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Weld Defect Detection Using Ultrasonic Testing (UT) and Phased Array Ultrasonic Testing (PAUT)

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DECLARATION

I declare that this thesis entitled "Effect of Probe Angle of Ultrasonic Testing (UT) and Phased Array Ultrasonic Testing (PAUT) in Weld Defect Detection" is the result of my own research except as cited in the references.

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Pengesanan Kecacatan Kimpalan Menggunakan Ujian Ultrasonik (UT) dan Ujian Ultrasonik Tatasusunan Berperingkat (PAUT).

ABSTRAK

Ujian ultrasonik (UT) merupakan kaedah ujian tanpa musnah (NDT) yang digunakan untuk mengesan kecacatan, manakala ujian ultrasonik tatasusunan berperingkat (PAUT) merupakan bentuk canggih UT dengan ciri-ciri tambahan. Kajian ini memberi tumpuan kepada pemeriksaan sampel pengimpal menggunakan teknik UT dan PAUT dengan menggunakan pelbagai sudut sonar. Perubahan sudut sonar membawa kepada perubahan dalam pembentukan gelombang dan saiz kecacatan semasa proses pemeriksaan. Matlamat objektif kajian ini termasuk memeriksa kecacatan pengimpal melalui penggunaan pelbagai sudut sonar dalam kedua-dua UT dan PAUT. Tiga sudut sonar, iaitu 45º, 60º, dan 70º, digunakan untuk pemeriksaan. Kesannya terhadap pengesanan kecacatan dinilai dengan menganalisis pembentukan gelombang yang dipaparkan dalam representasi A-scan dan, dalam kes PAUT, ia juga boleh dipaparkan dalam representasi S-scan. Penemuan menunjukkan bahawa pemilihan sudut sonar mempengaruhi ketepatan pengesanan kecacatan secara signifikan. Keberkesanan setiap sudut sonar bergantung kepada lokasi kecacatan dalam pengimpal. Secara umumnya, sudut sonar 45º lebih sesuai untuk kecacatan berhampiran permukaan, manakala sudut sonar 70º lebih berkesan untuk pengesanan kecacatan yang lebih dalam. Kesimpulannya, semua sudut sonar boleh digunakan secara berkesan untuk pengesanan kecacatan, tetapi perhatian yang teliti diperlukan untuk memilih kaedah yang optimum berdasarkan lokasi kecacatan.

Kata kunci: Sudut sonar, Kecacatan pengimpal, Pembentukan gelombang, UT, PAUT

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ABSTRACT

Ultrasonic testing (UT) is a non-destructive testing (NDT) method employed for detecting defects, while phased array ultrasonic testing (PAUT) represents an advanced form of UT with additional features. This study focuses on inspecting a weldment sample using UT and PAUT techniques by employing various probe angles. The variation in probe angles leads to alterations in wave formation and defect size during the inspection process. The aim objectives of this study include examining weld defects through the utilization of different probe angles in both UT and PAUT. Three probe angles, namely 45º, 60º, and 70º, were utilized for inspection. The impact of probe angle on defect detection was assessed by analysing wave formations presented in A-scan representation and, in the case of PAUT, it can also be displayed in S-scan representation. Findings indicate that the choice of probe angle significantly influences the accuracy of defect detection. The effectiveness of each probe angle is contingent on the defect's location within the weldment. Typically, a 45º probe angle is more suitable for defects near the surface, whereas a 70º probe angle is more effective for detecting deeper-seated defects. In summary, all probe angles can be employed effectively for defect detection, but careful consideration is essential to choose the optimal method based on the defect's location.

Keywords: Angle Probe, weld defect, Wave formation, UT, PAUT

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Nowadays, the welding process and system are important aspects of modern industrial production lines. The welding technique is typically used for joining and repair. When parts of a steel plate are joined by welding, a defect can occur. Weld defects can be a major issue in a range of industries, including construction, manufacturing, and aerospace. Therefore, the detection of defects in steel welds is important. Some welding defects include slag inclusion, crack, porosity, and lack of fusion can occur. Slag inclusions are non-metallic particles that become trapped either in the weld metal or at the weld interface. These inclusions are a consequence of faulty welding techniques, improper joint access, or a combination of both. However, when the proper technique is employed, slag inclusions can rise to the surface of the molten weld metal (Singh., 2016). According to Albannai, A (2020) a crack can occur in the weld metal due to the high temperature and cooling rates involved in welding. This defect can be caused by improper welding techniques or inadequate preheating. After that, porosity is the presence of small holes or voids in the weld metal, which can weaken the joint and reduce its resistance to corrosion. This defect can be caused by the presence of moisture, inadequate shielding gas, or incorrect welding technique (Salih et al., 2020). Lastly, lack of fusion occurs when the weld metal does not fuse completely with the base metal, leading to a weak joint. This defect can be caused by insufficient heat or inadequate weld preparation (Albannai, A., 2020). If the defects, such as cracks, are large enough, they will propagate under operation stress, and failure of the joint may result in physical and economic damages due to operational downtime while repairs are made (Kurtulmuş & Yükler., 2011). To avoid these defects, it is important to follow proper welding procedures, including adequate preheating, appropriate welding techniques, and proper selection of welding parameters.

Furthermore, inspection of the welds can also help to identify any defects that may occur. Detecting and characterizing these defects is essential for ensuring the safety and reliability of welded structures. There are non-destructive testing (NDT) techniques that are commonly used to detect and classify weld defects such as visual inspection, penetrant testing (PT), magnetic testing (MT), radiography testing (RT), and ultrasonic testing (UT). Visual inspection is the inspection method that involves inspecting materials or components with the naked eye or using tools such as magnifying lenses or borescopes. Meanwhile, the PT method is to inspect the surface cracks, porosity, and other defects in non-porous materials such as metal, ceramics, and plastics. The PT involves applying a penetrant solution to the surface, removing excess penetrant, applying a developer, and then inspecting for indications of defects. Then, MT is a method for detecting surface and near-surface cracks or other defects in ferromagnetic materials. MT involves the application of a magnetic field to the test material, followed by applying a solution of magnetic particles to the surface (Jung, M. Jae, et al., 2018). The particles will accumulate at areas of magnetic flux leakage caused by defects. The penetrant test and the magnetic test methods have several problems, such as the limitation of defect detection of the surface and subsurface. Furthermore, RT is a method that uses X-rays or gamma rays to penetrate the tested material and create an image on a film or digital detector. RT can be used to detect internal defects such as cracks, voids, or inclusions. However, RT has many limitations such as workers being exposed to radiation and long testing times that can result in production delays (Jung, M. Jae, et al., 2020).

