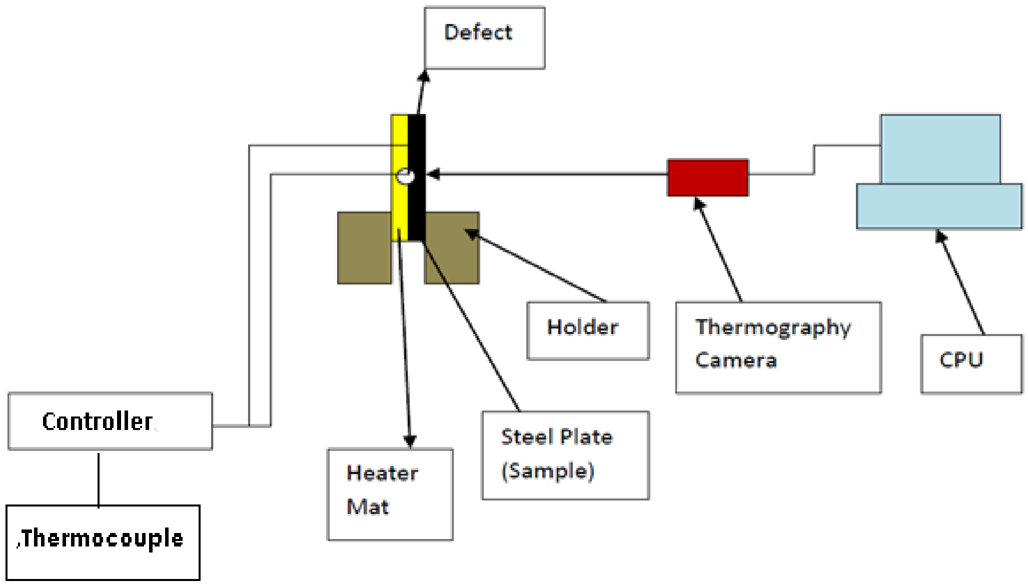


Figure 3-1 Experiment Setup

The controller was connected with heater mat and the sample. The connection between sample and controller will show the temperature of the sample. The sensor that is used in this experiment is Thermocouple Type K. This sensor was connected to controller and heater mat. The sensor was used in order to detect the heater if the heater is exceeding the temperature range that is set between 119^{O}C to 120^{O}C. If the temperature of the sample exceeds 120 ^{O}C, the sensor will turn of the controller until the temperature of the sample reach 119 ^{O}C. This will kept the sample at high temperature.

The problem occurred during the experiment was conducted is the heater mat was not functional. The alternative way to heat the sample was using a halogen lamp. Halogen lamp can supply heat to the sample but not as higher as the heater mat. The flooding light of halogen lamp will give a less efficiency because some of the heat source from the light will lose to surrounding. The efficiency of the halogen lamp will be lesser than heater mat that was attached directly on the sample.

In order to reduce inefficiency and avoid heat loss, the sample has been insulated by Rock Wool and also the surrounding of the experiment setup was insulated by Glass Wool.

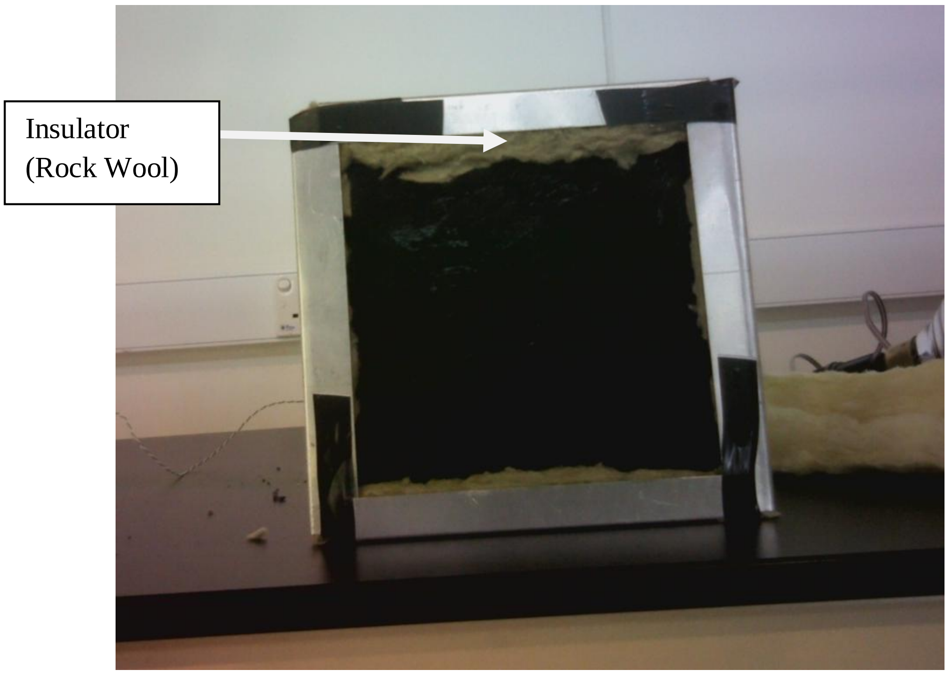


Figure 3-2 Insulated Sample (Front Side)

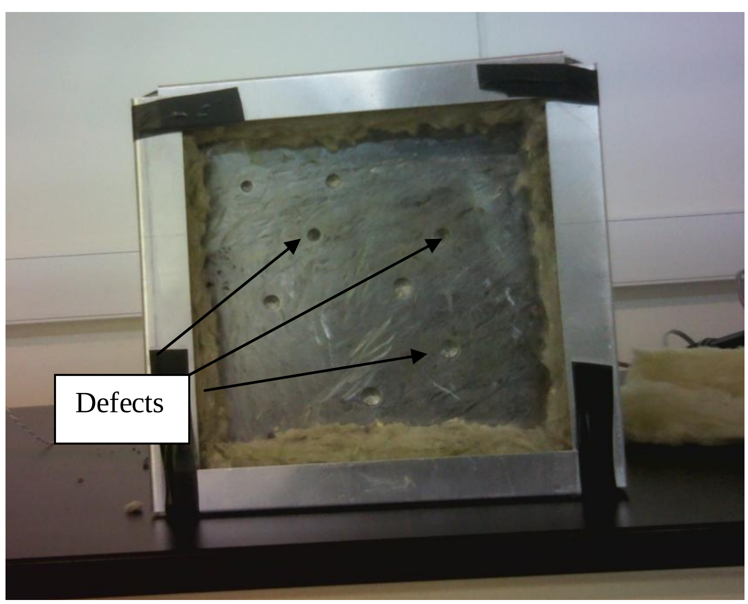


Figure 3-3 Defects (Backside)

