

Development of Defect Detection System using Thermography

Submitted in fulfillment of the requirements for the award of
Bachelor of Engineering degree in Mechatronics

by

Mughilan.R.B (39090028)

G.Siddartha (39090011)



**DEPARTMENT OF MECHATRONICS
SCHOOL OF MECHANICAL ENGINEERING**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

**Accredited with Grade "A" by NAAC | 12B Status by UGC | Approved by AICTE
JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119**

MAY - 2023

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DEPARTMENT OF MECHATRONICS

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **Mughilan.R.B (39090028)**, **G.Siddartha (39090011)** who have done the project work entitled "**Development of Defect Detection System using Thermography**" under our supervision from June 2022 to May 2023.

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Submitted for Viva Voce examination held on ____ May 2023

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DECLARATION

We, **Mughilan.R.B. (39090028)** and **G.Siddartha (39090011)**, hereby declare that the Project Report entitled “**Development of Defect Detection System using Thermography**” done by us under the guidance of **Dr. J.R. Deepak, M.E., Ph.D.** is submitted in fulfillment of the requirements for the award of Bachelor of Engineering degree in Mechatronics.

1. 

2. 

DATE: ____ May 2023

PLACE: Chennai, Tamil Nadu

SIGNATURE OF THE CANDIDATE

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ABSTRACT

Defects such as blowholes, pinholes, swell, metal penetration, hot tears, shrinkage cavity, lack of penetration, slag inclusion, wash and cuts, lack of fusion etc. are the common defects observed during manufacturing process. In order to identify these defects, destructive type testing were being carried out in general which may cause an irreversible change to the material under inspection in terms of its physical characteristics.

To avoid these irreversible changes Non-Destructive testing methods were introduced. There are different types of conventional NDT methods that are being widely used such as visual testing and penetrant testing. Even though there are various NDT testing developed and used for finding defects, there are limitations like detecting interior void, micro crack cannot be observed. Surface finish and ferromagnetic property of the material can also affect the inspection sensitivity.

In order to overcome this issue Infrared thermography (IRT) is proposed which can detect defects using thermal radiations. In this IRT technique the amount of radiation released by the object rises with temperature, allowing it to detect temperature changes. IRT technique is used in other applications such as bonding and sealing of metal materials and to diagnose breast cancer, fever screening, brain imaging, cardiology, peripheral vascular diseases etc. The aim of this work is to examine whether different types of defects in welded steel joint can be visualized thermographically and identify the defects appropriately based on the data collected from the IR camera. For this purpose a passive thermography kit is developed with a long wave infrared camera for collecting data and easy maneuvering.

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LIST OF ABBREVIATIONS

ANN	Artificial Neural Networks
PPT	Pulsed Phase Thermography
ECPT	Eddy Current Pulsed Thermography
FDCT	Fast Discrete Curvelet Decomposition
FRP	Fiber Reinforced Polymer
GFRP	Glass Fiber Reinforced Polymer
LST	Line Scanning Thermography
MT	Magnetic Particle Testing
IRT	Infrared Thermography
AE	Acoustic Emission
ET	Eddy Current
PT	Penetrate Testing
CFRP	Carbon Fiber Reinforced Polymer
RT	Radiography Testing

CHAPTER 1

INTRODUCTION

Numerous production processes, including drilling, welding, casting, grinding, etc., have an impact on the material's components and introduce flaws like cracks, holes, washouts, and cuts. Physical characteristics that can be evaluated by destructive testing processes include toughness, hardness, flexibility, and strength. But after carrying out destructive type testing, it changes the physical characteristics of the material permanently and makes them unfit to be used again, which is a major drawback of destructive type testing. Some of the common testing methods of destructive testing are hydrogen testing, corrosion testing, aggressive environment testing, hardness testing, fatigue testing.

One of the often-employed techniques for identifying defects in various materials is NDT. The primary objective of this defect detection is to evaluate the material's quality during the manufacturing process. Early defect detection can significantly lower operational and quality-related expenses while also assisting manufacturers in producing goods that meet consumer expectations for quality.

A series of inspection techniques collectively known as non-destructive testing (NDT) allow inspectors to assess and compile data on a system, product, or component without damaging it permanently. When it comes to making sure that assets are properly maintained, the significance of non-destructive testing cannot be understated.

The most straightforward justification for preferring NDT over destructive testing is that it allows the material or object under investigation to withstand the inspection without suffering damage, which saves time, money, and resources. With the exception of radiographic testing, almost all NDT techniques are non-harmful to people, which makes NDT particularly attractive. NDT techniques allow for a thorough and reasonably quick evaluation of assets, which is essential for guaranteeing job site performance and safety.

It has been demonstrated that NDT techniques are accurate and predictable, which are desirable qualities in maintenance. NDT testing techniques include visual inspection, eddy current testing, dye penetrant testing, magnetic particle testing, radiography and acoustic emission testing.

As a result, the capability of Non-Destructive Testing (NDT) to recognize and classify defects inside a composite material structure has significantly improved over time.

1.1 DEFECT DETECTION SYSTEM

Defect detection is the most important step in manufacturing process in order to check the quality of the material. The timely detection of defects can effectively reduce operational and quality related costs and helps manufacturer to meet consumer quality expectation. This defect detection system can be broadly classified into two type, Destructive and Non-Destructive testing based on the condition of the inspected material after the testing. As the name specifies the destructive type testing damages the inspected material and changes it physical properties whereas in Non-Destructive Testing is a much eco-friendly option which doesn't cause any damage to the inspected material which can be reused again and each of this material has its own advantages and drawbacks.

Defect detection system is mostly used at earlier stages of a manufacturing process in avail its maximum benefits and avoid any fatal failures. In some cases these systems can be automated to operate autonomously without any human intervention by using several sensors to a feedback system which can be controlled by a processor. Meanwhile in several other cases, especially in destructive type testing it need a human labor to analyze and inspect the properties of the tested material.

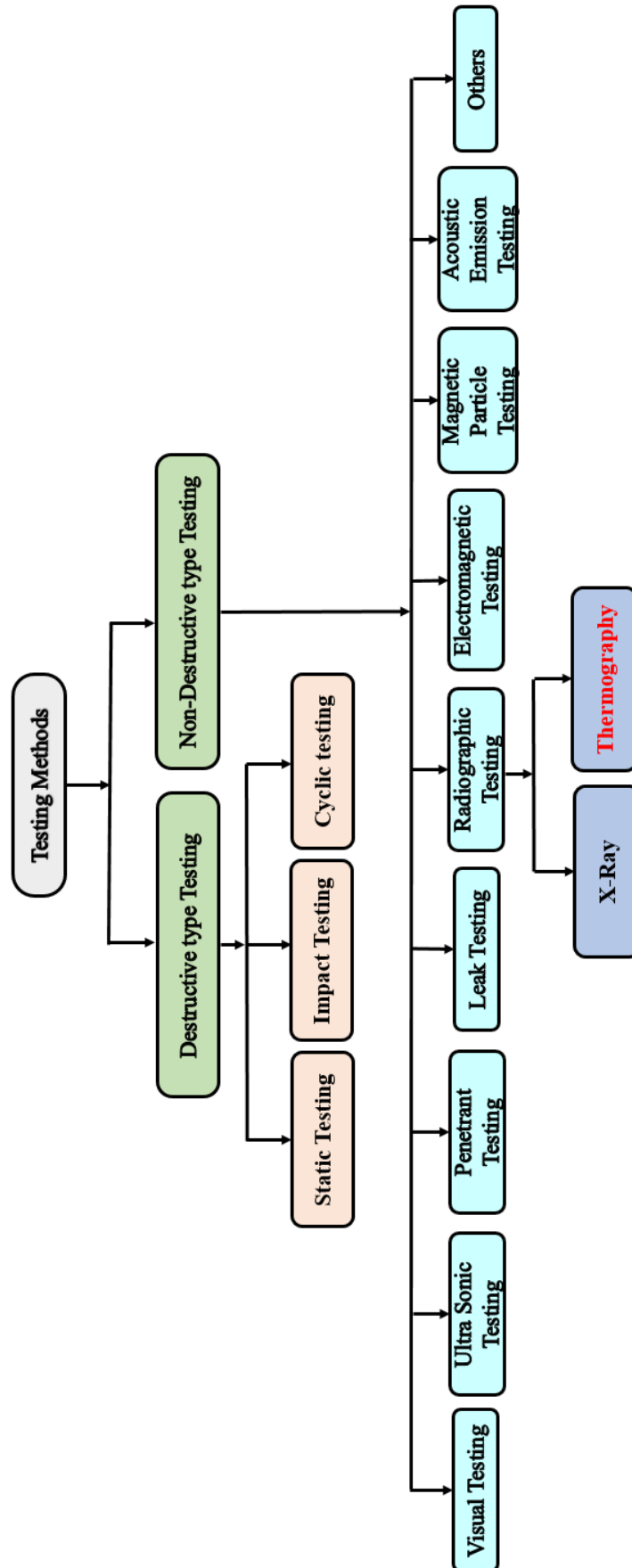


Fig:1.1 : Classification of Defect Detection Methods

1.2 DESTRUCTIVE TESTING

Destructive testing is a type of testing that examines the failure point of a component, asset, or material by permanently damaging or altering the inspected material. In order to get insight of how the material operates under pressure, inspectors submit the material to several destructive test methods. Toughness, hardness, flexibility, and strength are all physical attributes that can be determined using destructive testing procedures.

Popular destructive tests are tensile test and tensile test is mainly used in checking

- Tensile strength
- Yield strength
- Elongation

Charpy test is also used in destructive testing which is used to identify toughness of the material as well as hardness.

1.2.1 Disadvantages of Destructive Testing

- Destructive testing is quantitative in nature, implying that the results are absolute.
- Destructive testing has the potential to be damaged and destroyed, and therefore cannot be used again.
- During destructive testing, a sample of the metal is extracted from the huge plate, and whatever properties the metal displays, the same properties are visible throughout the entire plate. Only destructive testing causes this.
- Destructive testing is accurate and trustworthy.
- Destructive testing is commonly used in the design process.
- Destructive testing is a costly process.

1.2.2 Methods of Destructive Testing

- Aggressive environment testing.
- Corrosion testing.
- Fracture and mechanical testing.
- Fatigue testing.
- Hardness testing.
- Hydrogen testing.
- Residual stress measurement.

1.3 NON-DESTRUCTIVE TESTING

Non-Destructive Testing (NDT) refers to a set of inspection techniques that allow inspectors to assess and collect data about a material, system, or component without causing irreversible damage to it.

1.3.1 The Importance of NDT

The importance of non-destructive testing cannot be overstated when it comes to ensuring that assets are properly maintained.

Here are the top reasons why so many companies around the world use NDT,

- Savings

The most obvious argument is that NDT is more desirable than destructive testing because it allows the material or object being investigated to survive the inspection without being damaged, saving money and resources.

- Safety

NDT is especially intriguing since, with the exception of radiographic testing, practically all NDT techniques are non-harmful to people.

- Efficiency

NDT methods enable a complete and relatively quick assessment of assets, which is critical for assuring job site safety and performance.

- Accuracy

NDT methods have been proved to be precise and predictable, which are desirable attributes in maintenance operations aimed at ensuring human safety and equipment longevity.

1.4 CLASSIFICATION OF CONVENTIONAL NDT METHODS

- Visual Non-destructive Testing (VT)
- Ultrasonic Non-destructive Testing (UT)
- NDT radiography (RT)
- NDT Eddy Current (ET)
- NDT using Magnetic Particles (MT)
- NDT Acoustic Emission (AE)
- NDT Dye Penetrant (PT)
- Testing for Leaks (LT)

1.4.1 Visual Non-Destructive Testing

The act of gathering visual data on the status of a material is known as visual non-destructive testing. Visual testing is the most fundamental method of inspecting a material or object without modifying it. Inspectors can perform visual testing with their naked eyes by visually inspecting a substance or object. Inspectors use flashlights to increase the visibility with better lighting during indoor Visual Testing.