Meanwhile, the ultrasonic test method became a major NDT technique in nuclear plants because the advantages that testing gives include safety considerations, quality factors, time-saving, and cost-saving (Kurtulmus & Yukler., 2011). Ultrasonic testing (UT) uses a single transducer to generate ultrasonic waves that pass through the testing material. The waves are then reflected by the transducer and converted into electrical signals that can be analyzed to determine the presence and location of defects (Marquez & Muñoz., 2020). Besides that, phased array ultrasonic testing (PAUT) is a particularly effective technique for detecting and characterizing defects in the weld. PAUT is generally considered to be a more advanced and precise technique. This is because PAUT uses an array of multiple transducers to generate and receive ultrasonic waves (Jung, M. Jae, et al., 2018). This allows for more precise control over the direction and timing of the waves, which can be adjusted to optimize the inspection for the specific types of defects or material. The use of PAUT can provide more detailed information about the size, shape, and location of defects in the test material. It can also be used to detect defects that may be missed by UT, such as those located at an angle to the material surface. PAUT produces an image of a received signal via electronic control, where each element delivers ultrasonic waves to a single probe.

After that, the imaging method produces A-, B-, and C-, and collects defect location and size in multiple directions. The amplitude of an ultrasonic signal as a function of time is provided by the A-scan. The B-scan offers information about the specimens' vertical portions. The C-scan generates 2D image ultrasonic data that can be viewed as a top or plan view of the test material. Typically, probe angles are expressed in degrees and can range from 0 to 90 degrees. The most commonly used probe angles in NDT are 45 degrees, 60 degrees, and 70 degrees. A 45-degree probe angle is often used for detecting defects that are located near the surface of the material. A 60-degree probe angle is often used for detecting defects that are located at an intermediate depth within the material. A 70-degree probe angle is typically used for the inspection of thicker materials.

1.2 Problem Statement

The potential problem with ultrasonic testing (UT) or phased array ultrasonic testing (PAUT) is that probe angle selection can be important for the accuracy and reliability of the inspection results. Different angles can provide different levels of sensitivity (Honarvar., 2020) and resolution for various types of defects, and selecting the most suitable angles may require careful investigation and testing. Certain angles have some limits in their application. For example, if the probe's angle is too steep or too shallow, it can result in a decreased sensitivity for certain types of defects, particularly those near the weld's surface. This increases the possibility of undetected defects, which could compromise the weld's integrity and safety as well as the entire structure.

The angle of the ultrasonic beam when inspecting welds is an important parameter that can affect the ability to detect and characterize weld defects. The angle should be selected based on the weld thickness, the sorts of defects being inspected, and the testing materials. However, due to the complex geometry of the welds, detecting weld defects by angle using UT and PAUT might be difficult. By carefully analysing the geometry and characteristics of the weld being inspected, and by understanding the strengths and limitations of different probe angles, NDT technicians can optimize their inspections to ensure the safety and reliability of the weld and the overall structure. The purpose of this study is to determine the effectiveness of UT and PAUT in detecting weld defects by probe angle.

The operator's skill level is another issue as it plays a critical role in conducting UT and PAUT inspections. This is because it can significantly impact the accuracy of defect identification during the inspection process. For example, UT may involve several spurious echoes depending on the size, shape, material, and type of object applied; therefore, UT is likely to commit errors when distinguishing spurious echoes in the defect echo. Hence, it requires sufficient training and experienced inspectors (Jung, M. Jae, et al., 2020).

1.3 Objectives

The objectives of this study are:

i. To identify the weld defects by using different probe angles in ultrasonic testing (UT).
ii. To analyse the waveform for each weld defect using UT and PAUT methods.
iii. To investigate the differential between UT and PAUT method.

1.4 Scope of Study

A comprehensive review of existing literature on ultrasonic testing (UT) and phased array ultrasonic testing (PAUT) using angle probes to detect weld defects will be conducted to identify their principles, limitations, and applications. A range of UT and PAUT equipment with angle probes of 45, 60, and 70 degrees will be studied to determine the optimal equipment and techniques for detecting weld defects in structures. Various types of weld defects will be examined, including porosity, lack of fusion, slag inclusion, and cracks. Data will be collected from various structures of types of weldments, to determine the effectiveness of angle probes in detecting weld defects. The collected data will be analysed using statistical methods to determine the accuracy and reliability of angle probes in detecting weld defects. A comparative analysis of the effectiveness of different angle probes of 45, 60, and 70 degrees will be conducted to determine their advantages and disadvantages in detecting weld defects. Based on the findings of this study, recommendations will be made for the optimal use of angle probes in UT and PAUT for detecting weld defects.

1.5 Significances of Study

The study aims to improve the accuracy and reliability of non-destructive testing (NDT) methods such as ultrasonic testing (UT) and phased array ultrasonic testing (PAUT). These techniques are widely used in the industry for defect detection and material characterization, and any advancements made in these methods could lead to more efficient and effective testing practices. Defects in welded joints can compromise the structural integrity of the final product, and accurate detection of these defects is essential for ensuring the quality of the weld. The proposed study could help develop more robust techniques for detecting and characterizing weld defects. The detection of defects in welded joints is crucial for ensuring the safety of structures and equipment. By improving the accuracy and reliability of NDT methods, the proposed study could help prevent catastrophic failures that could result in injury or loss of life. Early detection of defects in welded joints can save significant costs associated with repairing or replacing faulty equipment or structures. The proposed study could lead to more efficient and effective testing practices that could result in cost savings for businesses and industries.

CHAPTER 2

LITERATURE REVIEW

2.1 Ultrasonic Testing (UT)

Ultrasound waves exhibit consistent velocities within specific materials, and they travel in straight lines when passing through homogeneous mediums. When ultrasonic waves transition between materials with differing sound velocities, refraction occurs, causing the sound beam to reflect at the boundary between the two materials. Similar to light waves, ultrasound waves adhere to the fundamental laws of physics. By exploiting the refraction phenomenon, ultrasound probes can be designed to direct sound beams into materials within defined limits and at various angles. The ability of ultrasound to detect weld defects stems from its capacity to reflect at the interfaces between materials with distinct acoustic properties. Furthermore, ultrasound can provide precise positional information about a given reflector, leveraging the constant velocity of sound in a specific material and its straight-line propagation when suitable equipment is employed.

2.1.1 Principle

The mechanical vibrating of a material's particles generates sound. The material's particles vibrate around a fixed point at the same frequency as the sound wave when it passes through it. The particles simply respond to the wave's energy; they do not move with the wave. The wave's energy is what travels through the substance.