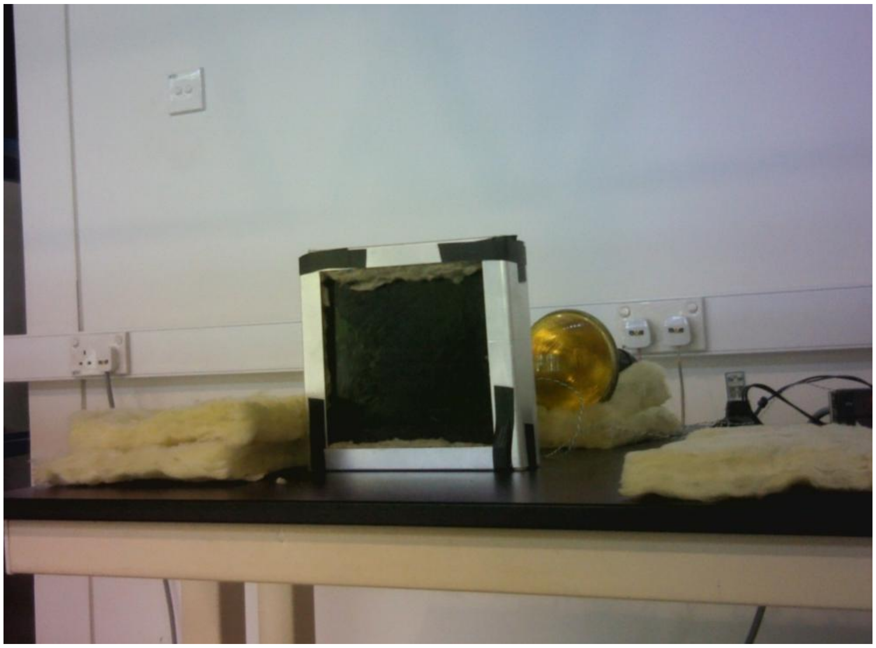


Figure 3-4 Sample Before Heated

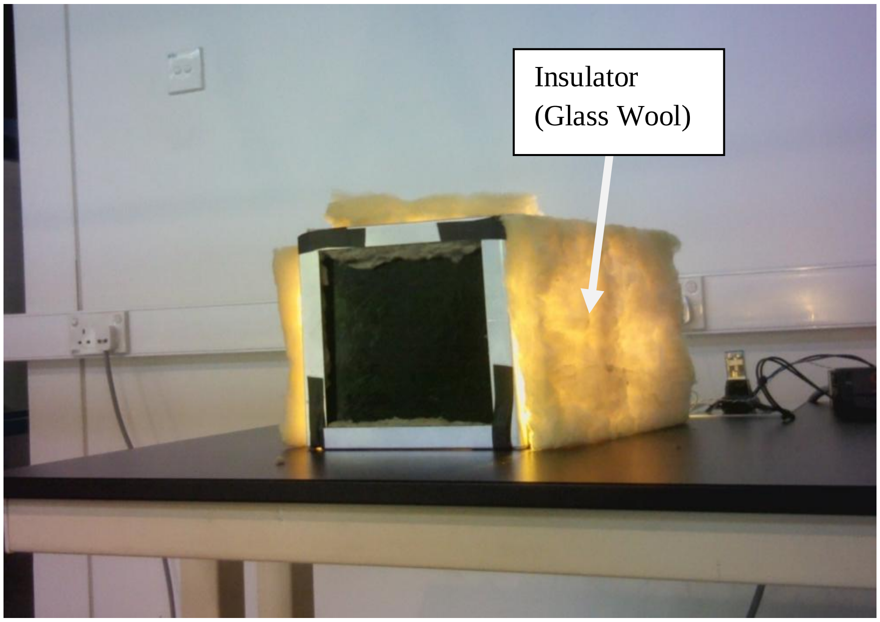


Figure 3-5 Sample When Heated

Based on the Figure 3-5, glass wool has been used to insulate the halogen lamp to prevent heat loss.

3.2. Project Activities

3.2.1. Making the Defects

Three defects that has same depth but different diameter has been applied to the sample by using drilling machine. The summary of the dimension of defects can be referred at the Table 3-1:

Table 3-1 Defects Dimension

Defect	**Diameter**	**Depth**
Defect 1	8 mm	8 mm
Defect 2	6 mm	8 mm
Defect 3	10 mm	8 mm