An RVI (Remote Visual Inspection) tool, such as an inspection camera, can also be used for visual testing. NDT inspectors may employ a robot or drone to place the camera, or they may simply hang it from a rope.

1.4.2 Ultrasonic Non-Destructive Testing

The practice of delivering high-frequency sound waves into a substance in order to detect changes in its properties is known as ultrasonic non-destructive testing. Ultrasonic testing, in general, employs sound waves to detect flaws or faults on a material's surface.

One of the most prevalent Ultrasonic Testing procedures is the pulse echo. Inspectors use this approach to introduce noises into a material and quantify the echoes (or sound reflections) caused by flaws on the surface as they return to a receiver.

1.4.3 NDT Radiography (RT)

Radiography Non-Destructive Testing is the process of detecting flaws in materials using gamma or X-rays. In radiography testing, radiation from a radioactive isotope or an X-ray generator is directed through the substance under test and onto a film or another sort of detector.

The readings from the detector form a shadowgraph, which shows the material's underlying properties. Radiography testing can reveal features of a material that are difficult to see with the human eye, such as density changes.

1.4.4 NDT Eddy Current (ET)

Eddy Current Non-Destructive Testing (ECNDT) is a sort of electromagnetic testing that employs measurements of the strength of electrical currents (also known as eddy currents) in a magnetic field surrounding a material to derive conclusions about the material, including the location of defects.

During Eddy Current Testing, inspectors examine the flow of eddy currents in the magnetic field surrounding a conductive material to look for disruptions caused by flaws in the material.

1.4.5 NDT Using Magnetic Particles (MT)

Non-Destructive Magnetic Particles Testing is the process of looking for flaws in a material by looking for interruptions in the flow of the magnetic field within it. In order to use Magnetic Particle Inspection, inspectors must first create a magnetic field in a material that is easily magnetized.

Iron particles are placed to the material's surface after the magnetic field is created, indicating pauses in the magnetic field's flow. These disturbances serve as visible cues of where the material's flaws are located.

1.4.6 NDT Acoustic Emission (AE)

The act of employing acoustic emissions to find possible faults and irregularities in a material is known as non-destructive testing. Acoustic Emission Tests look for bursts of acoustic energy, often known as acoustic emissions, induced by material flaws. The material's intensity, position, and arrival time can be evaluated to offer information about any faults.

1.4.7 NDT Dye Penetrant (PT)

Penetrant non-destructive testing, also known as Liquid Penetrant Testing, is the process of using a liquid to cover a material and then looking for cracks in the liquid to detect defects in the material. Inspectors will first cover the substance being examined with a solution containing visible or fluorescent dye during a penetrant test.

Inspectors then wipe away any extra solution from the material's surface, leaving it in defects that "break" the surface. Inspectors then use a developer to draw the solution out of the problems, after which they utilize ultraviolet light to reveal flaws (for fluorescent dyes). Color is visible in normal dyes due to the contrast between the penetrant and the developer.

1.4.8 Testing for Leaks (LT)

The technique of examining leaks in a vessel or structure in order to find faults is known as leak non-destructive testing. Leaks in a vessel can be discovered using a pressure gauge, soap-bubble tests, and electronic listening equipment, among other approaches.

1.5 NON-DESTRUCTIVE TESTING USING THERMOGRAPHY

Thermography is a non-destructive testing technology for detecting and measuring minor temperature variations in assets and plant sites to aid in the detection of deterioration. With its quick and cost-effective use, thermography can aid in the maintenance of industrial plants and equipment.

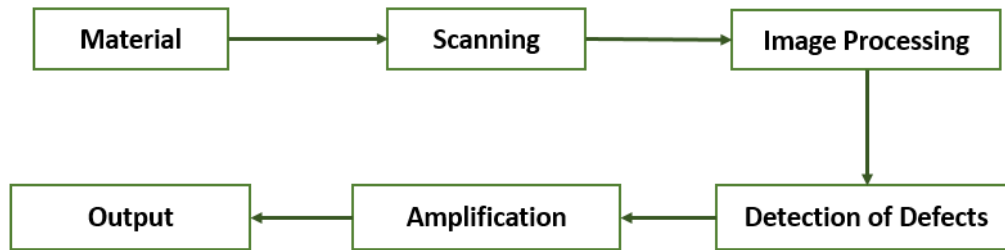


Fig:1.2 : Stages in Thermography

1.6 DIFFERENT TYPES OF DEFECTS THAT CAN BE DETECTED USING IRT

- Cracks
- Blow holes
- Cavity
- Pores

1.6.1 Cracks

There are several different types of cracks on the materials and some are easily visualized by naked eye under some lighting conditions but to detect the very minute cracks with high speed and accuracy we use an IR thermal camera. The main motive of this system is to process the image by capturing the geometric dimensions of the cracks. However, the main source is generating sufficient heat to the material and then it can give more accurate results in detecting more minute cracks on the materials. While, the deepest curves of the two different cracks which are joined together can be clearly seen in the image. That segmentation of each crack makes it easier to separate the properties of defects. Various kinds of parameters like length and width and the distance covered to measure the cracks is done using this system.

1.6.2 Blow Holes

While casting a metal there is a possibility that gas porosity occurs due to the escape of certain gases like nitrogen or hydrogen from the molten. In most cases blow holes can be inspected manually. But generally manual inspection is a slow process and not so accurate. These holes can be identified using our thermography method by defining its shape and dimensions. In general blow holes form in a shape or circles and bubbles which can be identified using an image processing system.

1.6.3 Cavity

Cavity formation occurs due to the same reason why blow holes are formed. But the gas molecules are trapped inside the metal surface making a hollow cavity inside the metal which may weaken the material at that particular spot. Since these cavities are formed underneath the surface it can't be identified during manual inspection or by using conventional methods. But by using a thermography method we can spot those locations of the cavity. Because heat can't be distributed evenly across those areas with cavities and the edges with higher temperature can be viewed clearly using our image processing technique.

1.6.4 Pores

Pores are the open spaces which are found on the material with very minute holes all around the materials. When the metal cools or heated up the material shrinks and due to that shrinkage pore is formed. Many industries when they do additive manufacturing process these kinds of defects are quite common. There are many non-contact and contact methods to identify these pores but here we are using an IR thermography method which detects the pores inside and outside of the material. Infrared cameras recognize the distribution of temperature to identify the fault. Taking experimental and simulation results we can easily categorize these pores. Simulation results cannot be obtained to detect the pores if the temperature is below 293K. Experimental values were obtained by capturing the defects and by using an image processing system. Hence, the quality of the material is checked.

1.7 THERMOGRAPHY

Infrared Thermography is a contact-free NDT technique developed to detect defects in metals in order and address issues before they result in higher maintenance costs, service interruptions, catastrophic equipment failure, and/or equipment damage.

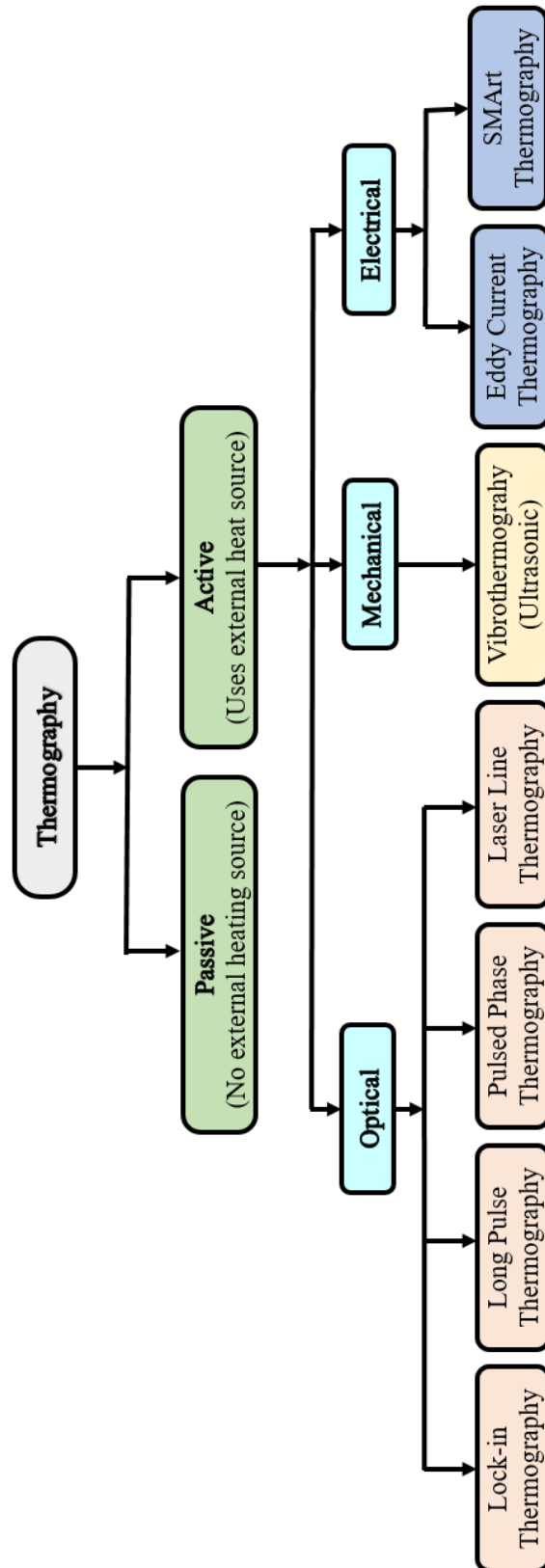


Fig:1.3 : Classification of Thermography Techniques

1.7.1 Working Principle of Thermography

The working of infrared thermography is based on a physical phenomenon that every object with a temperature greater than absolute zero or -273.15°C will emit electromagnetic radiations which are infrared in nature. This emitted wave is infrared in nature and its intensity is directly proportional to its temperature. Therefore, without making direct physical contact, the temperature of a body can be determined by measuring its intensity.

When a material is heated over the surface, the heat will not be distributed evenly throughout its surface in the presence of defect. This temperature difference can be used to map the defect location and identify its geometrical parameters. Thus, faults or discontinuities caused during a manufacturing process can be identified using an IR thermal receiver/image sensor with high accuracy. Thickness assessment is a potential benefit in addition to fault detection. Additionally, thermography is being employed in a number of medical applications like diagnosis of breast cancer, brain imaging and is also an ideal tool for health screening.

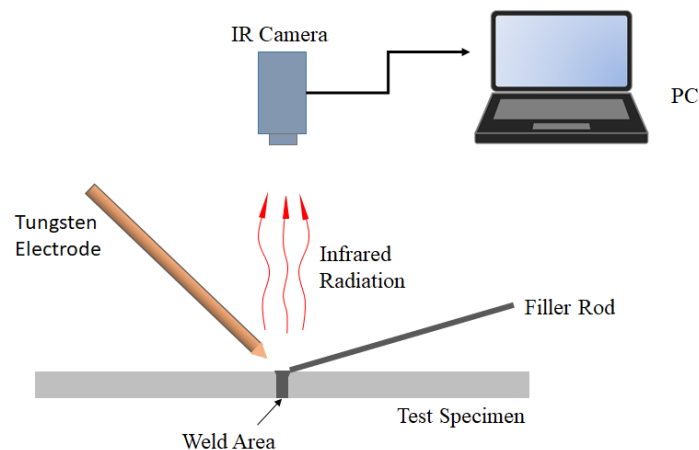


Fig:1.4 : Schematic representation of Passive Thermography

1.7.2 Applications of Thermography

- **Electrical Component Inspection**

Thermography is the easiest way to inspect three phase electric circuits in industries by comparing the measured temperature to their normal working temperature. By inspecting the thermal gradients of the circuit any abnormalities in the circuit due to overload or unbalance can be identified

- **Medical Field**

Thermography is being used vastly in the medical field from testing body temperature to the diagnosis of cancer. It is one of the safest testing method for cancer because it doesn't involve any kind of radiations. Thermography is an economical and easy to operate system in the medical field to monitor patients with high accuracy and quickly.