2.1.1 (a) Velocity

Velocity in ultrasonic testing (UT) is the speed at which ultrasonic waves propagate through a material. Ultrasonic waves are mechanical vibrations with frequencies above the human hearing range, typically in the megahertz (MHz) range (Abramov, 2019). Two main types of velocities are commonly discussed in UT: longitudinal waves, which travel parallel to the direction of the wave and are typically faster than other types of waves in most materials; shear waves, on the other hand, travel perpendicular to the direction of the wave and usually have a lower velocity than longitudinal waves. Velocity sound in the material can vary depending on the angle of incidence. The calculation of velocity can be described by this formula below:

$$v(\theta) = \frac{v(0°)}{Cos\ (\theta)} \qquad \text{Equation 2.1}$$

2.1.1 (b) Frequency

The number of oscillations or cycles of a sound wave that take place in a second is referred to as frequency. The unit of measurement is typically cycles per second (cps) or Hertz (Hz). ASNT states that the typical range of UT frequency is between 50,000 cycles per second (50 kHz) and 25,000,000,000 cycles per second (25 MHz). Applications for evaluating laminated materials have recently been developed that use frequencies in the 400 MHz region. To test materials without harming them, UT utilizes ultrasonic waves. High-frequency ultrasonic waves are produced by the transducer and directed towards the test material. In ultrasonic testing, frequency is a critical factor that affects the capacity to identify and describe material defects. The features of the test material and the particular requirements of the inspection are taken into consideration when choosing an acceptable frequency.

2.1.1 (c) Wavelength

In UT, the wavelength is a fundamental concept related to the characteristics of ultrasonic waves. The wavelength (λ) of an ultrasonic wave is the distance between two consecutive points in a wave that is in the same phase. For example, from one peak to the next peak or from one trough to the next trough. The relationship between wavelength, frequency (*f*), and the speed of sound (*v*) in a material is described by the formula:

$$\lambda = \frac{v}{f} \qquad \text{Equation 2.2}$$

Higher frequencies that have shorter wavelengths are typically used for inspecting thinner materials or detecting smaller defects, while lower frequencies that have longer wavelengths are used for inspecting thicker materials or when deeper penetration is needed.

2.1.2 Concept of Detection

The material that will be examined transmits sound. The defect detector shows the sound that was reflected in the probe. The defect detector can show the distance that the sound travelled. The signal from the back wall echo can be seen on the defect detector. It is possible to measure the material's thickness from the first pulse signal to the backwall echo signal.

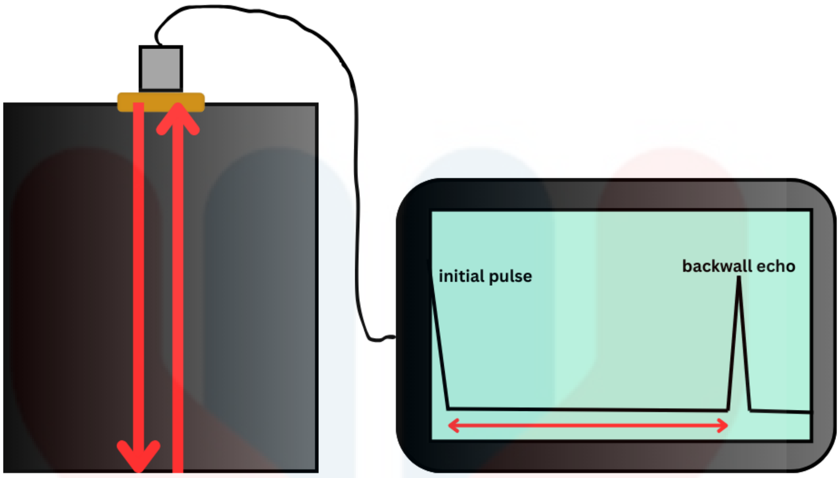


Figure 2.1: Illustration of sound reflected to probe.

In addition, the presence of a defect in the sample appears on the flaw detector screen less distant from the bottom of the material when the material is imperfect. Defect signal is the term for it. Depending on the kind of defects, the defect signal provides a representation of wave formation. The depth of the defects may be read by using the screen marker as a reference.

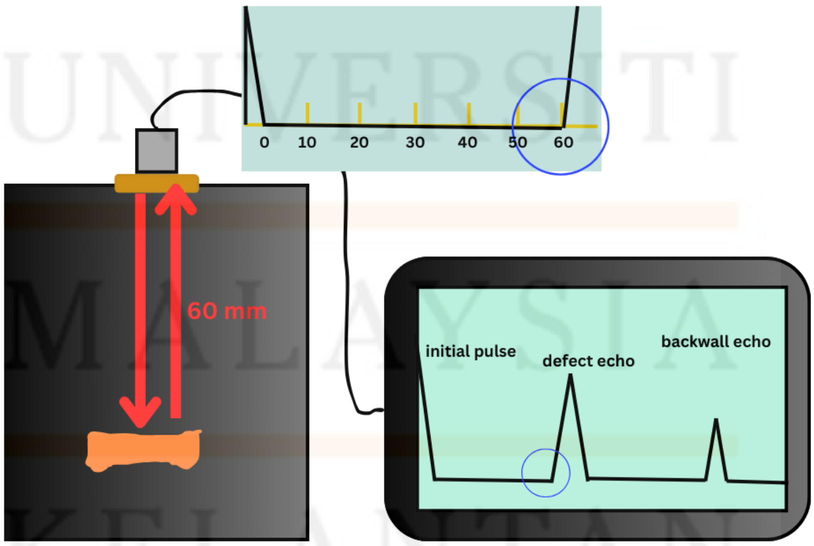


Figure 2.2: Illustration of sound reflected when a defect occurs.

The signal for thickness or depth measurement will be more to the left of the screen the closer the reflector is to the material's surface. Sound travels less distance through thinner materials. An ultrasound transducer connected to a diagnostic device is passed over the sample being examined during an ultrasonic test. Usually, a couplant keeps the transducer and sample apart.

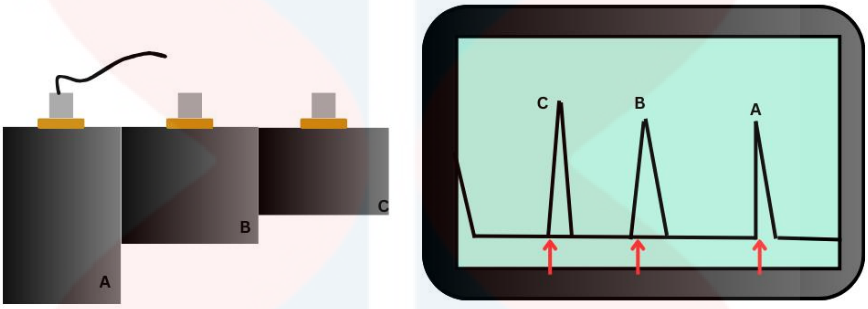


Figure 2.3: Illustration of sound reflected in different thicknesses.