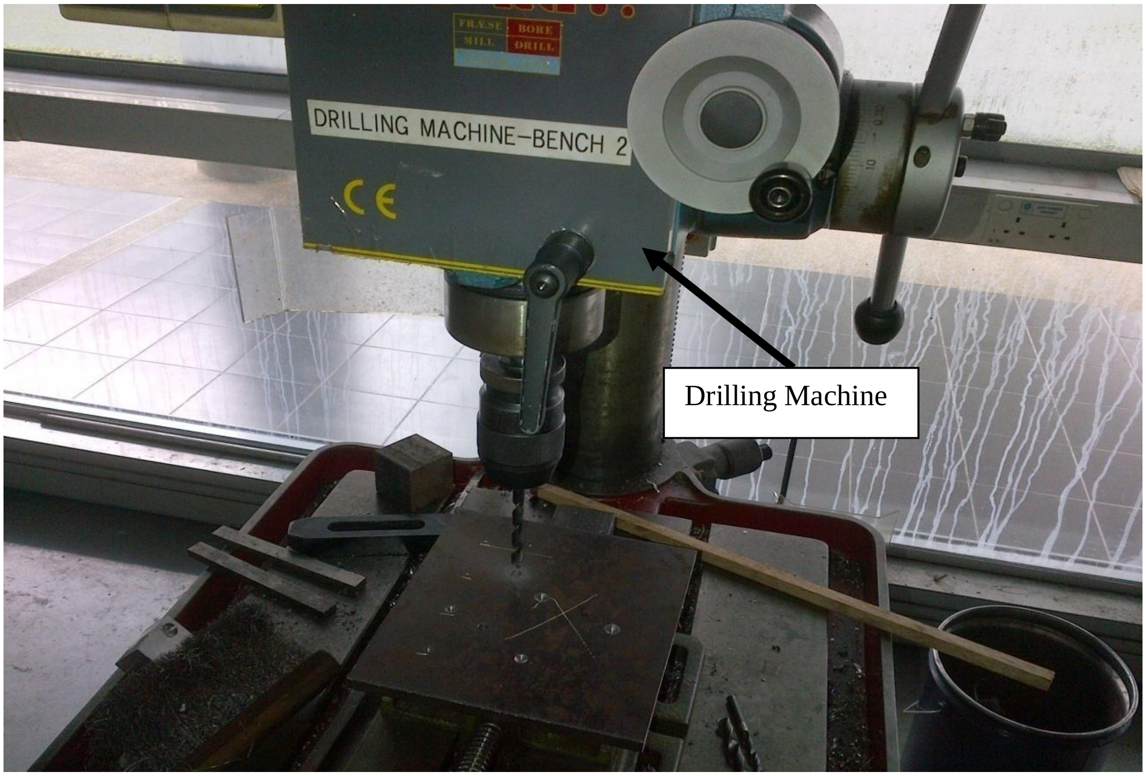


Figure 3-6 The Making of the Defects on the Sample

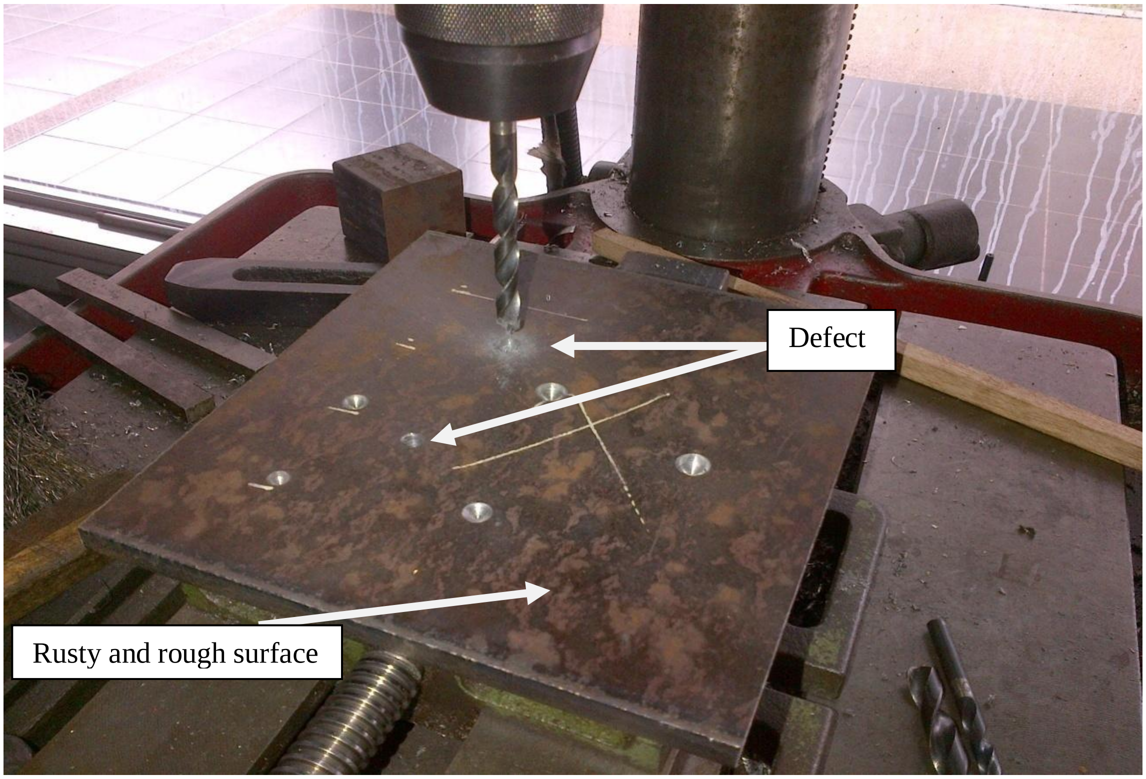


Figure 3-7 The Making of the defects on the Sample

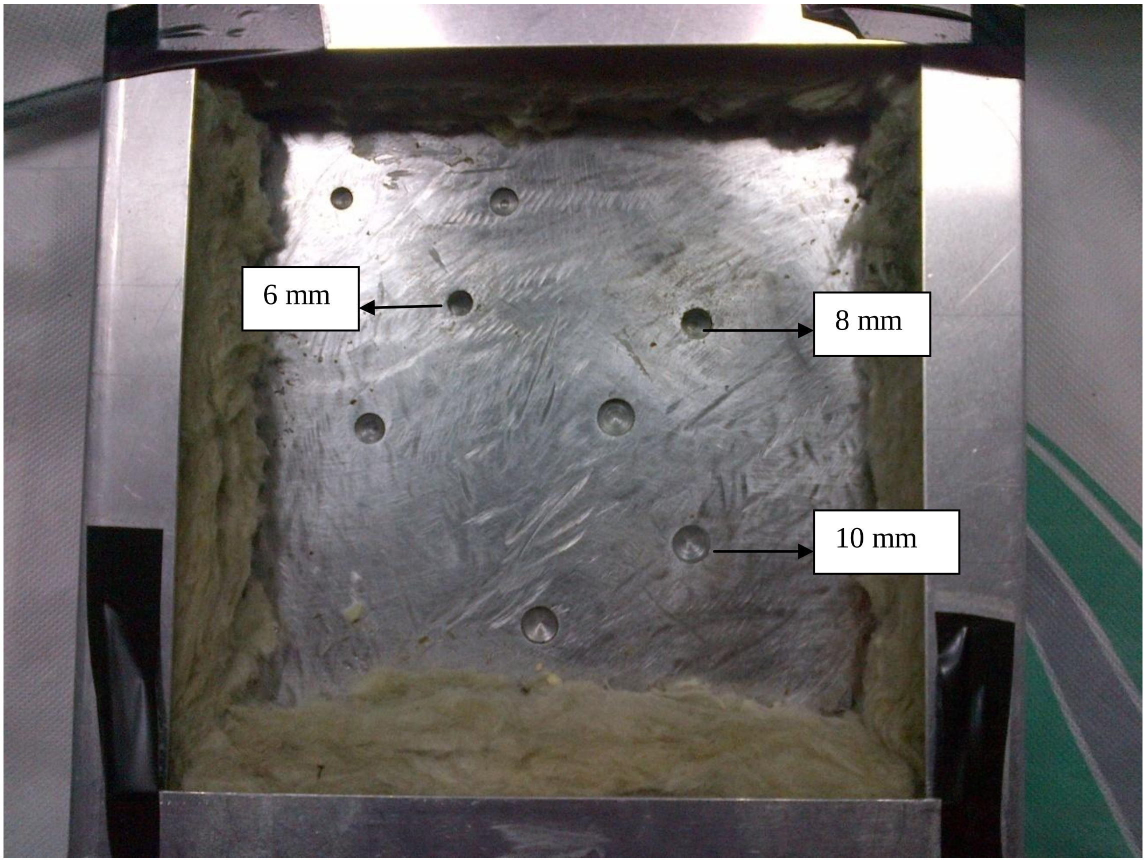


Figure 3-8 Defect Dimension

3.2.2. Grinding and Painting the Surface of the Sample

The surface has been grinded to remove the rusting from the sample and to make the surface smoother. This is because, after first trial of the experiment, the roughness and the rusty on the surface of the sample are disturbing the thermal images. The rusty and rough sample can be seen at Figure 3-7.

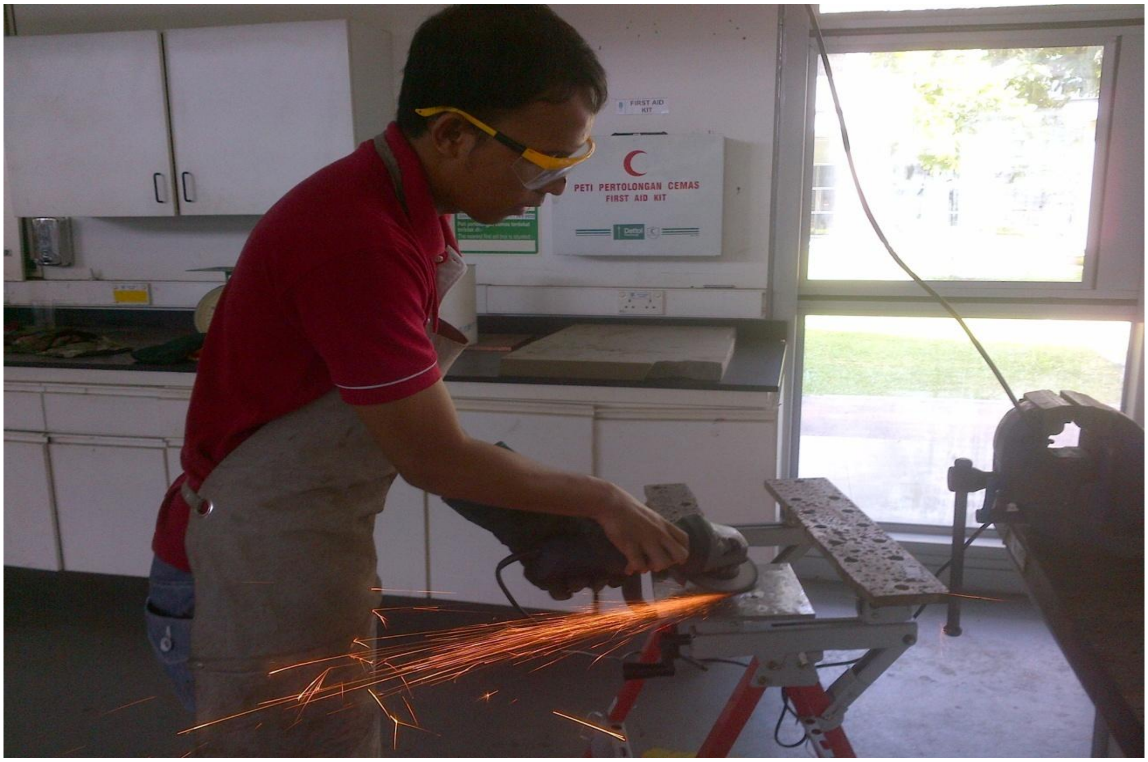


Figure 3-9 Grinding Process

Figure 3-10 Before and After Grinding

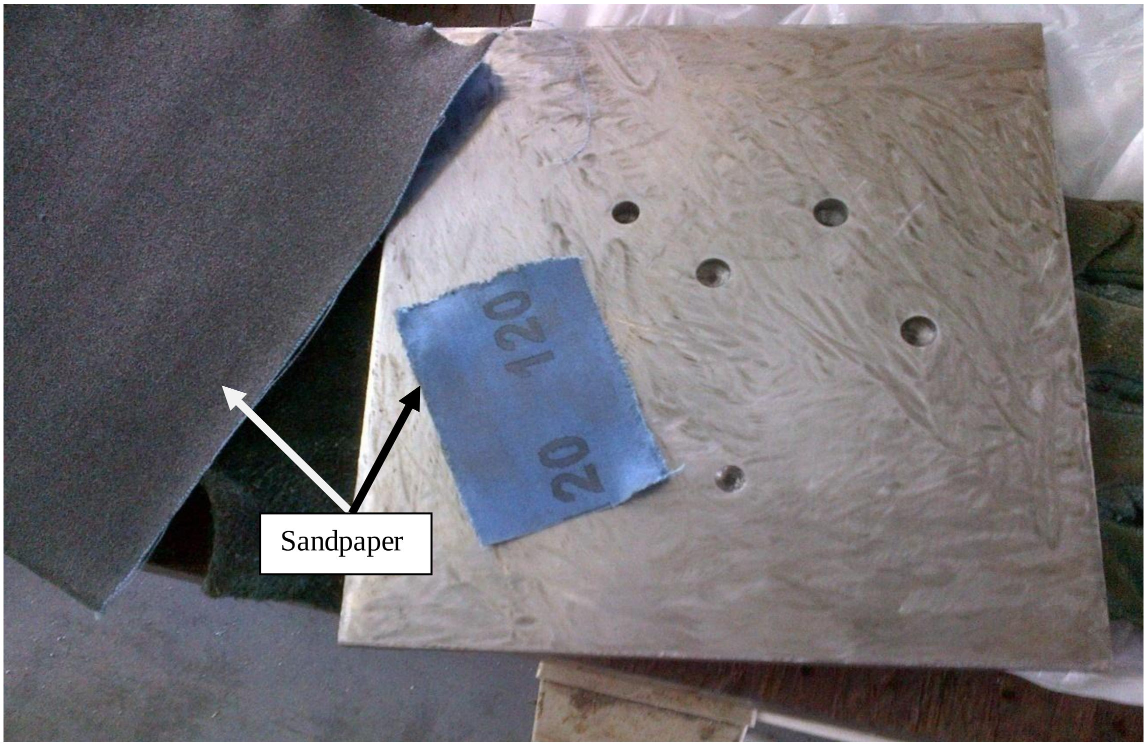


Figure 3-11 Sample after grinding and before smoothened by sandpaper

The sample that has been grinded was smoothened by sandpaper and then the sample was painted in black colour. This is because the black color on the surface or known as blackbody will give high emissivity and reduce reflection. This will enhance the result and thermal image. The sample that has been painted in black is shown in the Figure 3-12.