- **Internal Corrosion**

Internal corrosion in pipe lines is one the common factor for an unexpected shutdown. Since these internal corrossions cannot not be inspected by visual testing, methods like thermography is used to inspect the pipelines regularly. By measuring the intensity of the emitted infrared waves the areas with internal corrosion can be easily identified and can avoid unexpected shutdowns.

- **Water leakage**

Checking for water leakage or moisture is the most difficult issue to detect in a building before the existence of thermography. But now a days, thermal cameras are usually used to identify internal rain leaks or any other water leakages inside the wall easily. Thermal images cannot sense water moisture level in the wall but it can detect minute temperature differences and thermal patterns which reveals the existence of water leakage.

1.7.3 Advantages of Thermography

It displays a visual representation of temperatures across a vast area so that they can be compared. It has the ability to track moving targets in real time. It can detect deterioration, such as higher temperature components, before they fail. It can be used to measure or observe in regions where other approaches are unavailable or

dangerous. It is a non-destructive way of testing. It can be used to inspect shafts, pipes, and other metal or plastic components for flaws. It can be used to detect items in low-light conditions.

1.7.4 Limitations of Thermography

There are cameras that are both less expensive and pricier. Due to the expense of the bigger pixel array (state-of-the-art 1280 x 1024 pixels), quality cameras frequently have a high price range (often US\$3,000 or more), although less expensive variants (with pixel arrays of 40x40 up to 160x120 pixels) are also available. The image quality suffers as a result of fewer pixels, making it more difficult to discern proximal targets within the same field of view.

In addition, there is a difference in refresh rate. In no full window mode, certain cameras may only refresh at 5–15 Hz, whereas others (e.g. FLIR X8500sc) refresh at 180Hz or even higher. Many models fail to provide the irradiance measurements that are used to create the output image; the lack of this information, combined with incorrect calibration for emissivity, distance, ambient temperature and relative humidity means that the resulting images are inherently inaccurate temperature measurements.

When images are based on certain items, particularly ones with unpredictable temperatures, it might be difficult to interpret them effectively, although this difficulty is mitigated by active thermal imaging. Thermal images are created by thermographic cameras using the radiant heat.

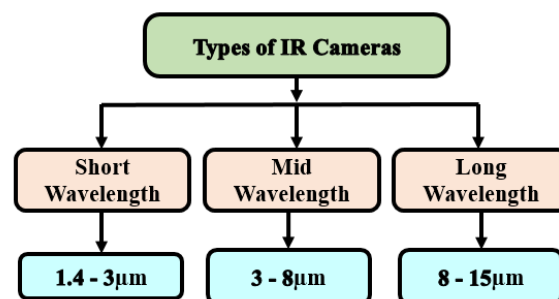


Fig:1.5 : Types of IR Cameras

CHAPTER 2

LITERATURE SURVEY

2.1 LITERATURE SURVEY BASED ON APPLICATION OF THERMOGRAPHY

2.1.1 Development of a New Crack Identification Method Based on Singular Current Field Using Differential Thermography

T.Sakagami and S.Kuba proposed a new NDT technique for detecting cracks in steel plates. A modulated electric current was passed through the samples and differential thermology was used to capture the images. They claimed this technique gives more accurate results in crack detection due to its sensitivity over cracks. When the current is made to pass through the sample with cracks it is found that the electric field creates a singular temperature field around the tips of the crack. And these points with higher temperature can be easily found and located using an Infrared thermal camera which plays a major role in this NDT method.

The method was based on Joule effect heating. So it's concluded that they have proposed a new NDT based method for detecting cracks on steel plates using a thermography method. This method can be used in the detection of fatigue cracks in structures like an ageing aircraft. [15]

2.1.2 HE–NE Infrared Laser Source for Detection of Geometrical Dimensions of Cracks and Scratches on Finished Surface of Materials

Nikolay Nazaryan, Claudio Campana, Saeid Moslehpour , Devdas Shetty invented a new system for analysing the defects on the material using He-Ne infrared laser source which helps us to concentrate more errors and dimensions of cracked, scratches on the surface. To measure the major geometrical dimensions, like for example height and breadth of the cracks and scratches on the material a low voltage power source of red He-Ne laser is used. Well, Nikolay Nazarayan proposed a Galibeian beam expander which is used to increase the beam diameter by nearly 15 times more.

Thus, using this expander, we can adjust the length as well as width of the cracks and scratches on a finished surface. These steps used to detect such issues increased in measuring accuracy. To have a very clear output the inside walls were coated with soft, dark graphite and a mirror slit is tested by plating nickel-chrome coating and the laser beam which passes through the mirror possesses very high reflectivity. Finally, in this paper, the author invented an innovative method for detecting very minute scratches on a finished metallic surfaces and microcracks as well as parts of the material were identified with the help of laser beam and a Galilen expander has created a strong relationship between the images of the defects like scratches and cracks and mainly gives best geometrical dimensions such as heights and widths.

After collecting these data, it was classified that these types of improvements in this system can be continued focusing on the increased detection of the micro-surfaces optical lenses and metallic mirrors etc. This technology proposed by Nikolay Nazaryan can be used in many mechanical industries which has a good correlation between the expected values of the defects and the experimental values. Further in future a lot of tremendous growth can be seen in this technology. [10]

2.1.3 Automation Detection of Cracks in Buried Concrete Pipe Images

Sunil.k.Sinha and Paul W. Fieguth developed a new idea for automatic detection of cracks and scratches in buried concrete pipe images. Basically, the author proposed a two-step approach to solve the detection of cracks in buried pipes. He used the crack detector and segmentation of pipe method which is used to filter the different types of cracks and compare the statistical properties of both the images of the material. In the first step two different kinds of detectors are used to extract the defect which was D1 and D2 detectors. The second method was cleaning and linking were studied clearly and outputs are presented for different types of pipes. Well, by examining the cracks in a segmentation process the original image gets subtracted from a few plain images in order to adjust light intensity on the materials.

Feedback from both the methods come to a conclusion that it has a unique result and a finite direction of each pixel of the camera. In this paper a new kind of approach for the automated crack detection filters has been collected and verified

with manual reference data which has helped to improve the experimental results. This method can detect minor and major cracks. It is one of the best automated experimental research methods to perform good results for underground pipes. [16]

2.1.4 Thermo-Inductive Surface Crack Detection in Metallic Materials

Oswald Tranta and Gernot Wally together proposed a new method of thermography using Eddy current as a heat source for the material. The heated material in return emits Infrared rays which is captured using an infrared thermal camera. The penetration depth depends on the material properties. For example, magnetic materials possess very low depth for eddy current compared to other materials. They carried out finite element simulations in order to find the heat distribution throughout the material and to find out the surface cracks. In this experiment it was observed that the temperature was relatively higher around the edges of the crack.

This is due the heat dissipation caused due to the resistance and the induced eddy current that was passed through the material. This technique was expected to be used for inspection of small surface cracks. The experiment was concluded with identifying cracks with depth of 0.1 - 1 mm successfully in a magnetic material using eddy current and an Infrared camera. [12]

2.1.5 Modelling and Evaluation of Electrical Resonance Eddy for Submillimetre Defect Detection

Yew L. Hor¹, Vinod K. Sivaraja, Yu Zhong, Bui V. Phuong and Christopher Lane introduced a technique using eddy current to detect the sub millimeter defects before it becomes damaged and to ensure its safety for longer life of the material. Generally this method was used to examine defects by Electromagnetic Modeling (EM) that has been developed to simulate the feedback of eddy current with respect to the cracks and within the structure.

However, the difference between crack to crack within the medium can be calculated with the help of some theorems. Thus this simulation of solving the defects using eddy current gives us accurate field behavior of the structure. Eddy current is one of the finest methods to detect the breaking structure of the material and its equipment setup was simple and cost-free. Eddy current produces high frequency

where the detection system can suffer from electromagnetic noise and to avoid those issues he has improved signal- noise technique for small cracks such as pulsed eddy current which increases electrical resonance. They generally developed a simulation model to just follow the electrical resonance for the detection of sub millimeter cracks, especially for titanium alloy that gives a better output by simulation and by theorems. Their works mainly focused on the eddy current electrical resonance probe which operates at MHz frequency which leads to the greater sensitivity in analyzing sub millimeter defects and then it can provide a good optimization design compared to analytical methods. [23]

2.1.6 Detection of Surface Crack Defects on Ferrite Magnetic Tile

Xueqin Li, Honghai Jiang , Guofu Yin came up with the solution in detecting cracks on the ferrite magnetic tile. He developed an automatic cracking setup to identify dark and low contrasts cracks on the surface. These types of ferrite material are generally used in motors, control devices, automobile sector etc. Cracks on the magnetic tiles are developed during the manufacturing process. Nowadays, the cracks on the surface of ferrite magnetic material are recognized by manual work but the efficiency of detecting such defects was low and time consuming. Considering these factors Xueqin Li came up with a low cost automatic detection system with large reliability. The method he decided to detect cracks based on FDCT (Fast Discrete Curvelet Decomposition) which just focuses on the image extraction and defect segmentation it generally classify the type of a crack and simultaneously separates the defects from the normal surface and it enhances the image to design a magnetic material accurately.

The magnetic tile surface consists of grinding textures that can make it more complex in identifying the crack detection so to eliminate those grinding textures FDCT method is introduced to extract cracks. This paper clearly tells that the fast discrete curvelet transform method and the robustness of the system made it easier in improving accuracy rate of nearly 94% and width of the cracks which greater. [21]

2.1.7 Active Thermography for Debonding Detection in FRP Retrofitted Concrete Structures

Ying Xu, Soonkyu Hwang, Qingyuan Wang, Donggun Kim, Congcong Luo, Jinyeol Yang, Hoon Sohn developed equipment for debonding detection in FRP retrofitted concrete structures using laser active thermography. FRP materials face repair under many conditions that the defects can be clearly seen between the plate and the substrate. Interfacial debonding casually occurs at the end of the bonded plate and also improper bonding can also make the plates de-bonded. He used the line laser beam method to detect the defects from a long distance by producing sufficient heat to the material. However, to implement more heat we use optical lamps, which were the most used heat source for IRT but it has very low heat density and it cannot measure the defects from far distances.

It is generally considered that the maximum distance between the optical lamps and the measured material should be not more than 0.75m to 1m. So, in this case detecting concrete beams is little difficult and with the laser active thermography it is quite easier and this laser technique is compared with statistical simulations and lab experiments and came to the conclusion that laser active thermography can detect the faults over 5 meters of distance. So, it can recognize the damage of more than 9mm diameter and it also minimizes false alarms due to outermost noises. The power source consumption of the laser is 15W. Moreover, due to the limited experiment techniques the study for the optical lamps which measure only up to 1m of distance maximum which is based on thermal imaging line laser will be continued to future research. [24]

2.1.8 Crack Detection in Aluminum Parts by Using Ultrasound-Infrared Thermography

Xingwang Guo and Vladimir Vavilov proposed a new method for identifying fatigue cracks in the thick aluminum body of aircrafts. Generally, in aircrafts there are chances of cracks occurring over their body due to long term usage and of dynamic loads. And these cracks can even lead to a catastrophic failure. Xingwang Guo and Vladimir Vavilov proposed a new method of identifying these cracks using a special technique of Ultrasonic IR thermography which is also known as vibrothermography. This new technique was introduced since the conventional NDT methods like

penetrant testing using liquid can be quite messy and time consuming and have difficulty in finding out the cracks. Even magnetic particle inspection cannot be carried out in aluminium and most of the other methods are single-point.