2.1.3 Pulse Echo Method

The method most commonly used in the UT of materials is pulse echo. When an echo is received before the back-wall echo, it indicates the presence of a defect. The transmitter and receiver probes are on the same side of the sample. The cathode ray tube (CRT) screen is calibrated to display the difference in distance between the specimen's back wall echo and the time of echo arrival. As a result, a defect's location can be precisely determined.

2.1.4 Angle Beam Technique

Ultrasonic waves are transmitted into a test sample at a predefined angle to the test surface using the angle beam technique. Defects whose orientation is unsuitable for identification by normal beam technique are located using transverse waves at different angles of refraction between 35º and 80º.

2.1.4 (a) Snell's law

In angle beam testing, the longitudinal beam passing through the wedge or couplant is refracted when the sound beam enters the test object if the ultrasonic velocities in the liquid used in immersion testing or the wedge material used in contact testing differ from the ultrasonic velocities in the test sample. An equation called Snell's law can be used to calculate incident or refracted angles.

According to Snell's law, the velocity of sound in the first medium is equal to the velocity of sound in the second, and the sine of the angle of incidence in the first medium is equal to the sine of the angle of refraction in the second medium. Snell's law is expressed mathematically in the equation below:

$$\frac{\sin\theta_I}{\sin\theta_R} = \frac{V_I}{V_R} \qquad \text{Equation 2.3}$$

where θ_I is the incident angle from normal of the beam in the liquid or wedge, θ_R is the angle of the refracted beam in the test material, V_I is the velocity of the incident beam in the liquid or wedge and V_R is the velocity of the refracted beam in the test object.

Trigonometric tables are needed for computations involving angles of incidence or refraction. Decimal fractions are used to represent the sine (sin) ratios. A common unit of measurement for velocity is centimetres per microsecond (cm/µs). To convert cm/µs units to (cm/s) x 10^5 units, shift the decimal point one place to the right. To get cm/s, multiply in./s by 2.54. For both longitudinal and shear waves, angular connections between media can be found using Snell's law.

2.1.5 Beam Index Point (BIP)

The beam index point is the point at which the centre of the sound beam exits from the wedge, often used as a reference point for distance measurements. Commonly available wedges have the nominal BIP marked on them, however, this can move slightly with wedge wear and small variations in acoustic properties, so many test procedures call for verifying the BIP as part of initial calibration. Observe the echo from the 100 mm radius of the block. The radius used depends on the calibration block that is used. Then, move the wedge forward and backwards and locate the point at which this echo peaks. The peak memory function available in most instruments can be used to draw the echo envelope for confirmation. Note that if velocity and zero calibration have not yet been performed, this peak will not appear exactly at the 100 mm point on the screen scale.

2.1.6 Ultrasonic Defect Sizing Technique

In UT, sizing techniques are employed to determine the size and location of defects within a material. There are a few common sizing techniques that are usually used in UT. Each sizing technique has its advantages and limitations, and the choice depends on factors such as the type of testing material, the size and nature of defects, and the required accuracy of sizing.

2.1.6 (a) Amplitude

The simplest technique for correlating the amplitude of the signal with the magnitude of the defect is this one. Usually, a calibration curve is constructed that connects the signal amplitude to the area or size of known flat bottom holes. The size of defects is estimated using this curve. The technique is limited to defects with sizes less than the diameter of the beam.

2.1.6 (b) dB Drop

This is a typical ultrasonic testing procedure. This method involves moving the UT probe across the fault and measuring the 6 dB drop points. This measurement has to do with how big the defects are. In general, the technique works for defects bigger than the beam size. The technique measured beam width and large defects when applied to defects smaller than the beam size.

2.1.6 (c) Diameter Amplitude Correction (DAC)

DAC curve is used to plot the difference in amplitude between reflectors of the same size at increasing distances from the transducer. As the sound beam passes through the test piece, these reflectors provide echoes whose amplitude in the far field usually decreases with distance because of attenuation and beam spreading. Beam spreading, nearfield effects, and material attenuation are all graphically compensated for by a DAC curve. Regardless of their depth or distance, reflectors of the same size as those used for calibration will always provide echo amplitudes that match the curve height in a DAC configuration. In a similar vein, echoes above or below the curve will be produced by reflectors that are larger or smaller than those used for calibration.

2.1.6 (d) Time Varied Gain (TVG)

A similar method of presenting that makes up for the same acoustic factors as DAC is TVG. TVG increases gain as a function of time (sound path length) to bring all of the reference echoes to the same height, usually 80%, as opposed to sketching a curve across the display that follows the reference reflector peaks downward as sound is attenuated. Though a single gain number is usually provided, it's crucial to remember that on a TVG display, instrument gain changes across the screen. Nowadays, a lot of flaw detectors let the user switch between TVG and DAC displays in one configuration.

2.1.7 Advantage

One of the primary advantages of UT is its high sensitivity. UT can detect small cracks or defects that may not be visible to the naked eye, making it an invaluable tool for identifying hidden flaws in a material. In addition, UT has a great depth of penetration, allowing it to inspect thick materials such as pipes, tanks, and other large structures. Another key advantage of UT is its speed. UT can be performed quickly, which is especially beneficial when testing large areas or structures. This can save time and money for companies that need to inspect materials regularly. Portability is another advantage of UT. Portable UT equipment is available, making it possible to perform inspections in the field or at remote locations. This means that materials and structures that are difficult to transport or access can still be inspected with ease. Finally, UT is highly versatile and can be used on a variety of materials, including metals, plastics, composites, and ceramics. This makes it an ideal testing technique for a wide range of industries, from aerospace to construction.

2.1.8 Limitation

Firstly, UT requires a smooth and flat surface to produce accurate results. Rough or irregular surfaces can interfere with the sound wave transmission and produce false readings. This means that materials or structures with uneven surfaces may not be suitable for inspection using UT. Secondly, UT requires a skilled technician who is trained in interpreting the results and identifying flaws or defects. The accuracy of UT results depends heavily on the expertise of the technician performing the inspection. Any mistakes in interpretation can lead to false results and incorrect conclusions about the condition of the testing material. Thirdly, the accuracy of UT results can be affected by the properties of the testing material, such as its density, grain structure, and temperature. Materials with complex structures or properties may require more advanced UT techniques, which can be time-consuming and expensive. Fourthly, UT is not suitable for inspecting materials or areas that are difficult to access or are located in confined spaces (Felice & Fan., 2018) This means that materials or structures that are not easily accessible may require a different testing technique or may not be able to be inspected at all. Finally, the cost of UT equipment can be high, and the expense of training and certification for technicians can add to the overall cost. This can make UT an expensive testing technique, particularly for smaller companies or projects with limited budgets.

2.2 Phased Array Ultrasonic Testing (PAUT)

PAUT is an advanced non-destructive testing technique used to inspect and evaluate the integrity of materials and structures. It utilizes ultrasonic waves to detect and characterize flaws, defects, or anomalies within the material being tested. Overall, PAUT offers advanced inspection capabilities, increased flexibility, and improved defect characterization, making it a valuable tool in non-destructive testing applications.