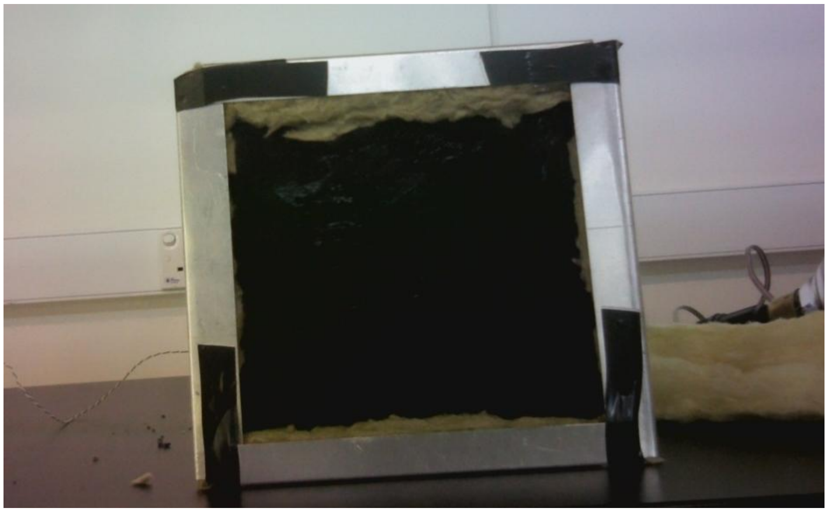


Figure 3-12 Sample that has been painted in black

3.2.3. Conducting the Experiment

Procedure

1. The defects with diameter 6 mm, 8 mm and 10 mm has been applied on the backside of the sample.
2. The sample has been insulated by rock wool.
3. The heater mat has been attached at the backside of the sample. (Facing Defect)
4. Because the heater mat was not functional or broken, the halogen lamp was used as an alternative to heat the sample.
5. The infrared/thermography camera has been placed 500 mm away from the sample.
6. The halogen lamp was turned on and heated the sample.
7. The infrared camera was turned on and the front side of the sample was recorded for 50 minutes during heating.
8. The temperature was recorded at every two minutes.
9. The thermal images were taken.

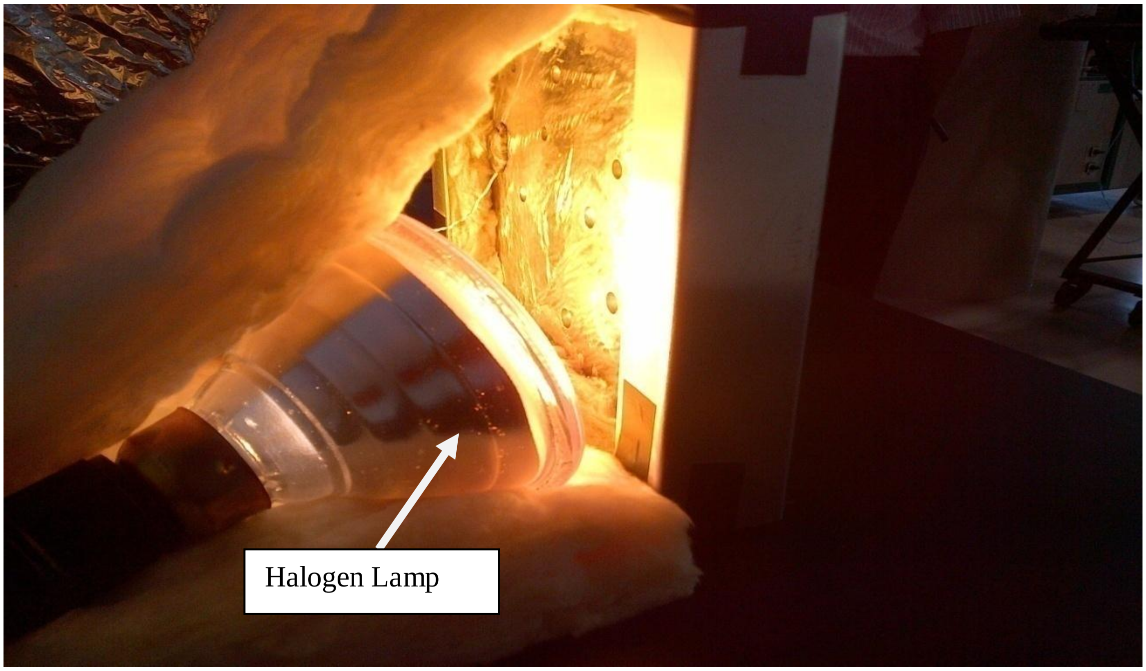


Figure 3-13 Heating of Sample by Using Halogen Lamp

Figure 3-14 Infrared Camera Recorded Thermal Image of the Sample

Based on the Figure 3-14, the Infrared camera is recording the thermal image of the sample. By using "Spot" from Infrared Camera, the temperature reading of Defect can be recorded. The spot is placed at each defect area but at the front side of the sample (defect is at the backside of the sample).

Figure 3-15 Example of Spot Temperature

Figure 3-15 shows the "Lava" type thermal image. There are five spots that have been placed on the sample tested. Each of the spot shows the temperature of their location.

In the experiment, three spots have been placed on the defect in order to identify the temperature of the defect and will be compared with temperature of the sample (detected by the controller)

3.3. Key Milestone

Several targets have been set for the FYP I and FYP II. The schedules are shown in Table 3-2 and Table 3-3:-

Table 3-2 Process and Key Milestone of FYP II

No	Detail / Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Project Work Continues								M								
2	Submission of Progress Report								I								
3	Project Work Continues								D								
4	Pre-SEDEX																
5	Submission of Draft Report								S								
6	Submission of Dissertation								E								
7	Submission of Technical Paper								M								
8	Oral Presentation																
9	Submission of Project Dissertation (Hard Bound)																

Process

Milestone

Table 3-3 Process and Key Milestone of FYP I

No	Detail / Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of project topic								M							
2	Preliminary research work								I							
3	Literature review								D							
4	Submission of extended proposal															
5	Proposal defense								S							
6	Project planning								E							
7	Submission of interim draft report								M							
8	Submission of interim report															

Process

Key Milestone

3.4. Tools

Below are the list of the tools and equipment needed to conduct this experiment:

1. Infrared Camera
2. Steel Plate (Dimension = 200mm x 187mm x 10mm)

Figure 3-16 Sample Dimension (this picture is taken before grinding and defect making process)

3. Heater Mat with dimension 200 mm x 150 mm (240 V, 100 W)
4. Halogen Lamp as an alternative to replace heater mat (240 V, 80 W)
5. Controller
6. Thermocouple Type K
7. Rock Wool
8. Glass Wool
9. Drilling Machine
10. Black Paint
11. Grinder