So there was a need for a fast, easy to operate NDT method that can produce an output image. This method basically works on the combination of thermography and ultrasonic waves. This combination converts mechanical energy directly to thermal energy allowing a selective imaging of the defect. This method was proven to be a promising tool for detecting cracks in ceramic and metals with high accuracy. The major application of this method was inspection of aircrafts and their maintenance. But the major disadvantage that was observed in this method was, ultrasonic thermography was affected by a number of factors like type of material, contact pressure and few others. But it was a promising solution which effectively detected closed cracks. However internal cavity detection was left for future research. [20]

2.1.9 Effects of Crack Surface Roughness on Crack Heat Generation

Characteristics of Ultrasonic Infrared Thermography

Lihong Donga, Bozheng Wangb, Haidou Wanga, Ming Xianga, Xi Chena, Guozheng Maa, Yuelan Dia, Wei Guoa, Jiajie Kangb, Xinyuan Zhoua examined a crucial effect of fatigue crack defects that are detected by using thermal characteristics of ultrasonic thermography. He uses grade 45 steel samples and puts a crack on it and he tested the crack surface roughness. More specifically he found that fatigue crack regions generated more heat because of the crack surface roughness and the frictional force occurred on the cracks that analyzed by finite element simulation [ABAQUS Software], Frictional force makes a contact with the cracked zone oppositely so it can cause more heat on the cracked region and it makes a path to determine the defected region under ultrasonic thermography and he mentioned that various types of roughness in crack surface makes friction coefficient change which leads to change in contact force of the cracked surface and disturbs the heat generation too.

Ultrasonic thermography, also known as Ultrasonic IR thermography detection, gives more accurate results when compared to other popular detection systems. L Dong clearly mentioned that Mr.plum was the only man who had presented a paper

about crack surface roughness and he finally concluded that the contact area between crack faces is almost less than apparent contact area. So, frictional heat generation occurs in contact regions that conclude heat generation of friction is non uniform. From these points, we clearly come to investigate the effect of the roughness of the crack surface by the Ultrasonic method on the heat generation. He took the specimen and applied a fatigue load that slightly developed the crack and he took four kinds of materials and applied different tensile fatigue loads for each material. He observed morphology of these specimens and determined the roughness of the surface by using a laser dimensional profile instrument. [7]

2.1.10 A Comparison of the Vibro-Modulation and Thermosonic NDT Techniques

Marco Morbidini and Peter Cawley proposed a new method for the prediction of thermosonic signals from the fatigue crack in metal. They mentioned that Thermosonic is one of the most effective NDT methods that can be used to identify defects such as composite's delamination and surface cracks in a metal. A high-power acoustic horn type is used to produce a complex vibration field which gets reflected and rubbed against the defect resulting in emission of heat energy. This resulting temperature change can be measured using an infrared camera. They believed that this method can provide a rapid output and can be suitable for large area testing. There are two different fashions that are followed in this method. One is lock-in and the other one is burst phase. In lock-in the ultrasonic waves used to excite the structure are of low frequency. The main advantage here is the used excitation power is very low compared to the burst phase. In the burst phase much higher frequencies are bursted towards the structure. The main aim of the burst phase is that it consumes less time to excite the structure and create temperature differences that can be captured using an infrared camera. By using this method, they have claimed that they achieved a very quick defect detection and also very small cracks were identified. The acoustic horn is an exciting factor that excites the structure in this method too. The damping of the ultrasonic waves and the heat produced due to its excitation depends on the size of the cracks present in the material. By testing this method on simple models, they found uniform heating over the tips of the cracks alone. Hence these temperature differences that were captured are used to predict the location of the crack. [9]

2.1.11 Detection of Small Surface-Breaking Fatigue Cracks in Steel Using Scattering of Rayleigh Waves

D.A. Cook and Y.H. Berthelot proposed yet another new method for detecting surface cracks in steel using Rayleigh waves. The main goal of this experiment was to find small fatigue cracks. They believed that Rayleigh waves are the most appropriate method of finding cracks in a free surface of a specimen. There are many advantages in using Rayleigh waves due to its property of being elastic and also its speed of propagation is independent of its frequency. The detection of the cracks was based on the amplitude of the surface wave pulse that was being monitored.

The experiment was carried out in low cycle and high cycle fatigue regimes. They conducted this experiment with a steel specimen with a machine-made elliptical notch that provided adequate stress for the formation of micro cracks in that steel piece. Even though there was a strong curvature in the piece, Rayleigh waves were able to identify cracks as small as 80 nanometers. They were able to achieve an output image that is quite realistic in shape in case of any large cracks. But that was not the case in small cracks. Their output images were quite unrealistic. The major disadvantage of this method that concerns me is that you may need to have prior knowledge of where cracks might form in order to achieve accurate results. This is due to the limited area that can be probed at higher frequencies. [4]

2.1.12 A Technique Combining Laser Spot Thermography and Neural Network for Surface Crack Detection in Laser Engineered Net Shaping

Wenxiong Shi, Zhangyu Ren, Wei He, Junsong Hou, Huimin Xie, Sheng Liu proposed a laser engineered net shaping crack detection of the surface with the combination of laser spot thermography and neural network technique. Laser engineered net shaping (LENS) is mostly used in additive manufacturing processes. Imperfect manufacturing process parameters may lead to defects like cracks and blow holes. Therefore, to monitor those problems they developed an online non-destructive testing which is nothing but a neural network. They focused on a method called laser spot thermography (LST) and the specification of this system is non-contact and high sensitivity. This technique is utilized to spot the crack parameters in LENS components with their location as well as temperature of the material is

tracked using neural network system. The neural network basically develops strong relationship with inputs and outputs data such as crack length, amount of heat produced, and characteristics of cracks and holes.

The absolute error displayed for LENS samples while collecting data for cracks showed a minimum error of 2.0 micrometer while 6.0 micrometer being the maximum limit. LST-NN Technique is the best method to attain reasonable accuracy in finding all the properties of detecting cracks. Mechanical properties of the cracks can affect the LENS components and can lead to failure equipment. Therefore, considering these factors the parts are generally made up with unique materials such as ductile iron and nickel-based alloys which are consistent with high sensitivity cracking. Hence it is very important to monitor the procedure of lens process and in addition to that quality as well as structure of the component should be verified which may mislead to give false results if left unnoticed. [19]

2.1.13 Crack Imaging by Scanning Pulsed Laser Spot Thermography

Teng Li, Darryl P. Almond, D. Andrew, S. Rees presented a new technique involving image processing of thermal images of a material heated up using a laser. This technique was termed pulsed thermography since it uses pulsed laser beams as a heating source for thermography. This technique is a non-contact NDT method of testing that is suitable for quick inspection of the material for any impact damage or cracks. A 3d simulation was developed by them that represents the heat flow in that material after heating it up and also, they developed a ghost point method which is used to deal with cracks and defects in an efficient way. By using this technique geometry of the cracks and the parameters of the system were extracted as output. The most important operating parameters in this experiment is the laser power and its pulse duration. This method is proved to be a successful method by conducting a number of experiments over a defective metal. One of the advantages of this technique is it doesn't need any surface preparation. However, the surface needs to be free of any damages or deep scratches which may affect the linear flow of heat to the crack. In this paper they were just concentrating over the defects on the surface and they didn't propose any technique for the defects below the coating. Also one of the major disadvantages of this method is that it is not suitable for the metals cracked due to fatigue or creep. [18]

2.1.14 Geometric Characterization of Cracks in Welding Using IR Image

M. Rodríguez-Martín, P. Arias developed a new solution based on data acquisition also known as thermal test. They generally heat the material with minimum temperature and then it shows the defects and flaws in welding. Moreover, research on Non-destructive testing is taking place from the last 25 years as vast progressive techniques are being implemented regarding design and alignment of welding. Whereas, in his research he identified a problem on a particular element. For example, if a material is gone through under a heavy weight or any other load under high pressure then there will be an analysis of cracks identified on the material. Thus, they depended on the geometry of cracks, size- morphology and orientation of the cracks. Well, Defects with huge errors can be easily identified by the naked eye but in the case of very minor defects it is a little difficult to detect through a visual inspection. To solve these issues an infrared thermography (IRT) is developed to recognise the faults and cracks for the Non-destructive inspection materials based on its reliability, capacity, accuracy and portability for detecting with maximum speed and a good efficiency. The most interesting point from the infrared thermography is it can be used to identify the defects in the subsurface of the welding and it tracks the faults inside the metal to measure its depth.

The method proposed in the paper makes the morphology of confessing the various types of cracks in welds easier when compared to non-destructive techniques like visual inspection, magnetic particles etc. With the help of IR camera and the optimum lighting it could make an accurate detection then it allows to identify the characterization of defect. This paper mainly highlights 3D representation of temperature pixel values. So, without the usage of an IR camera it is very difficult to identify the level of accuracy in welding and even more methods like image tests which need better lighting or more complex equipment. The purpose of an IR camera is to measure the length of the crack on the inside and outside of the material. RGB is one of the methods in IR used for measuring the longitudinal and transverse measurements but the accuracy of this method decreases due to the relationship between length and width of cracks. Finally, the IR system is an easy method to implement in many industries which will be easy to detect the defects while manufacturing the products. [14]

2.2 LITERATURE SURVEY BASED ON THERMOGRAPHY TECHNIQUES

2.2.1 Long Pulse Thermography

By using Long Pulse Thermography (LPT) and Shearography, a combined technique was proposed for identifying flaws in rubber-metal bonds. A 5 mm thick cylindrical carbon steel shell was chosen as a substrate for 250x250mm specimen plate.

The plate's top surface was simultaneously examined in the lab room temperature and the images were captured using a 640x512 pixels mid-wave infrared camera (FLIR A6700SC) with up to 50 Hz of sampling frequency a shearography system. The sample surface was evenly warmed using a 532 nm-wavelength expanding laser beam.

The viability of combining two different techniques and the quality of bonding in the rubber-to-metal bonded specimens has been investigated in this study. Based to FEM simulation and experiment results, it was found that shearography is much sensitive to the bumps on the surface caused due to uneven glue thickness in the specimen. A processed image was generated by using various imaging techniques including TSR and PLSR. [22]

2.2.2 Eddy Current Pulsed Thermography

Eddy Current Pulsed Thermography [ECTP] technique was developed to find concealed crack faults in corroded metal surfaces. The testing was done on a metallic bar with a dimension of 90mmx30mmx7mm which was suspected to have three internal cracks. The test results were observed by examining the captured IR image and three cracks were identified and mapped in the image.

The coil was excited using an induction heating system with an excitation frequency ranging from 150–400 kHz, 2.4 kW of maximum power and 400 ARMS of maximum current. The thermal reactions of the specimen were captured using SAT-HY6850 IR camera which has an 80 mK sensitivity, 320*240-pixel resolution, and 50 Hz of frame rate.

It was discovered that combining ECPT with Principle Component Analysis (PCA) offers a practical and efficient technique to find hidden cracks. [3]

2.2.3 Lock-In Thermography

- Using Ultrasonic Probe

By using Phased Array Ultrasonic Probe and Lock-in thermography image capturing technologies a technique was proposed in the year 2016, to identify the delamination defects on a multi-layered composite plate. While carrying out this experiment a 15mm Polytetrafluoroethylene Teflon disc was placed in between two layers of a composite material measuring 600*600mm and were examined. As a result, a delamination fault was detected and observed at the depth of 0.4mm [8].