2.2.1 Concept of Detection

The phased array probe is made up of numerous small ultrasonic components that can be pulsed individually. A pattern of constructive interference is created by altering the timing, for as by pulsing each element sequentially along a row, to produce a beam at a specific angle.

2.2.1 (a) Phased Array Probe

A mosaic of transducer elements that allow the individual control of each element's excitation timing to generate certain desired effects, including beam steering or beam focussing.

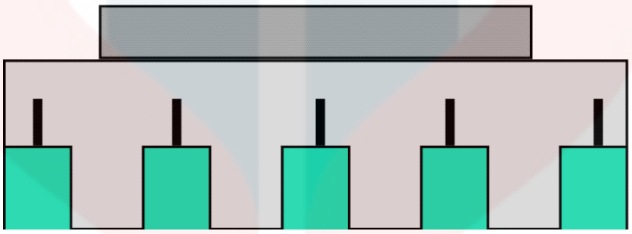


Figure 2.4: Illustration of phased array probe

2.2.2 Features of Phased Array

The ability to electronically modify acoustic probe characteristics through phased array technology is achieved by adding shifts in time to the signals that are sent to (pulse) and received from (echo) each array probe element. Phased array probes can be used with any UT technique for defect detection and sizing because detection applications are similar to UT techniques.

2.2.2 (a) Beam Steering

Beam steering involves adjusting the direction of the ultrasonic beam, allowing for better coverage of the inspected material. This is achieved by controlling the timing and amplitude of the signal sent to individual elements in the phased array probe.

2.2.2 (b) Beam Focusing

Beam focusing, on the other hand, concentrates the ultrasonic energy at a specific depth within the test material. By adjusting the time delay of the signals sent to each transducer element, the waves can be focused at a desired point. This enhances the resolution and sensitivity of defect detection, improving the overall performance of the inspection.

2.2.2 (c) Focal Law

A collection of computed time delays needed to excite an array in a way that will produce a wavefront with a predefined direction and depth focus is referred to as a focal law. It is the result of combining element gain, element number, and element delay. Several local laws are needed for different angles or depths of focus, and these are usually produced inside the phased array device. Time delay calculations made manually are extremely difficult, if not impossible. This task will be completed by the phased array instrument's powerful software and quick processor. The operator only needs to enter the desired angle and depth of focus. Instruments are used to apply the necessary focal law.

2.2.3 Advantage

One of the key advantages of PAUT is its improved inspection capability. PAUT can inspect a large area in a single scan, which significantly reduces inspection time and cost. This can be particularly beneficial in large structures or components, such as pipelines or aircraft, where UT techniques can be time-consuming and labour-intensive. Additionally, the technique allows for the detection of smaller defects with high accuracy (Taheri & Hassen., 2019), providing a higher probability of detecting defects that may not be visible using UT techniques. Another significant advantage of PAUT is its enhanced data interpretation. PAUT produces a visual representation of the data, making it easier to interpret the results. This can aid in the identification of defects that would have been missed using UT techniques (Javadi et al., 2020). The visual representation of the data also allows for easier communication between technicians, engineers, and other stakeholders, enabling faster decision-making.

PAUT is also highly accurate and can detect and measure the size and shape of defects with a high degree of precision. This is particularly useful in detecting planar defects, such as cracks, which can be challenging to detect using UT techniques. The ability to accurately measure defects can help engineers determine the severity of the defect and make informed decisions about repair or replacement. Finally, PAUT can be performed with minimal surface preparation, as the ultrasonic waves can penetrate through surface coatings and contaminants, such as rust, grease, and paint. This can save time and reduce costs, as there is no need to remove surface coatings before performing the inspection.

2.2.4 Limitation

One significant limitation of PAUT is the cost of equipment. PAUT equipment can be expensive, which can limit its accessibility for smaller companies or those with a limited budget. The cost of the equipment may also be a barrier to adopting the technique for companies that do not have a consistent need for NDT services. Another limitation of PAUT is the requirement for skilled technicians with specialized training and certification to operate the equipment and interpret the data accurately. PAUT requires a high level of technical knowledge and understanding to set up and operate the equipment, as well as interpret the data produced. This can be a challenge for smaller companies or those with limited access to trained technicians. PAUT also requires a complex setup process that can be time-consuming and challenging, particularly for large and complex structures. This can add additional costs and time to the inspection process, which may not be feasible for companies with tight deadlines or limited budgets. Finally, PAUT has limited applications and is not suitable for inspecting highly attenuating or scattering materials, such as concrete or cast iron. This is because the ultrasonic waves will be significantly attenuated, reducing the depth of penetration and accuracy of the results. In these cases, alternative NDT techniques may need to be used to obtain accurate and reliable results.

2.3 Data Presentation

Information from ultrasonic testing can be presented in several different formats. There are more common formats used including A-scan, B-scan, C-scan, and S-scan.

2.3.1 A-scan

A scan (Amplitude Scan) is a basic form of ultrasonic testing that displays the amplitude of a single ultrasound pulse as a function of time. It provides a graphical representation of the ultrasonic signal, with the vertical axis representing the amplitude of the reflected signal and the horizontal axis representing the time (Jung, M. Jae, et.al, 2018). Relatively defect size can be estimated by comparing the signal amplitude to that from a known reflector. Meanwhile, reflector depth can be determined by the position of the signal on the horizontal sweep.

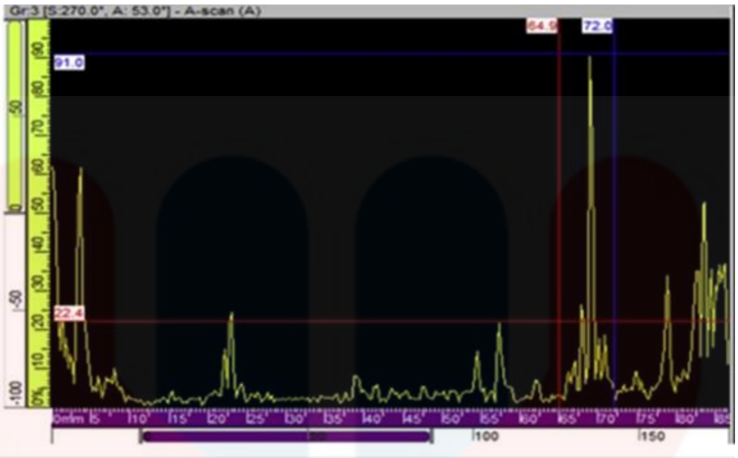


Figure 2.5: A-scan representation.