12. Sandpaper

Figure 3-17 Heater Mat

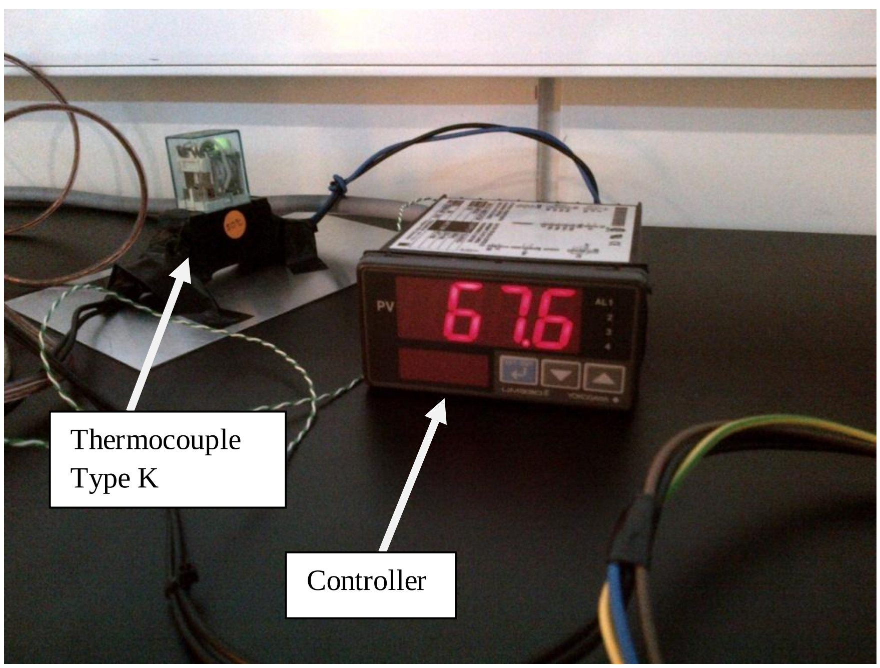


Figure 3-18 Controller and Thermocouple Type K

CHAPTER 4

4. RESULT AND DISCUSSION

4.1. Thermal Image

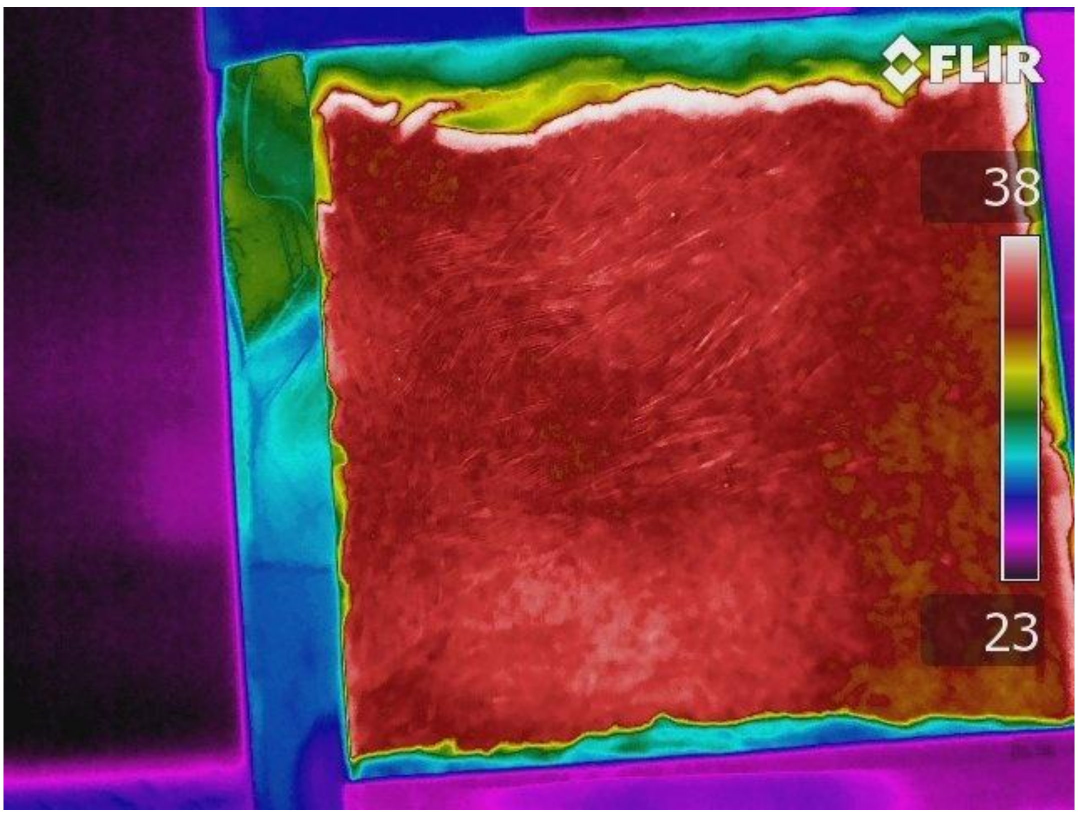


Figure 4-1 "Rainbow" Thermal Image of Sample (Sample Temperature = 38^{o}C approx)

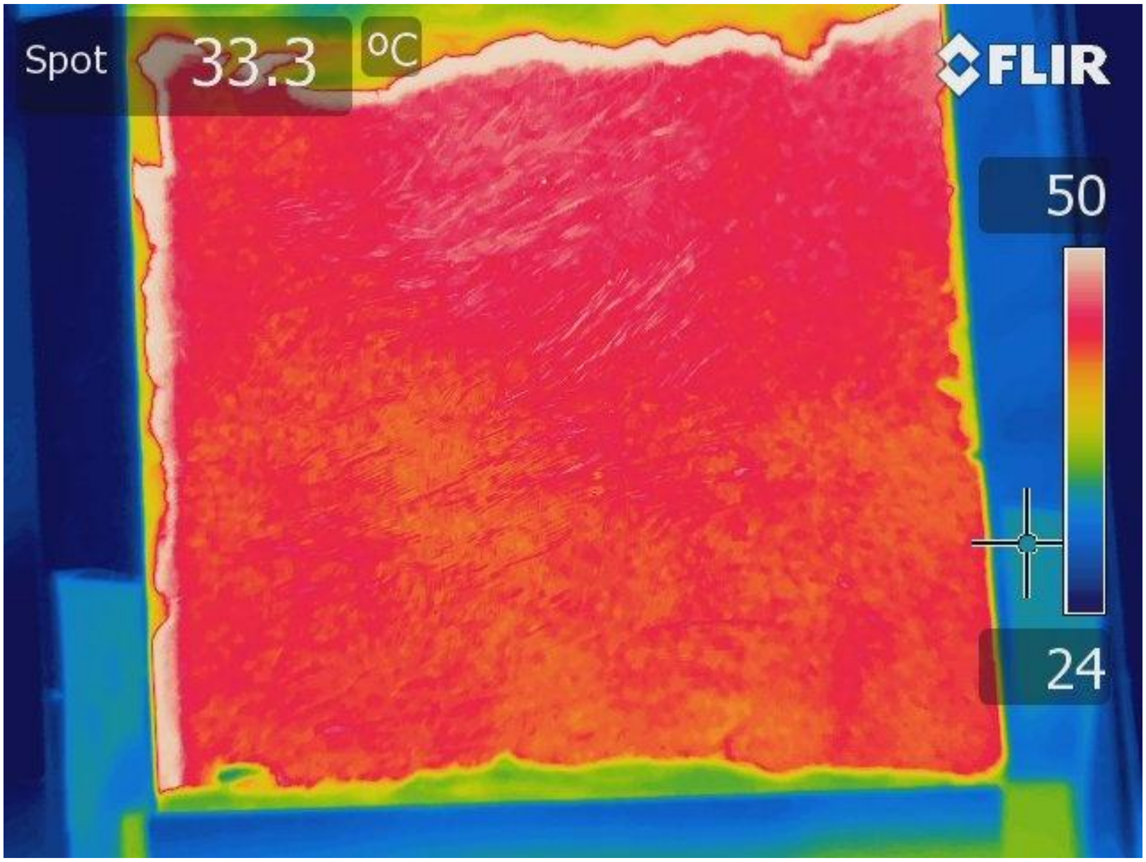


Figure 4-2 “Rainbow” Thermal Image of Sample (Sample Temperature = 50^{o}C approx)

The thermal image that has been recorded does not show any image of defect from t= 0 min to t = 50 min. The surface of the frontside of the sample in the thermal image shows a same colour which indicates that the temperature is uniform along the surface. This is because the sample used in this experiment is too thick. This will cause the heat transfer from the defect to the surface uniformly distributed along the surface. So, the temperature difference between defect area (that are measured from the frontside) and surface of the frontside of the sample is very small and colour of defect area and sample at the thermal image is the same.

Moreover, the depth of the defects was not deep enough for this kind of sample thickness. The other justification for this situation is the heat losses to surrounding. The sample was not fully insulated. The surface and the backside of the sample were exposed to surrounding.

The heat from halogen lamp also losses to surrounding because the flood light of halogen lamp does not go directly toward the backside of the sample. Even though there are glass wool insulated along the pathway of the light, but the light can also go out from the insulator because there are some gaps between the insulators. The heat losses to surrounding makes the heat needed to heat the defect until reach a temperature that will distinguish the colour of the defect and the sample in the thermal images.