- Using Artificial Neural Networks (ANN)

By using thermography along with computational simulations and Artificial Neural Networks (ANN) embedded faults like holes were detected and located in composite plates. For carrying out this experiment, nine samples of a composite material, made of epoxy resin and unidirectional epoxy glass as the reinforcement and fibre respectively were used along with drilled holes to simulate defects. The samples were manufactured by using 20 layers of 1000 x 1000 mm sheets and were cut into the dimensions of 90 x 90 mm.

The epoxy kinds that were used are LR385 and LR386 along with hardeners LH385 and LH386. BMS 9-3-7781 type H3 class 7 glass fibre was used along with a FLIR GF320 thermal camera with 50mK of thermal sensitivity, resolution of 240x320 pixels, and a spectral range of 4-8 μ m was used for carrying out the experiment. Sample 9 composite plate with a hole of 1.5mm radius and 3/4 of plate thickness depth is used for calibration in this experiment.

Computational simulations and ANN were used in order to identify the size and shape of the defects in materials like plates and pipes and characterise the defects based on their dimensions. [6]

- Using Laser Ultrasonic

By Combining laser thermography, laser ultrasonic, and an optical microphone a new technique was developed to inspect artificial dis-bonds of various depths and shapes in 3mm thick Carbon Fiber Reinforced Polymer (CFRP) materials.

All of the samples used in this study were manufactured commercially. The average resin quantity is $35 \pm 3\%$ /weight with the average fiber area load of 150 ± 6 g/m². The 20 layers of unidirectional carbon fiber prepreg in the laminate gave the specimens their 3 mm thickness. Four CFRP specimens were experimentally studied in order to find out various kinds of delamination faults based on its geometry. The excitation laser light source was a 45W CW 808-nm diode. A micro lens array was used to collimate, homogenize, and disperse the laser beam throughout the area. The infrared thermal picture sequence was recorded with a cutting-edge mid-infrared camera with spectral range of 3.6 μ m-5.1 μ m, resolution of 640*256 pixels and a frame rate up to 145 Hz with NETD less than 20 mK.

Grooves of 0.2mm depth were made on both the surfaces of the specimen which was able to be detected by employing an optical microphone and the demonstrated LU method. By using LIT system, holes with diameter to depth ratio greater than 2.5 were detected effectively. [13]

2.2.4 Optical and Pulsed Phase Thermography (PPT)

Optical and Pulsed Phase Thermography (PPT), two of the most popular IRT techniques, were used in this work as an effort to find a more effective way to control the quality of sheet metals. In this experiment, ImageIR 8300 IR camera from InfraTec GmbH with cooled InSb Detector and a resolution of 640x512 pixels were used to identify defects in two mild steel (Dc05) specimens with an electron zinc coating of 0.8mm thickness and cracks of known dimensions (1mm width).

Results from flash lamp and induction excited PPT were compared and examined on specimens I (10mm long) and II (30mm long). Radiation absorbed by the specimen was greater from inductive excitation than the flash lamp excitation with a difference of 0.5rad. The viability of employing inductive excited PPT as a superior option has been demonstrated through this experiment. [1]

2.2.5 Laser Line Thermography

In this experiment, laser line thermography method was used for detecting defects in steel bars at high temperature up to 600°C. By comparing two samples of different types, one with an oxide layer and another without one, it was examined how the oxide layer affects crack detection.

A steel block (ST37/DIN 17100/ASTM A283) with fake notches of dimension 100x100x40 mm was served as the sample for the experiment. Sample surface is energized by using a 510W continuous wave (CW) diode laser with a wavelength of 940 nm. A laser line of dimension 30x0.6 mm was produced using an assembly. An infrared camera was used to record the temperature dispersal across the surface of the sample. FEA simulation and numerical model was developed for both the samples. [11]

2.2.6 SMarT Thermography

In this work, SMarT (Shape Memory Alloy) Thermography technique was proposed for identifying damages in big components that are subjected to heavy loads and excessive pressure. Regular net of SMA wires were added in the matrix to the traditional carbon or glass fiber reinforced composite laminates which acts as an internal heat source due to its electro-thermal properties. Compared to other techniques, SMarT thermography claims to need a low source of power for heating the component.

A GFRP composite panel with a number of simulated faults has been investigated numerically and experimentally to ascertain the technique's sensitivity, its range of applicability, and its reliability.

A flat GFRP laminate panel made of 8 unidirectional plies of dimension 210 x 300 mm and an overall thickness of about 8 mm with a common orientation 0° has been used for this experiment. Also Pulsed thermography was employed for detecting the defects along with the help of MATLAB and Local Boundary Contrast algorithm for visualisation and mapping the locations of the defects that is present in between the heat source (SMA) and thermal camera. The temperature difference between the defects and other region is 0.8 K which is relatively low but easily measurable. [5]

2.2.7 Infrared Thermal Imaging Technique for Kenaf/Epoxy Fiber

Using infrared thermal imaging technique, a unique method was introduced to find flaws in composite materials made of epoxy and kenaf bast fiber. After thermal stimulation, defects such as hot-spots, voids, misaligned fibers, pockets of undesired cross linker, resin-rich zones, and bubbles were able to be detected. Investigations were made using optical microscopes and Scanning Electron Microscopes (Hitachi S-3400N) to support thermography outcomes which resulted with the accuracy of 95%. Kenaf bast fibers were trimmed to a length of 230 mm and epoxy was used as a binding agent.

The samples were made by compressing the epoxy and kenaf bast fiber together using a hot-press compression and a mould similar to the one used for creating epoxy samples. Specimens were made in the dimensions of 5 mm in height by 15 mm in breadth and were made in various thicknesses of 1 mm, 3 mm, and 5 mm. [17]

2.2.8 NDT Based Design of Joint Material for IRT

This research introduced an infrared thermography-based bonding fault detection in composite structures. The investigated material was a laminated composite made of TORAYCA T300 carbon fiber and HEXPLY M10R/38%/UD150/CHS (4.7mm thickness). Thermal stimulation was carried out using a halogen lamp with maximum power of 1000 W and FLIR Titanium retrofitted camera of 350*256 pixels is used to perform thermal acquisition along with Altair software. It was suggested that adding conductive boron nitride particles to the epoxy joint in this work, will increase the efficiency and accuracy of IRT. [2]

Using traditional NDT techniques, fault analysis and detection in various types of materials has been made relatively simple and high-quality results have been obtained. NDT techniques are often inexpensive innovations. Thermography is a type of Radiographic NDT methods in which the test is done by inducing a temperature difference through the metal and measuring the intensity of emitted infrared rays in order to identify the faults. It is possible to examine the defects as well as its geometrical dimensions, form, and size with a small temperature difference as small as 0.8k.

These technique plays a significant role in the monitoring of materials during their operation or manufacturing process. NDT procedures requires trained workers, and it might be challenging to interpret the results with a portable equipment. Because of its higher degree of accuracy and efficiency in producing results many researches are being done on thermography-based NDT methods.

Table 2.1 : Summary of Review on Thermography Techniques

S. No.	Technology/ Techniques	Materials	Dimensions of the material	Results / Defects analyzed
1	Long Pulse Thermography & Shearography	Rubber-metal bonded structures	A 5 mm thick cylindrical carbon steel shell was chosen as a substrate for 250x250mm specimen plate.	Identified cracks in rubber-metal composites by imaging techniques PLSR & TSR.
2	Eddy Current Pulsed Thermography	Corroded Metal surface	90 x 30 x 7 mm	Hidden cracks in corroded metal surfaces.
3	Lock-in Thermography using Ultrasonic probe.	A Multi Layered Composite Plate.	A Composite Plate of about 600 x 600 mm with 15mm of Polytetrafluoroethylene Teflon disc placed in between.	Delamination defect was detected at a depth of 0.4mm
4	Lock-in Thermography using Artificial Neural Networks	Composite Plate	Sheets cut into the dimensions of 90 x 90 mm	Holes were detected in composite plate in order to determine shape and the size.

5	Lock-in Thermography using Laser ultrasonic	Carbon reinforced Polymer (CFRP)	Four Specimens were used with 3mm thickness. (Average resin quantity- $35 \pm 3\%$. Average Fiber - 150 ± 6 g/m ² .)	Dis-Bonds, grooves and holes were examined.
6	Optical & Pulsed Phase Thermography .	Two Mild Steel (Dc05) specimens.	Specimen - I 10mm long Specimen - II 30mm long (With a common thickness of 0.8mm)	Cracks in sheet metals are identified with 1mm dimension.
7	Laser Line Thermography	Steel Block (ST37/DIN 17100 /AS TM A283)	A Steel plate with dimensions 100 x 100 x 40 mm.	Defects in steel bars at high temperature of about 600 C.
8	SMArt Thermography & Pulsed Thermography .	A Flat GFRP Composite panel	GFRP composite panel with dimensions 210 x 300 mm and a thickness of 0.8mm.	Delamination faults in GFRP panel.
9	Infrared Thermography Imaging technique.	Epoxy & Kenaf Bast Fiber	Three fibers in a common dimension of 0.5 x 1.5 cm and with various thicknesses of 0.1cm, 0.3cm, and 0.5cm.	Defects in Kenaf blast fibers. Hot-Spots, voids, misaligned fibers etc.

10	Active Thermography for Erosion in rotary blades	Curved GFRP composite	Four layers of laminates with length and inner radius of 230mm and 22mm and with a wall thickness of 22mm	Internal Voids between the lamination
11	NDT Based design of joint material.	Carbon fiber and HEXPLY	Carbon fiber of thickness 4.7mm	Dis-bonds in composite Structures.

CHAPTER 3

AIM AND SCOPE

3.1 AIM

To develop an Infrared Thermography based defect detection system for inspection purpose.

3.2 OBJECTIVES

- Identifying different types of defects that may occur in a material during welding operation.
- To capture thermal images of the material and display it over a screen.
- Classifying types of defects into different category by examining the thermal images captured.

3.3 PROBLEM DEFINITION

Generally, while casting a metal structure or while welding two different metals it is common to have defects such as surface cracks, deformation or internal cavity. These defects may even end as a catastrophic failure of the particular part if left unrectified. These defects were identified by either altering the material or destroying it permanently in the past before the arrival of Non-Destructive Testing (NDT) methods in the industries.

Conventional NDT methods are widely used in many industries at present because of their high accuracy and due to their ability of rapid inspection and also it is an economical way of testing a material without damaging any part. This method basically examines the properties of the materials, structure, and classifies different types of defects like scratches, cracks, holes etc. NDT methods also provide accurate parameters of the crack like length and width of the defect etc.

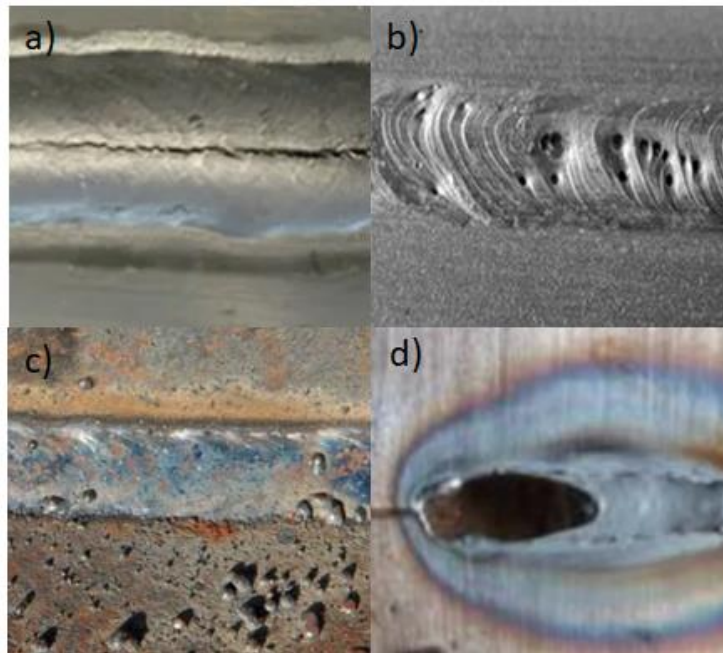


Fig:3.1 : Different Types of Defects like a) Crack, b) Pores, c) Splatter, d) Burn-Through Formed During Welding

3.4 DRAWBACKS OF CONVENTIONAL METHODS

There are quite a few drawbacks in conventional NDT methods that are listed below

- There is no way to tell if there is an interior void or a minute crack.
- The polish of a component can occasionally affect inspection sensitivity
- Changes in magnetic permeability can also affect it.