(Source: Jung, M. Jae et al., 2018)

2.3.2 B-scan

B-scan (Brightness Scan) is a two-dimensional cross-sectional display of the ultrasonic signal (Jung, M. Jae, et al 2018). It provides a horizontal view of the inspected material, allowing for the identification and measurement of flaws, thickness variations, and other internal structures. In the B-scan, the ultrasonic transducer is moved along the surface of the inspected material, and the resulting signals are displayed as a continuous line representing the profile of the inspected section.

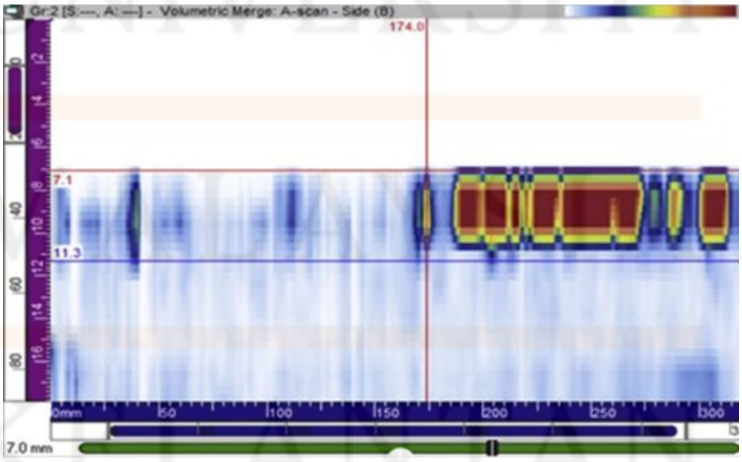


Figure 2.6: B-scan representation.

(Source: Jung, M. Jae et al, 2018)

2.3.3 C-scan

C-scan (Computer Scan) is a planar representation of the ultrasonic signal that provides a visual display of the inspected area (Jung, M. Jae, et al 2018). It is commonly used for mapping and imaging purposes, especially when evaluating large or complex structures. In C-scan, a grid or raster pattern is applied to the surface of the material, and the ultrasonic transducer is moved along this pattern. The resulting signals are recorded and processed to create a two-dimensional image, where each pixel represents a specific location on the material.

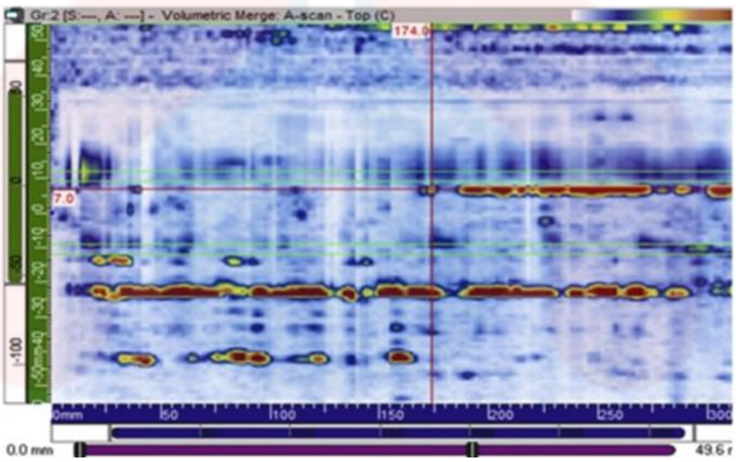


Figure 2.7: C-scan representation

(Source: Jung, M. Jae et al, 2018)

2.3.4 S-scan

S-scan (sector scan) is a specialized technique used in phased array ultrasonic testing (PAUT). It involves using an array of transducer elements to steer and focus the ultrasonic beam in a specific direction. The S-scan image is a sector-shaped representation that shows the coverage of the ultrasonic beam over a range of angles and depths. It provides information about the orientation and location of defects. S-scan is particularly useful for inspecting complex geometries, such as welds, where the beam angle and focus need to be adjusted to effectively inspect different regions.

2.4 Probe Angle

Probe angle refers to the angle at which an ultrasonic or phased array probe is oriented relative to the surface being inspected. The probe angle can have a significant impact on the ability to detect and characterize defects in materials or structures. Different probe angles are used depending on the type of material being inspected and the type of defects that are expected. In general, a lower angle provides better sensitivity to surface-breaking defects, while a higher angle provides better sensitivity to defects that are located deeper within the material.

2.4.1 Probe Angle of 45º

A probe angle of 45 degrees is commonly used in UT and PAUT for the inspection of welded joints. This angle allows the ultrasonic waves to be transmitted through the weld at an angle that is perpendicular to the expected orientation of defects, such as cracks or lack of fusion. This orientation provides a better opportunity to detect and characterize these types of defects, as they will reflect the ultrasonic waves to the probe at a detectable level.

A 45-degree probe angle is a commonly used angle in ultrasonic because it allows for a good balance between sensitivity and penetration depth. It allows the sound beam to penetrate deeper into the material while still being able to detect defects located near the surface. The 45-degree probe angle is also useful for detecting defects that are located in the weld near the surface, as the angled beam can more easily penetrate these depths.

2.4.2 Probe Angle of 60º

A probe angle of 60 degrees is often used for the inspection of materials with a relatively flat surface, such as plates or sheets. This angle provides a compromise between sensitivity to surface-breaking defects and sensitivity to defects located deeper within the material. When using a 60-degree probe angle, the ultrasonic beam is emitted at a 60-degree angle to the surface of the material being inspected. The advantage of using a 60-degree probe angle for weld inspection is that it provides good sensitivity to defects located within the weld, such as lack of fusion, porosity, and cracks. The angle allows the ultrasonic beam to penetrate deep into the weld, providing good coverage of the weld volume. However, a 60-degree probe angle also has some limitations for weld inspection. The large beam spread at this angle can reduce the resolution of the inspection, making it difficult to detect smaller defects. In addition, the angle may not be suitable for detecting defects located close to the surface of the weld, as the ultrasonic beam may be reflected by the probe before it reaches the defect.

2.4.3 Probe Angle of 70º

A probe angle of 70 degrees is commonly used for the inspection of materials with a curved or irregular surface, such as pipes or tubing. This angle provides good sensitivity to defects located near the surface, while also allowing for inspection of the entire wall thickness. When using a 70-degree probe angle for weld defect detection, the sound waves are directed toward the base of the weld, which is where most defects are likely to occur. The 70-degree angle is useful for detecting defects such as lack of fusion, incomplete penetration, and porosity that are typically located at the bottom of the weld.

This type of probe angle is commonly used for inspecting materials with high attenuation, such as coarse-grained materials like cast iron, and for detecting near-surface flaws. The steep angle of incidence helps to minimize the attenuation of the ultrasonic waves as they propagate through the material and increase the sensitivity to near-surface flaws. However, the use of a 70-degree probe angle also has some limitations. The steep angle of incidence can cause the ultrasonic beam to refract or reflect away from the intended inspection area, reducing the accuracy and reliability of the inspection results. Additionally, the probe may need to be placed at a specific angle to obtain the desired inspection results, which can make the inspection process more challenging. However, it is important to note that the 70-degree probe angle may not be suitable for detecting defects that are located closer to the surface of the material.