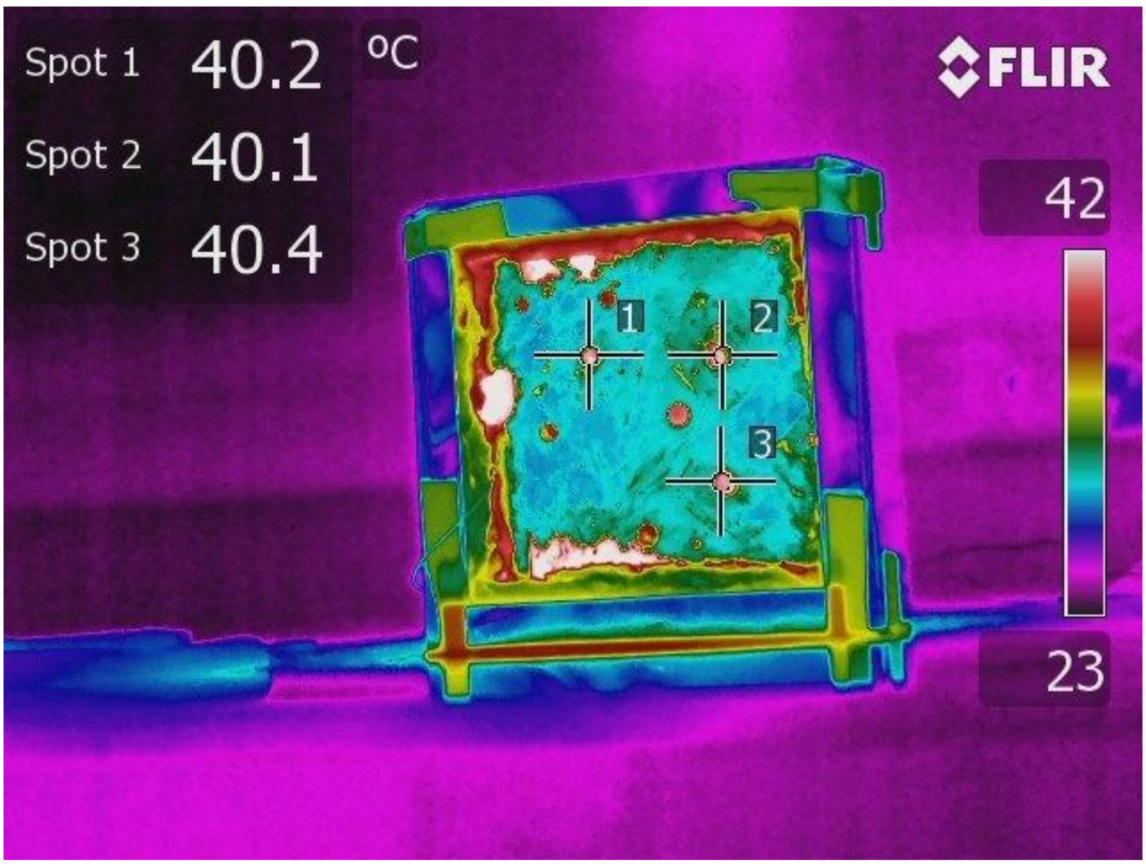


Figure 4-3 Thermal image from the backside of the sample and also represents the expected thermal image

The expected thermal image was the colour of the defects is different with the host/sample. The temperature of defect was assumed to be different with the sample because the thickness of the defect is different. The rate heat transfer at the defect will be higher and thus resulting a higher temperature of defect compared to host/sample. For rainbow thermal image, the expected colour of the defects was red which represent a higher temperature and the expected colour of the sample was yellow/green/blue or any colour that represent a lower temperature.

4.2. Temperature Differences

By using Infrared Camera and Controller, the temperature of the Sample/Host and defects were recorded. Based on the thermal image, the even though the thermal image cannot distinguish the colour of the defect and the sample, but by using “Spot” from the Infrared Camera, the temperature of the defect can be read at the surface from the front side of the sample. This result shows that the infrared camera still can detect the defect because of the different temperature but cannot distinguish the colour of the defect and the sample because the temperature different might be low. The temperature differences are increasing from time to time. But because of heat loss to surrounding and low heat source (if the experiment was done by using heater mat, the temperature and temperature difference will be higher because the map is attached directly on the sample and supply more heat because it has higher current compared to halogen lamp), the temperature difference does not increase anymore.

Table 4-1 Temperature Reading For Sample and Defects and Temperature Differences of Sample and each Sample

Time (Min)	Temperature °C				Temperature Differences °C		
	Sample	Defect 1 (8 mm)	Defect 2 (6 mm)	Defect 3 (10 mm)	Defect 1 (8 mm)	Defect 2 (6 mm)	Defect 3 (10 mm)
0.0	24.8	24.3	24.6	24.2	0.50	0.20	0.60
2.0	27.5	27.3	27.6	26.6	0.20	0.10	0.90
4.0	31.8	31.7	31.6	30.6	0.10	0.20	1.20
6.0	33.9	33.8	33.7	32.6	0.10	0.20	1.30
8.0	36.7	36.9	36.7	36.4	0.20	0.00	0.30
10.0	38.2	38.9	38.8	38.1	0.70	0.60	0.10
12.0	39.7	40.8	40.4	40.1	1.10	0.70	0.40
14.0	40.6	41.3	41.0	40.9	0.70	0.40	0.30
16.0	41.2	43.5	42.9	42.0	2.30	1.70	0.80
18.0	42.6	44.0	43.4	43.0	1.40	0.80	0.40
20.0	43.3	45.1	44.5	43.9	1.80	1.20	0.60
22.0	44.6	46.9	46.3	45.8	2.30	1.70	1.20
24.0	45.9	48.0	47.6	47.0	2.10	1.70	1.10
26.0	47.0	49.6	49.0	48.4	2.60	2.00	1.40
28.0	47.4	50.2	49.3	48.3	2.80	1.90	0.90
30.0	48.2	51.0	50.4	49.0	2.80	2.20	0.80
32.0	48.9	51.8	51.0	49.5	2.90	2.10	0.60
34.0	49.0	52.0	51.5	49.9	3.00	2.50	0.90
36.0	49.7	52.7	51.9	51.4	3.00	2.20	1.70
38.0	51.1	54.3	53.5	52.8	3.20	2.40	1.70
40.0	53.0	56.5	55.7	55.0	3.50	2.70	2.00
42.0	53.7	57.4	56.5	55.5	3.70	2.80	1.80
44.0	54.0	57.9	57.3	56.0	3.90	3.30	2.00
46.0	54.4	58.4	57.4	56.5	4.00	3.00	2.10
48.0	55.2	59.0	58.2	57.1	3.80	3.00	1.90
50.0	55.5	59.5	58.6	57.6	4.00	3.10	2.10

In order to get temperature differences, the equation below has been used:

$$Temperature\ Difference\ (°C) = |Defect\ Temperature\ (°C) - Sample\ Temperature\ (°C)|$$