CHAPTER 4

EXPERIMENTAL WORK AND SETUP

4.1 COMPONENTS USED FOR SETUP

4.1.1 IR Camera Module

The FLIR Lepton 3.5 is a radiometric-capable LWIR (Long wave Infrared – 8000 to 14000 nm) camera solution that is smaller than a dime, fits inside a smartphone, and is one tenth the cost of traditional IR cameras. Using focal plane arrays of either 160x120 or 80x60 active pixels. The radiometric Lepton captures accurate, calibrated, and noncontact temperature data in every pixel of each image. The sensor is generally mounted on a breakout board which requires an input power of 3.3V. So it can be powered directly from any 3V or 5V microcontroller or PC.

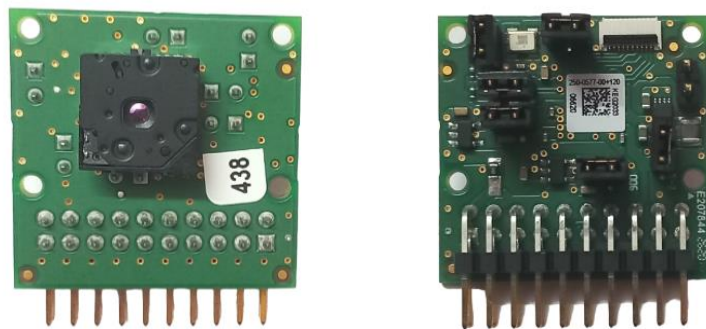


Fig:4.1 : Lepton 3.5 and it's breakout board

4.1.2 Wires and Sockets

Jumper wires are used to connect lepton 3.5 camera module with the raspberry pi and a type c cable is used to power up the microprocessor.

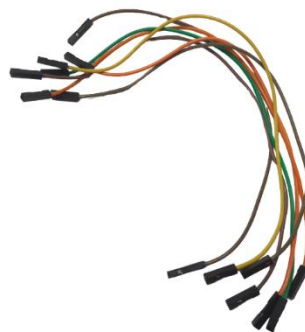


Fig:4.2 : Jumper wires

4.1.3 Raspberry Pi

Raspberry Pi is a small single board computer developed in the UK. The series that we are using in this project is Raspberry Pi 4 integrated with a 64 bit quad core cortex and runs at the speed of 1.5GHz. The configuration that is being used has 8gb of ram storage and also equipped with Bluetooth 5.0, gigabit Ethernet and wireless at 2.4GHz and 5GHz. This board has 4 USB ports for data transfer and SD card slot for memory storage as well as for storing the OS. It also consists of other ports like 2 HDMI ports for AV output, a type c port for powering the board and also a 3.5mm audio jack. The OS that has been flashed in this board is called Rasbian OS which is an open source OS developed from Linux.



Fig:4.3 : Raspberry Pi 4 model B

4.1.4 Power Source

Raspberry pi is powered directly from the 5 volt USB output of the computer and the infrared receiver gets its power from the 3.3 volt output port of the Raspberry Pi board.

4.1.5 Micro SD card

A micro SanDisk SD card of 32 GB is used as a storage for booting and saving the output data in raspberry pi.



Fig:4.4 : Micro SD card used

4.2 EXPERIMENTAL SETUP

The system consists of an IR camera Lepton 3.4 along with raspberry pi for collecting thermal data from the samples. The IR camera module is manufacture by FLIR and is an LWIR (Long Wave Infrared) type camera [9]. The radiometric Lepton captures accurate, calibrated, and non contact temperature data in every pixel of each image and has a pixel density of 160x120 pixels. The sensor is generally mounted on a breakout board which requires an input power of 3.3V. So it can be powered directly from any 3V or 5V microcontroller or PC.

The microprocessor that is used in this system is a Raspberry Pi which is a small single board computer developed in the UK. The series that had been used is Raspberry Pi 4 integrated with a 64 bit quad core cortex and runs at the speed of 1.5GHz. This processor has 8GB of ram storage and also equipped with 4 USB ports for data transfer and SD card slot for memory storage as well as for storing the OS. It also consists of other ports like 2 HDMI ports for AV output, a type c port for powering the board and also a 3.5mm audio jack. The OS that has been flashed in this board is called Rasbian OS which is an open source OS developed from Linux. A 32GB SanDisk micro SD card is booted with this Rasbian OS and has been installed in the respective slot in the raspberry pi. Raspberry pi imager software is used to boot the memory card with the OS.

Jumper wires are used to connect the breakout board of the camera module with the raspberry pi and a type c cable is used to power up the raspberry pi. Raspberry pi is powered directly from the 5-volt USB output of the computer and the infrared receiver gets its power from the 3.3-volt output port of the Raspberry Pi board. A java based image processing program called as ImageJ is used to view and render the gray scale images obtained from the camera. The tests are conducted in a weathering steel specimen welded using a laser at various voltage levels and on mild steel specimens welded using gas welding. All the specimens are 3mm thick. The camera is pointed towards the region of interest and 100 frames are captured and stored in the Raspberry Pi.

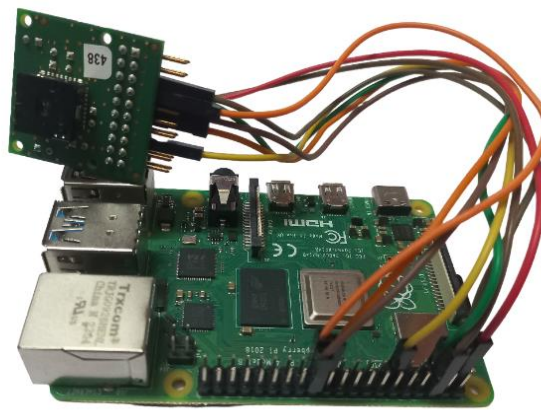


Fig:4.5 : Wiring connections

4.3 IMAGE PROCESSING

After collecting the thermal data from the camera module, the raw images are collectively stored in a folder. Then the ImageJ software is loaded and raw is selected from the open menu. Then the folder with the raw data is navigated and a file is selected. After opening the file, open all files from the directory check box should be clicked to open all the raw frames captured from the camera and sequence it into a video. Also the 16-bit unsigned format should be selected and 160x120 pixels should be mentioned in the pop up window before opening the files. Now the ImageJ software converts the raw data into a visible grey scale image sequence. The scaling the video can be upgraded by selecting scale option in the image menu to enlarge the image size for observing the image with much more accuracy.

To export this image sequence into a video file the file should be saved as AVI format which can be found in the file menu. By saving so the video file now can be transferred or viewed in any other devices. The grey scale images can also be saved as JPEG or PNG formats to view individual frames.

Using a Long-wave infrared camera module, Lepton 3.5 manufactured by FLIR a case study was conducted to identify the defects on a weld sample and casted iron piece. This IR camera produces a gray scale image of dimensions 160x120 as its output and has a dynamic range of -10 to +400. The IR camera module is connected

to a Raspberry Pi 4 to collect the data and store it. By observing the captured gray scale images, the artificial defect made on a casted iron piece in the form of hole is clearly visible and also the discontinuity of the weld can be viewed. These are the two most commonly occurring defects in the process of casting and welding. This observation represents the capability of thermography to be considered as an NDT method.

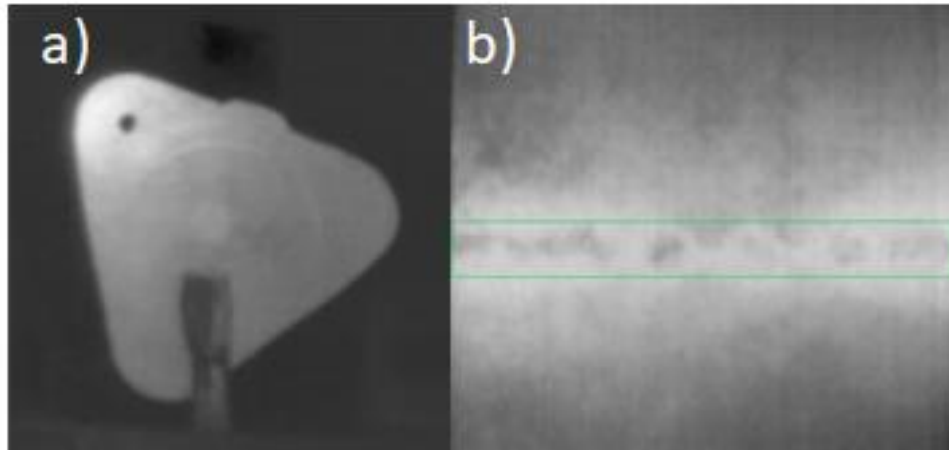


Fig:4.6 : Test Samples

Table 4.1 : Pin Configuration

Break Out board Pin	Actual name	Raspberry Pi Pin
P8	SCL	GPIO3
P5	SDA	GPIO2
P12	MISO	GPIO9
P7	CLK	GPIO11
P10	CS	GPIO8
P15	VSYNC	GPIO17
P1	Ground	grnd
P2	Vin	3.3v