2.5 Defects

Defects are undesirable features or conditions in a weldment that can compromise its quality, strength, and performance. Defects in weldments can be caused by a variety of factors, such as improper welding technique, poor material selection, or inadequate preparation of the workpiece. Ultrasonic testing (UT) is a non-destructive testing method that uses high-frequency sound waves to detect and characterize internal defects or discontinuities in materials. Two common types of defects encountered in ultrasonic testing are planar defects and volumetric defects. Planar defects are discontinuities that occur along a two-dimensional plane within the material. These can include cracks, delamination, and laminar discontinuities. Ultrasonic waves are typically transmitted into the material, and when they encounter a planar defect, a portion of the energy is reflected to the transducer. The reflected signals are analysed to determine the location, size, and nature of the defects. A common example of a planar defect is a crack in a metal weld. If there is a crack running along the weld, ultrasonic waves can be used to identify and evaluate the crack's characteristics.

Furthermore, volumetric defects, also known as three-dimensional defects, are irregularities distributed within the volume of the material. This category includes voids, porosity, and inclusions. Ultrasonic waves passing through a material will experience changes in amplitude and velocity when they encounter volumetric defects. These changes are detected and analysed to identify the size, shape, and location of the defect within the material. Volumetric defects can be found in castings, where irregularities such as air bubbles or other inclusions may be present. Ultrasonic testing helps to assess the integrity of the casting by detecting and characterizing these internal volumetric defects.

2.5.1 Slag Inclusion

Slag inclusion is a common welding defect that occurs when the molten metal solidifies and entraps small particles of slag, which is a non-metallic material that forms during the welding process. Slag is created when impurities in the metal, such as oxides, react with the flux that is used to protect the weld from atmospheric contamination (Singh., 2016). When slag is trapped in the weld, it can weaken the joint and reduce its overall strength. Slag inclusions can also lead to corrosion and other forms of damage to the weld, which can cause it to fail prematurely. In some cases, slag inclusions can be visible to the naked eye, while in other cases they may be hidden beneath the surface of the weld.

Slag inclusions can occur for a variety of reasons, including improper welding technique, incorrect welding parameters, and insufficient cleaning of the base metal before welding. To prevent slag inclusions, it is important to use the correct welding technique, ensure that the base metal is clean and free of impurities, and use the appropriate welding parameters, such as welding current and voltage, travel speed, and electrode size. If slag inclusions are detected in a weld, they can be removed using a variety of methods, including grinding, chipping, or re-welding the affected area. However, the best approach is to prevent slag inclusions from occurring in the first place by using proper welding techniques and parameters and ensuring that the base metal is clean and free of impurities.

Figure 2.8: Illustration of slag inclusion

2.5.2 Cracks

A crack defect is a type of imperfection or discontinuity in a material that occurs when a crack or fracture is present in the material. Cracks can form in various materials, including metals, ceramics, polymers, and composites, and can have different shapes and sizes. Cracks can have a significant impact on the strength, durability, and performance of a material and can lead to catastrophic failure if not detected and repaired.

In welding, a crack defect is one of the most significant types of defects that can occur. Welding involves the joining of two or more materials by melting them together, and if the welding process is not carried out correctly, it can lead to the formation of cracks in the weld area. Cracks in welds can occur due to various reasons, including improper preparation of the joint, excessive heat input, welding speed, and cooling rate. Cracks can be present in the weld metal or the heat-affected zone (HAZ) surrounding the weld (Singh., 2016), and they can be either longitudinal or transverse.

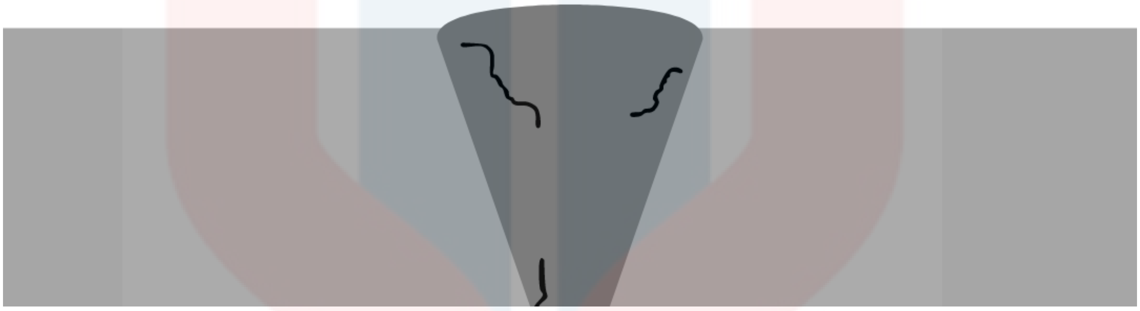


Figure 2.9: Illustration of the crack

2.5.3 Porosity

During the welding process, porosity can occur due to various factors, including contamination of the weld area, improper shielding gas, incorrect welding parameters, or inadequate cleaning of the welding surface. Porosity in welding refers to the presence of small voids or cavities within the weld metal, which are usually filled with gas, such as hydrogen, nitrogen, or oxygen (Singh., 2016). These voids can have a spherical or elongated shape and can occur either at the surface or within the weld. Porosity can weaken the weld and reduce its load-carrying capacity, leading to premature failure under stress. Porosity can have a significant impact on the material's mechanical properties, as it reduces the material's strength and increases its susceptibility to failure under load. In some cases, porosity can also lead to leaks, which can be dangerous in applications where the material is used to contain fluids or gases under pressure.

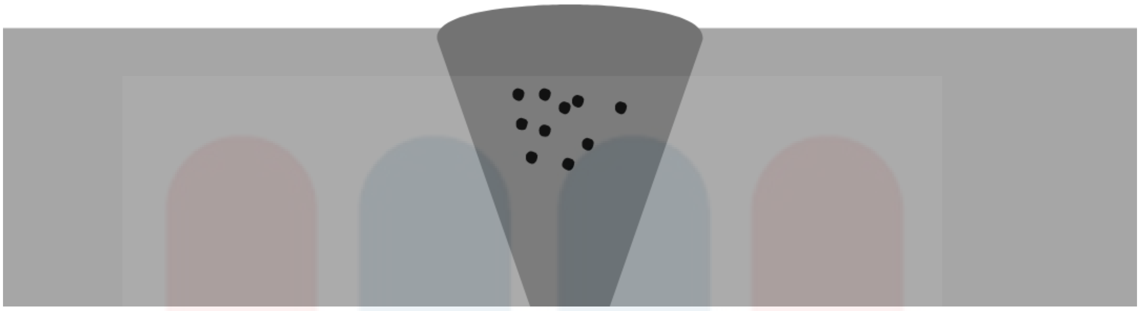


Figure 2.10: Illustration of porosity

2.5.4 Lack of Fusion

Lack of fusion is a type of welding defect that occurs when the weld bead does not properly fuse with the base metal or previous weld pass, resulting in an incomplete or weak joint (Singh., 2016). This defect can occur in any welding process where two or more materials are joined together using heat and pressure, such as arc welding, gas welding, or laser welding. A lack of fusion defect can occur due to a variety of reasons, including improper welding techniques, inadequate heat input, improper cleaning of the base material, or using the wrong welding parameters. The defect can also occur if there is contamination or oxidation present on the joint surface, preventing the weld material from fusing correctly with the base material.