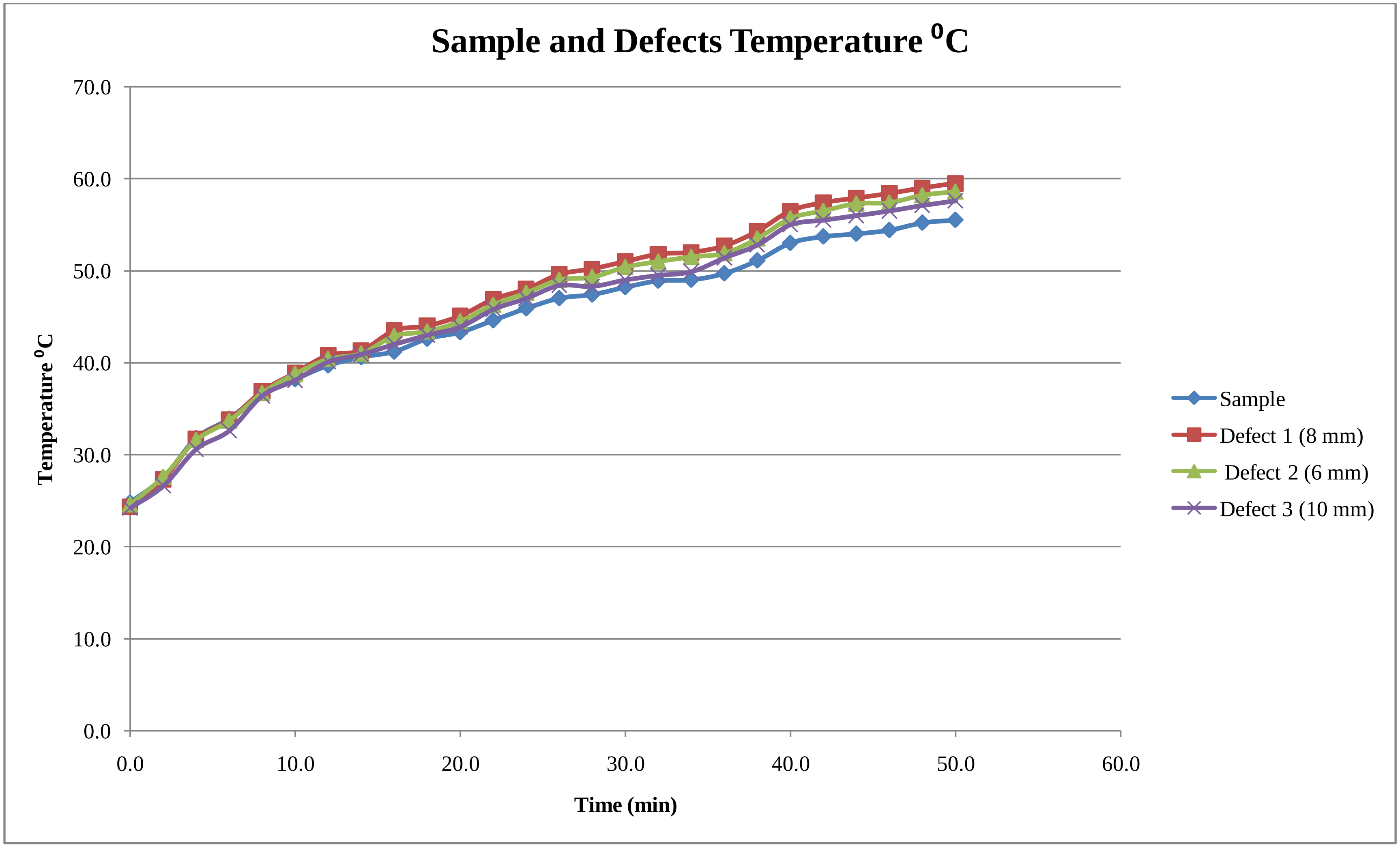


Figure 4-4 Graph of Temperature of Defects and Sample

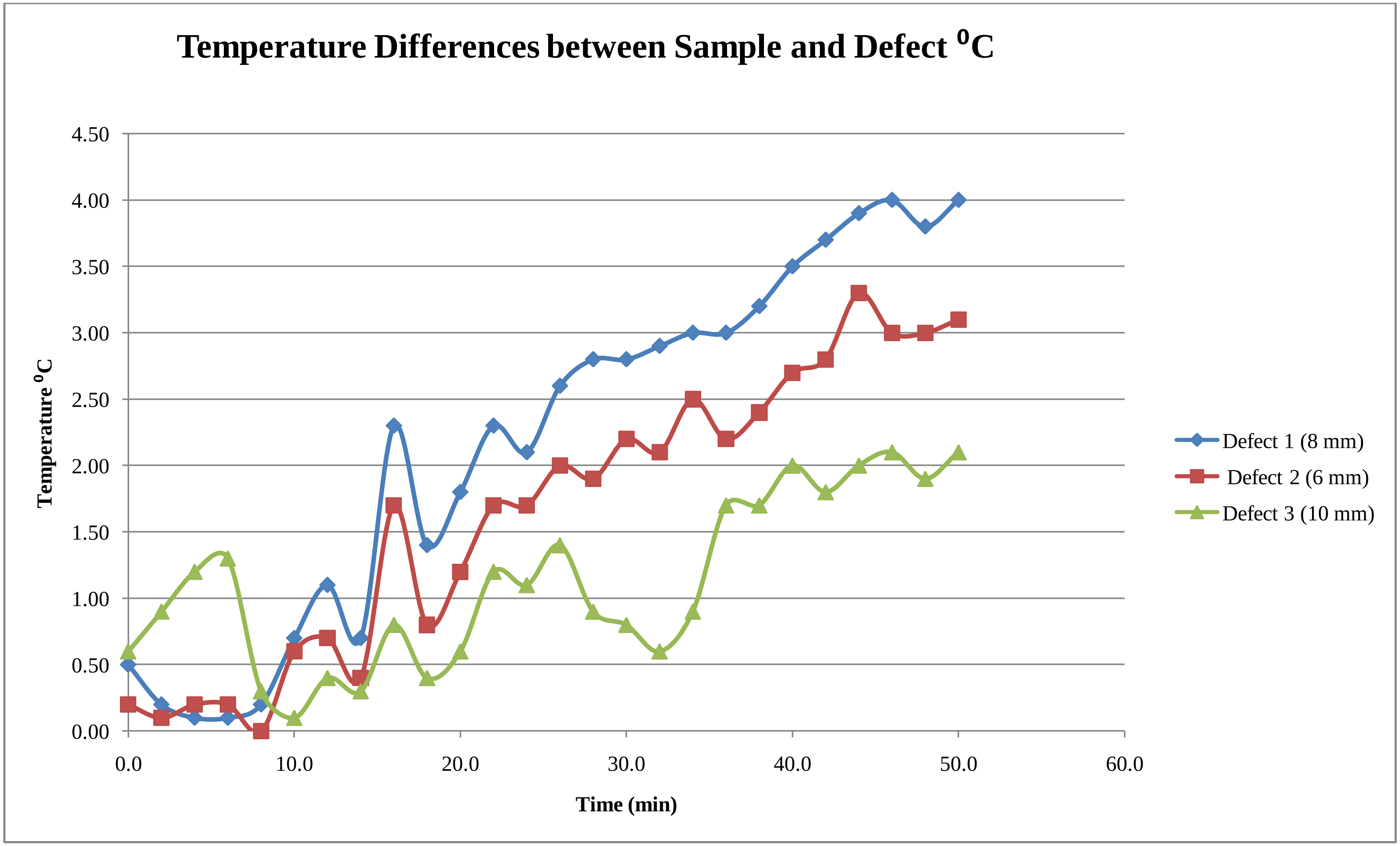


Figure 4-5 Graph of Temperature Difference between Defect and Sample

Based on the Figure 4-5, each of the defect temperature is different with the sample. The defect that has the highest temperature difference is Defect 1 which is 8 mm. The defect with the lowest temperature difference is Defect 3 which is 10 mm. The average temperature difference of the Defect 1 is 2.18°C, Defect 2 is 1.64°C and Defect 3 is 1.12°C. The main reason why the temperature difference of Defect 1 and 2 are higher is the light and heat from halogen lamp was focused on these two defects. These defects were received a lot of heat compared to the other. This will increase the rate of heat transfer at that area. The temperature differences for all the defects are increasing from time to time. If the experiment continued for a longer time or if the experiment has been done by using heater mat, the temperature differences might be higher and there is a possibility for the defect to visible at the thermal image because the temperature difference is higher.

4.3. Additional

The other observation that can be made is the scratches or small flaws on the surface at the front side of the sample can be detected by the thermal image. After the observation has been made on this thermal image, the colour of the rusty area is lighter than the colour of the host/sample/original as shown in Figure 4-6. All the defects made are can be seen clearly. This shows the Thermal Infrared can be used to detect the corrosion or defect at the surface of the piping in the offshore facilities in order to prevent the corrosion or defect to spread and become larger. The image in Figure 4-6 is the thermal image of the sample before grinding process.

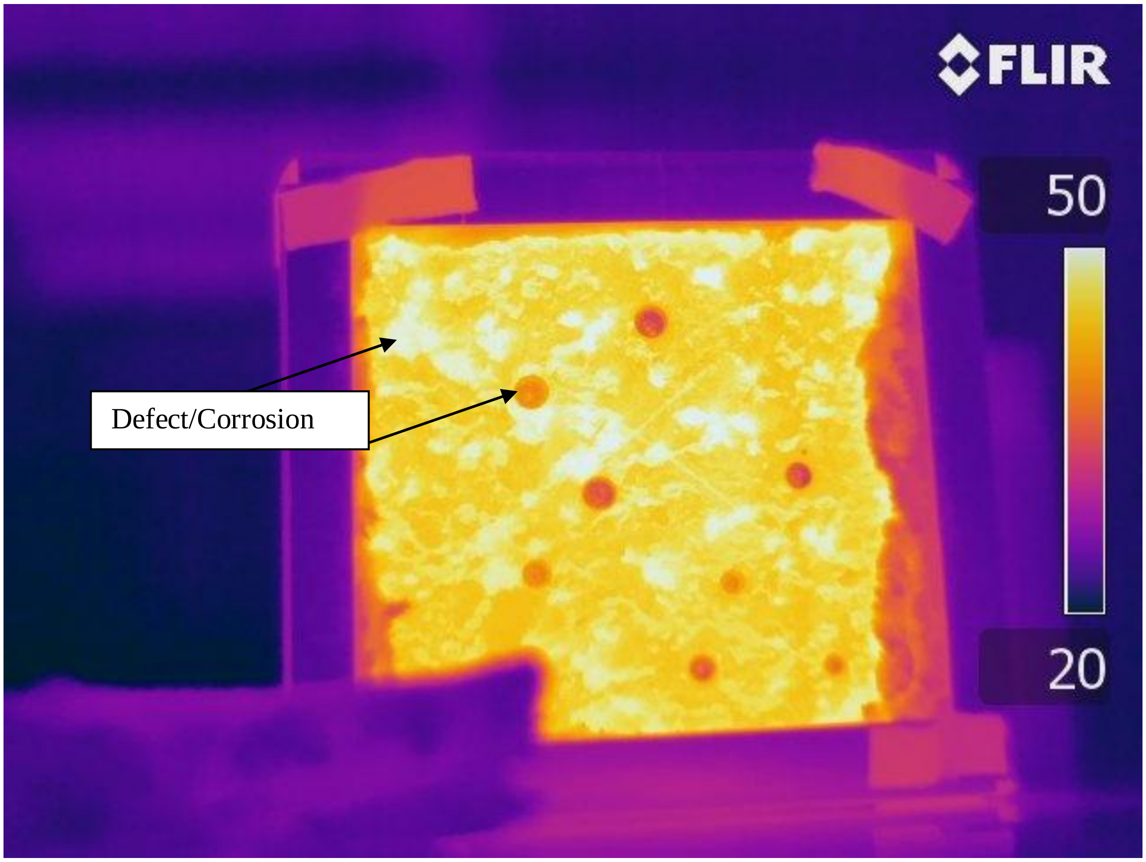


Figure 4-6 Thermal Image of the Sample (Before Grinded)

CHAPTER 5

5. CONCLUSION AND RECOMMENDATION

Based on the result, the defect still cannot be seen at the thermal image which means that this experiment doesn't meet the second objective which is to detect the internal defect by using infrared camera but the different temperature between the defect area and sample recorded can be concluded as one of the reliable result to detect internal defect.