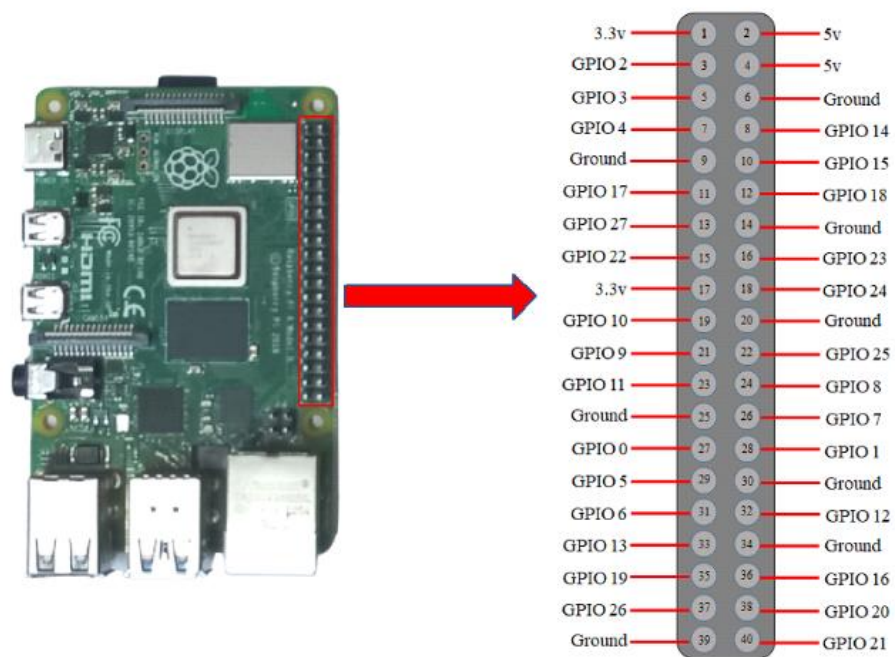


Fig:4.7 : Pin Configuration of Raspberry Pi 4

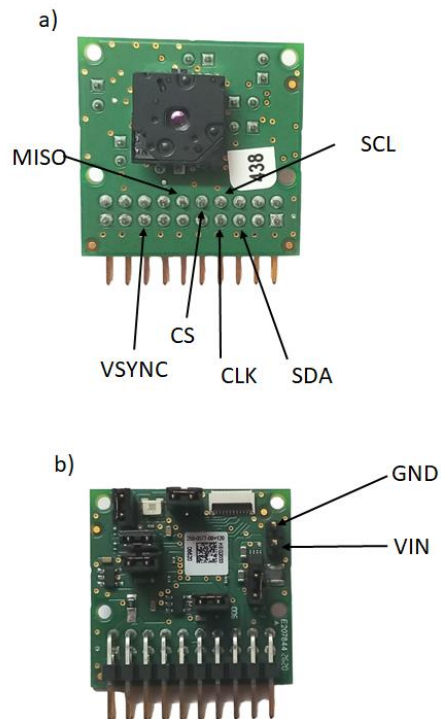


Fig:4.8 : Pin Configuration of Lepton 3.5

4.4 METHODOLOGY

- The first stage of our approach is to increase the intensity of emitted infrared rays by warming up the material to be inspected.
- This is done by passing a suitable amount of heat to the metal plate using a light source.
- After the first stage the emitted infrared rays are captured using an IR thermal receiver.
- When the heat is applied to a material it may not get distributed equally over the areas with defects.
- And this minor temperature difference is calculated by measuring the intensity of the received infrared rays.
- In next stage these received signals from the receiver are processed with the help of Raspberry Pi and is converted into a readable value or thermal image.
- This thermal image is then processed using a trained data set which can identify the flaws such as cavities, holes, and cracks.
- Once the image has been analysed, we may calculate the geometric dimensions of the flaws, such as length and width in different material segments to improve product quality.

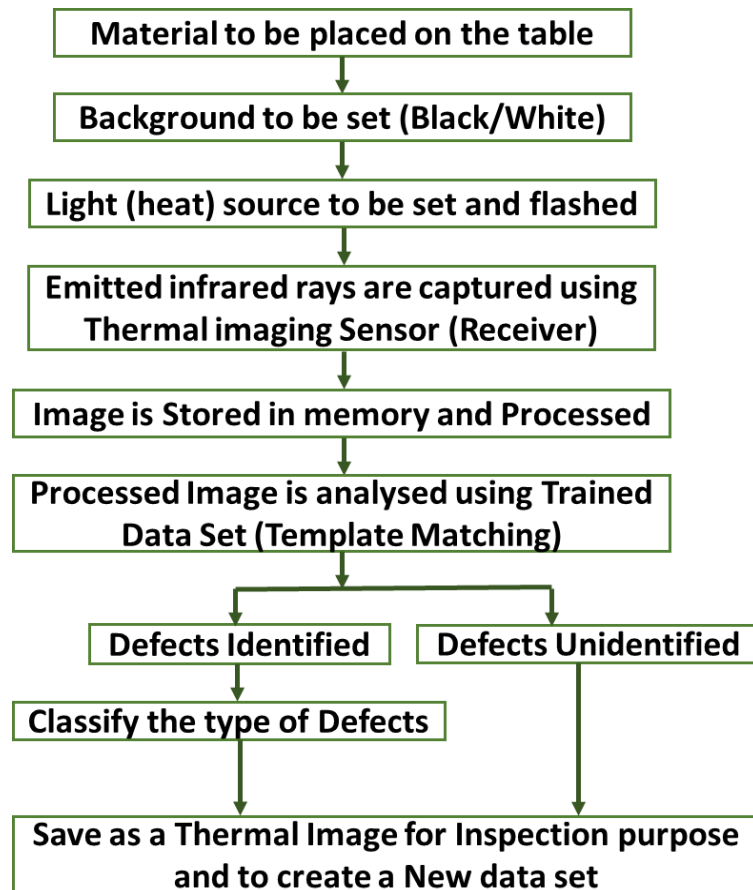


Fig:4.9 : Step by Step Procedure of Thermography

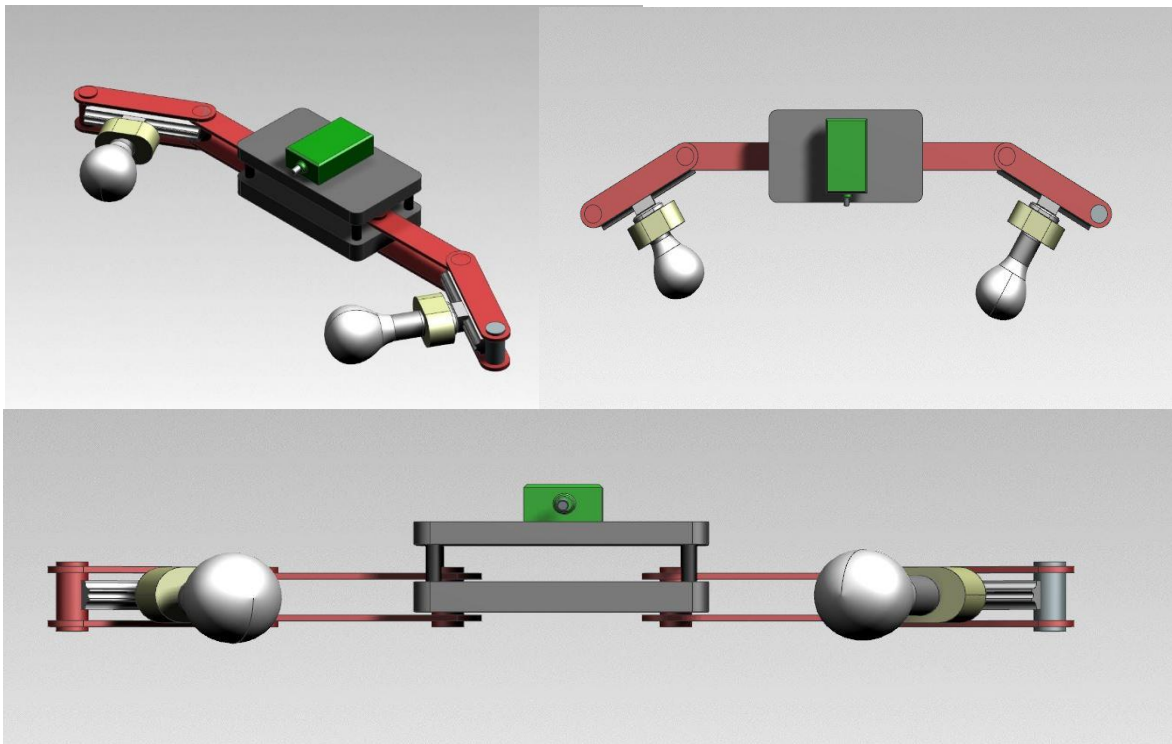


Fig:4.10 : Patent Design of Proposed Passive Thermography Kit

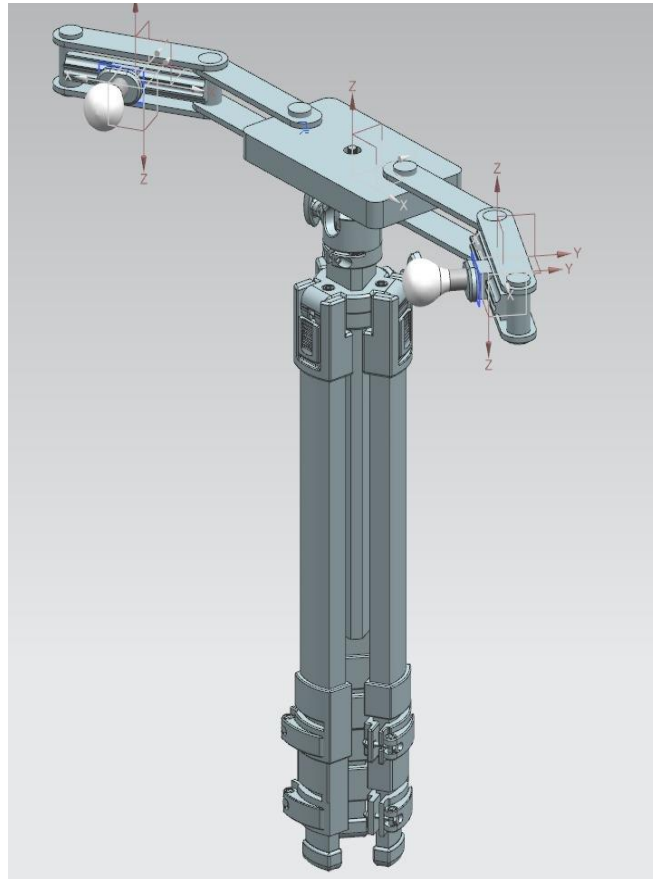


Fig:4.11 : CAD Design of Passive Thermography Kit's Frame Mounted on a Tripod

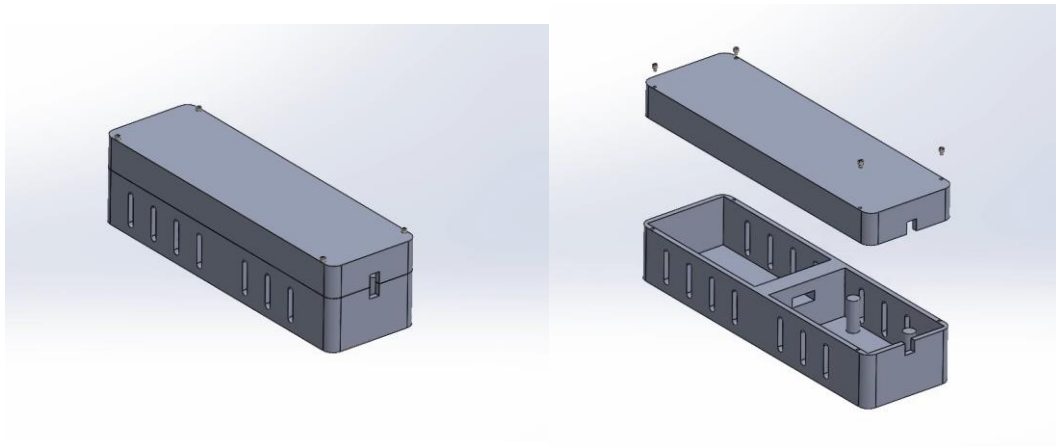


Fig:4.12 : CAD Design of Passive Thermography Kit's Camera Casing

CHAPTER 5

RESULTS AND DISCUSSION

To investigate the defects in the specimen, it is thermographically recorded and output data are obtained in form of grey scale image. Initially 100 frames are captured from the camera module and the process is repeated. Any loose connection of CLK pin may have a tremendous effect on the image quality and produce noise signals. The output image Fig. 5.1a shows the result of a burn through defect in a laser weld which is the region of interest in this case and the defect zone can be observed by the dark spot on the thermal image. This sort of defects occurs when laser temperature is much higher or when the laser's movement is slower than needed. Fig. 5.1b represents the thermal image of a proper weld which can be observed from the even heat distribution along the straight line of the weld. Fig. 5.1c represents a lack of penetration in the weld area. This defect is formed due to insufficient temperature or lack of filler in the weld area. This sort of defects may end up with a catastrophic failure of the component if left unnoticed [10].

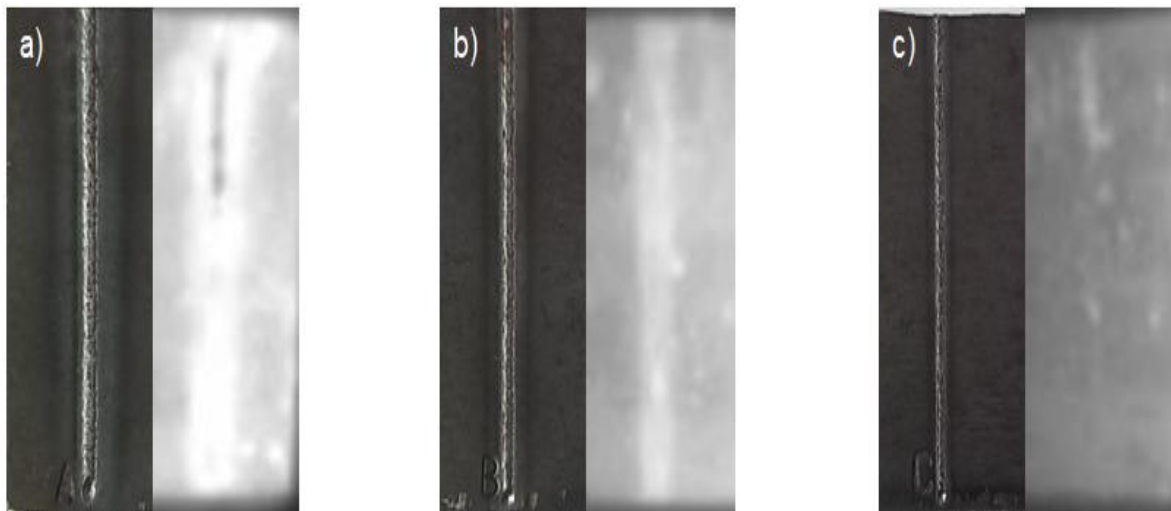


Fig:5.1 : Laser Welded Samples with a) Burn through defect, b) Perfect Weld, c) Lack of penetration

The following images represent various defects that are formed in a mild steel specimen during gas welding. Fig. 5.2a shows the welded side of a mild steel plate with burn through defect and Fig. 5.2b represents the back side of the welded plate where the filler material is formed into a lump. Fig. 5.2c displays the thermal image of this defect in which the irregular shape of the weld region caused by this defect can be observed and higher contrast level can be observed in case of burn through defect. Fig. 5.3a represents the image of welded region with excessive filler material and Fig. 5.3b represents the thermal image of it. Human error is the reason for these kind of defects in most cases where the weld rod is held in the same position for a prolonged period of time or excessive heat input.

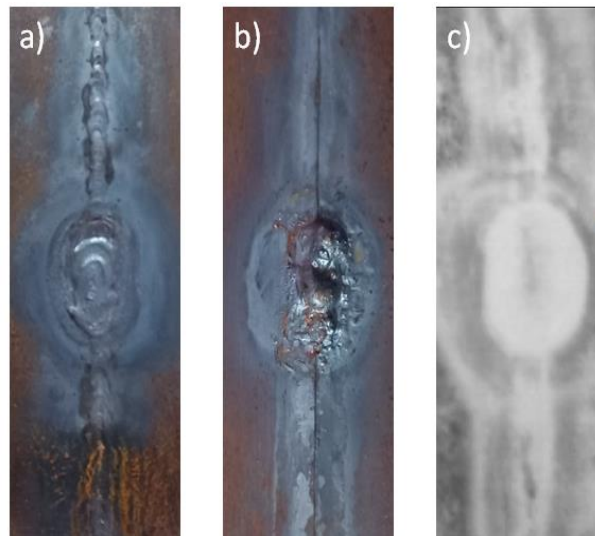


Fig:5.2 : Burn through defect formed during TIG welding

Fig. 5.4a represents image of a mild steel plate with cracks and the weld irregularities formed during the gas welding process. Fig. 5.4b displays the thermal image of these surface defects. Surface cracks are marked using red box and the surface deteriorations are highlighted using a green box for reference.

Cracks are another type of the most common defect that can be formed during the cooling of the weld region due to the stress generated when the weld solidifies. Pre heating the specimen before welding can help in reducing their occurrence.

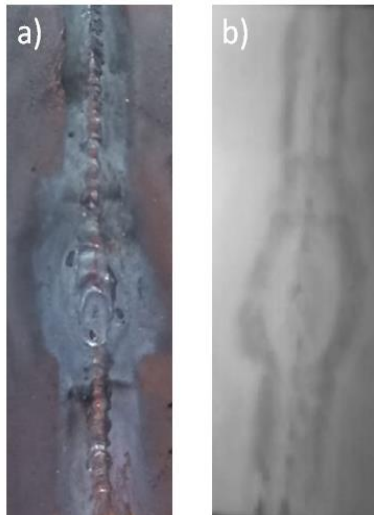


Fig:5.3 : Excessive use of filler

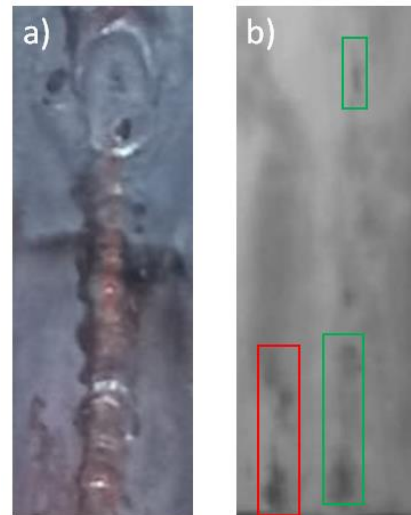


Fig:5.4 : Cracks and weld irregularity

Fig. 5.5 represents welded side of a mild steel plate with micro pores and the corresponding thermal image of two specimens in which the micro pores can be observed as the dark spots in the thermal image of the weld zone. This defect is commonly termed as weld porosity and is formed as a result of air being trapped in the weld metal.

When the weld solidifies, the trapped air tries to escape from the weld region which causes porosity on the weld surface. It is one of the most common defects that can be formed during the welding process. Inadequate shielding gas is one of the major reasons for this defect to occur. These pores can differ in size and micro pores are tough to identify with naked eyes.

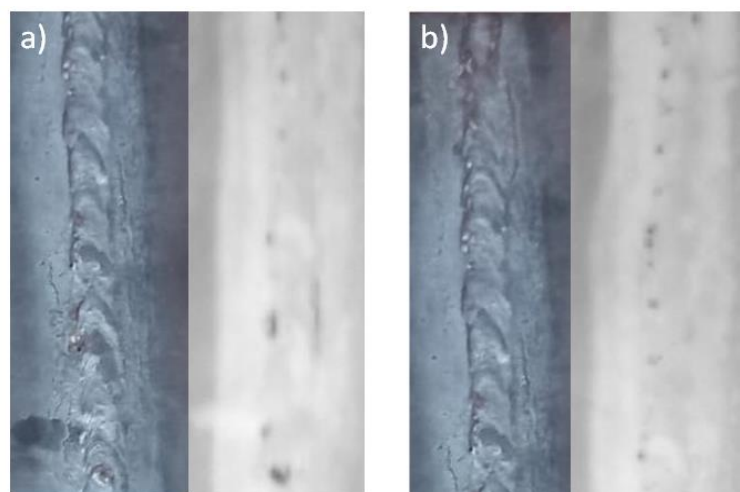


Fig:5.5 : Porosity formed during welding process

Fig. 5.6a represents image of a rusted mild steel plate along with its corresponding thermal image Fig. 5.6b in which the rust zones can be observed as the bright spots. Unlike previous case studies, the surface of the material have been heated before carrying out the experiment since there is no other active heat source like a welding process. So passive thermography is not applicable to this particular case study. Rusting is basically the oxidation of the steel formed when the Fe particles on the surface are exposed to oxygen and moisture. These rusts can ultimately reduce the life cycle of the component by slowly etching its surface which in turn affects the structural integrity of the component and weakens the metal by reducing its mass [13].

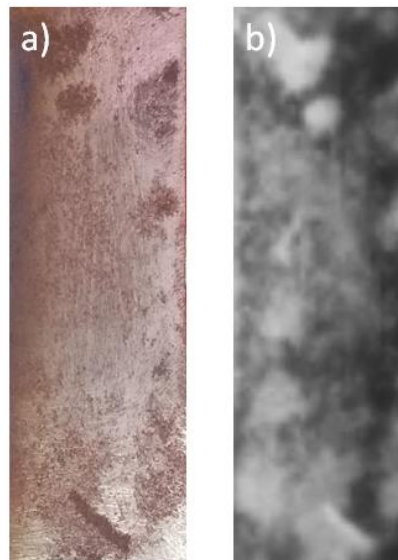


Fig:5.6 : Rusted corten steel specimen

CHAPTER 6

SUMMARY AND CONCLUSION

On the basis of finding flaws in diverse materials, numerous numbers of different technologies and procedures was been developed and each technology has benefits and drawbacks of its own. Despite of its drawbacks, thermography techniques has a higher level of accuracy and more advantages in detecting concealed defects and delamination defects in composite materials which most of the conventional NDT methods fails to do and unlike other radiography methods, thermography is harmless which is an added advantage. Mid wave infrared cameras were the most common type of IR cameras used in thermography due to its capability to detect the long-range targets. Due to the compact size of IR cameras, it is possible to build a portable kit for carrying out thermography testing in remote areas with an in-build power source.

In this research work passive thermography is used as a potential measuring method to locate, visualize and detect defects to ensure the structural integrity of the weld. For this purpose, specimens welded using laser at various voltage levels and specimens with different defects formed during gas welding has been examined using passive thermography technique and the following defects have been observed.

Laser welded weathering steel plates with a burn-through defect, perfect weld and another one with lack of penetration has been examined and the defects have been observed by irregular weld shape and dark spots over the weld region on the thermal image.

Two gas welded mild steel specimens with a burn through defect and with excessive filler material has been examined. In these cases, the shape of the defects are clearly observed in the thermal image and higher contrast have been observed in case of a burn through defect.

Two mild steel specimens with micro pores formed during the process of gas welding has been examined and dark spots have been observed in the thermal image of the weld zone representing the porosity.

A mild steel specimen with cracks and the weld irregularities formed during the gas welding process has been examined thermographically in which the defects have been observed in form of dark spots with irregular size and shape.

A rusted mild steel specimen has been examined using active thermography and the rust zones have been observed as bright spots in the thermal image. Passive thermography is not applicable for this particular case study as it doesn't incorporate any active source like a welding process.

The investigation demonstrates that passive thermography offers the ability to detect and visualize different defects in a welded component. Based on the differentiation of the defect types in the thermogram the structural integrity of the component can be analysed. As expected, the defects have been having an influence on how the heat spreads through the surface of the component which validates the applicability of the passive thermography in weld monitoring. The main application of this monitoring system would be in robotic welding in which the welding process is automated using a robotic arm. This monitoring system can be used to track the weld areas and monitor the quality of the weld autonomously and a feedback system can be built to correct the errors made by the robots. For the future work, it remains to be clarified at what depth the defect occurs and investigations have to be made in other types of manufacturing and machining processes like casting and drilling.

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ANNEXURE:

- Design Patent has been applied for a Passive Thermography Kit on 6th March, 2023.
- Review paper on the title of “Non-Destructive Testing Using Thermography: A Review” by J.R.Deepak, Mughilan.R.B., Guraja Siddartha has been presented in iCAM conference conducted by Sathyabama Institute of Science and Technology, Chennai on November 4th, 2022.
- Review Paper on the title of “Non-Destructive Testing Using Thermography: A Review” by J.R.Deepak, Mughilan.R.B., Guraja Siddartha has been presented in ICAARS conference conducted by PSG College, Coimbatore on 10th December, 2022.
- Review Paper has been communicated to Springer Journal
- Research on the title of “Development of Passive Thermography Non-Destructive Technique – A Case Study” by J.R.Deepak, Mughilan.R.B., Guraja Siddartha has been presented in ICDTM conference conducted by Sastra University, Thanjavur on 9th April, 2023.