For the recommendation, make a defect that has a deeper depth and also use a lesser thickness of sample.

The experiment must be done in a darker room to prevent reflection that can cause noisy in the thermal image. This will affect the result.

The sample and heater/halogen lamp must be fully insulated in order to prevent heat lost.

The experiment must be done by adding the deposit because one of the problems that frequently occur in piping is deposit which is caused by oxidation and microorganism.

CHAPTER 6

6. REFERENCES

Basrawi Marwan and Keck Danny Nondestructive Testing Technologies for the Oil Industry [Report]. - [s.l.] : Society of Petroleum Engineering, 2003.

Carlslaw H.S and Jaeger J.C Conduction of Heat in Solids [Journal]. - London : Oxford University Press, 1959. - Vol. 2nd.

Choi Manyong [et al.] Quantitative determination of a subsurface defect of reference specimen by lock-in infrared thermography [Report]. - Republic of Korea : Elsevier, 2008.

Feuillet V. [et al.] Defect detection and characterization in composite materials using square pulse thermography coupled with singular value decomposition analysis and thermal quadrupole modeling [Report]. - Bouguneais : Elsevier, 2012.

Inagaki Terumi, Ishii Toshimitsu and Iwamoto Toshikatsu On the NDT and E for the diagnosis of defects using infrared thermography [Report]. - [s.l.] : Elsevier, 1999.

Meola Carosena [et al.] The Use of Infrared Thermography for Nondestructive Evaluation of Joints [Report]. - [s.l.] : Elsevier B. V., 2004.

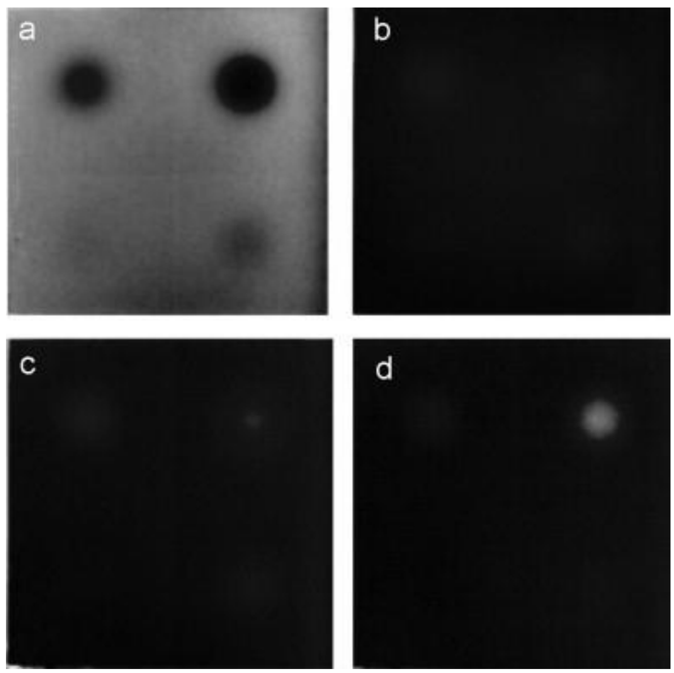
Meola Carosena A new approach for estimation of defects detection with infrared thermography [Report]. - Napoli : Elsevier, 2006.

Rao Prakash D. S. Infrared Thermography and Its Application in Civil Engineering [Report]. - 2008.

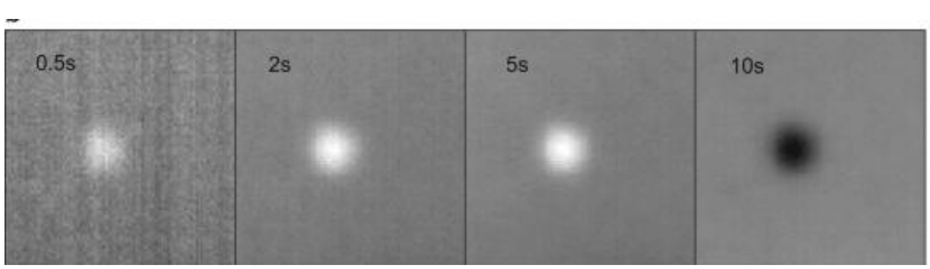
APPENDICES

Expected Result

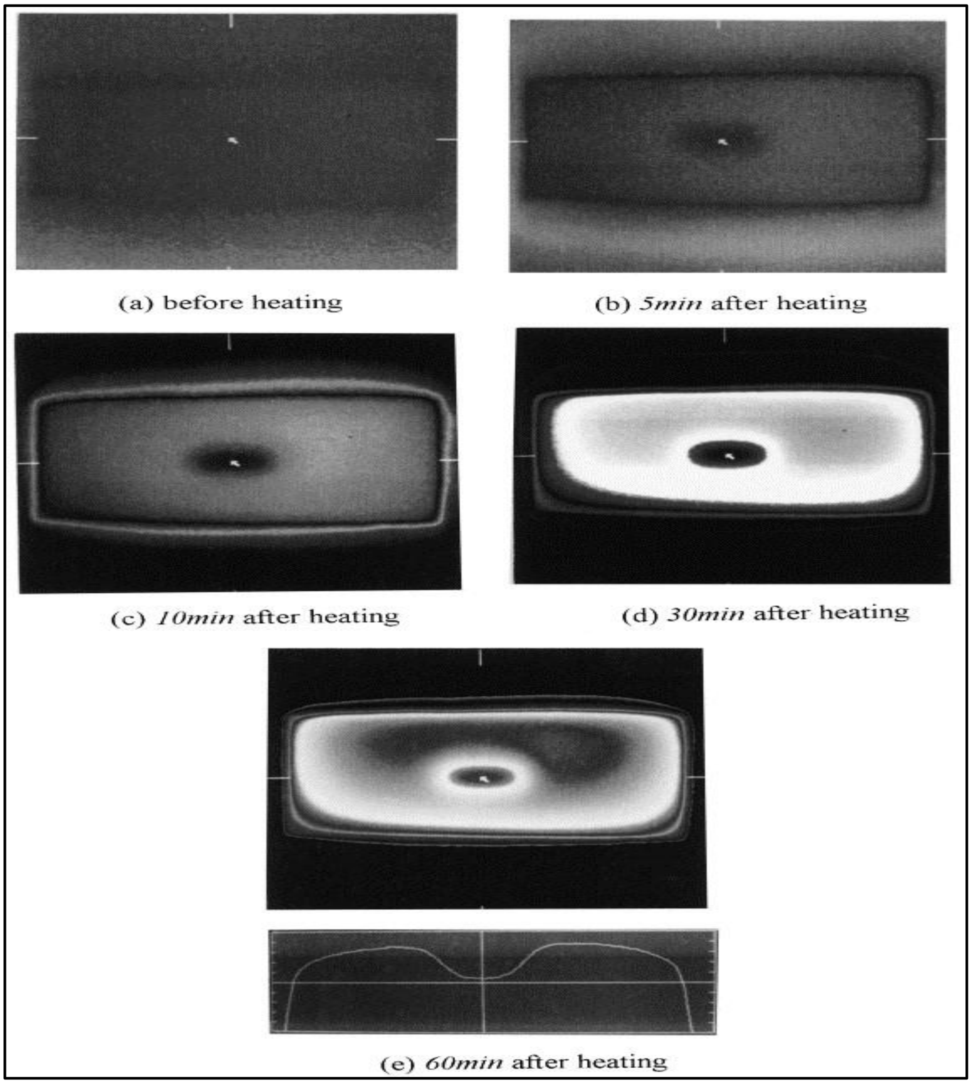
The expected result shown below is based on the report and journal referred



Thermal Images of a stainless steel specimen **(Choi, et al., 2008)**



Testing on composite sample for the duration of 10 seconds **(Feuillet, et al., 2012)**



Thermal images of acrylic resin testing object with diameter = 10mm and depth = 8mm
(Inagaki, et al., 1999)