Improper welding technique can lead to a lack of fusion defect when the welder does not properly control the heat input, welding speed, or electrode angle, resulting in a weld bead that does not properly penetrate or fuse with the base metal. Incorrect welding parameters, such as a low welding current or travel speed that is too fast, can also lead to a lack of fusion. When the welding current is too low or the travel speed is too fast, the weld bead may not have enough heat to properly melt and fuse with the base metal.

Figure 2.11: Illustration of the lack of fusion

2.6 The Sensitivity of The Detection

The sensitivity of detection refers to the ability of the testing method to detect small flaws or defects in the material being tested. In ultrasonic testing (UT), the sensitivity of detection is primarily determined by the frequency and power of the ultrasonic waves used to probe the material. Higher frequency waves can detect smaller defects but may not penetrate as deeply into the material. Higher power can also increase sensitivity but can also cause damage to the material being tested (Kim, Y. L et al., 2021).

In phased array ultrasonic testing (PAUT), the sensitivity of detection is determined by the number and arrangement of transducers used in the testing process. The transducers are used to emit and receive ultrasonic waves that are used to create an image of the material being tested. By using multiple transducers, the method can create a more detailed image of the material (Lopez et al., 2019), which can help to detect smaller flaws and discontinuities. However, the sensitivity can be affected by various factors such as the type of material, the geometry of the object being tested, and the skills and experience of the technician performing the test.

2.7 Wave Familiarization

Wave familiarization is an important aspect of NDT inspection as it helps the inspector identify potential issues with the weld before they occur. In NDT inspection, wave familiarization typically involves analyzing the various types of waves produced during welding and understanding how they can be used to detect potential defects. Wave familiarization is important in this process as the inspector must understand the different types of waves that can be produced and how they interact with the material being inspected.

On the other hand, detecting welding defects in NDT involves using specialized techniques and equipment to examine the weld for defects that may have occurred during the welding process. This can include using methods such as ultrasonic testing, magnetic particle inspection, radiography, and visual inspection. These techniques can identify defects such as cracks, porosity, lack of fusion, and other irregularities that may affect the strength and durability of the weld.

CHAPTER 3

MATERIALS AND METHODS

3.1 Material and Equipment

In this study, artificial test specimens used in this research which test specimen has different defects including slag inclusion, crack, porosity, and lack of fusion. In the context of welding, an artificial defect refers to a deliberately created flaw or imperfection in a sample weldment. Artificial defects are introduced during the welding process to simulate common welding defects that can occur in real-world applications. The sample used for testing has a thickness of 20mm and dimensions of 300mm in length and width, respectively. The material used is carbon steel (Figure 3.1).

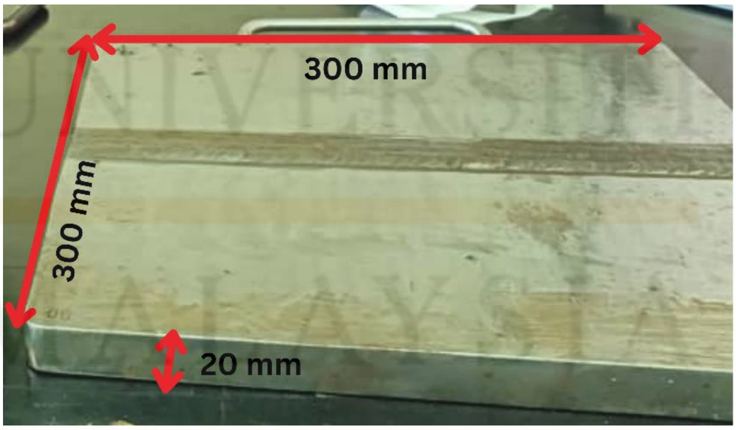


Figure 3.1: Measuring of sample

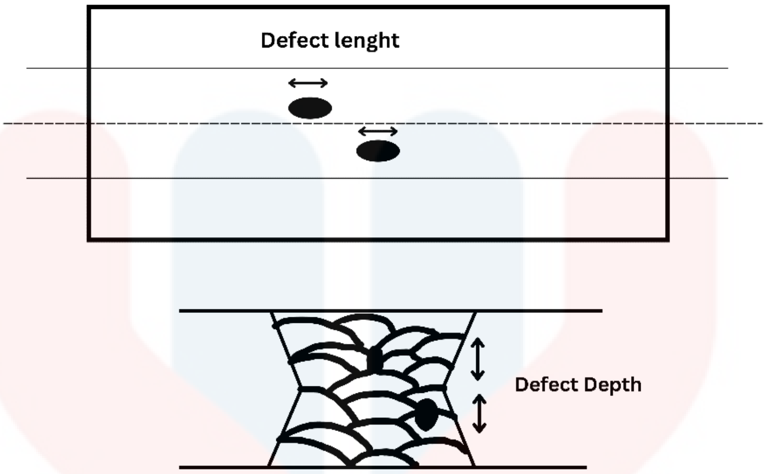


Figure 3.2: Illustration of a top view of the sample

Ethanol 70% was used to clean the surface of the sample. Then, grease was used as a couplant medium that was applied between the transducer and the surface of the sample. That is to ensure accurate readings. The flaw detector generates high-frequency sound waves and receives the echoes reflected from the test. For UT, the flaw detector uses Epoch LTC Olympus Meanwhile for PAUT uses OmniScan X3. Besides, probe angles 45º, 60º, and 75º were used with 2MHz frequency. PAUT uses a different design of probe angle because PAUT has multiple crystal elements so PAUT does not use a single probe angle. These devices emit ultrasonic waves into the material and receive the reflected signals. V2 and IIW calibration blocks as reference standards were used to calibrate the flaw detector and verify the accuracy of measurements.

3.2 Methods

Ultrasonic Testing (UT) and Phased Array Ultrasonic Testing (PAUT) are used for defect detection in test weldment. After the equipment is set up for both NDT techniques, the surface of the weldment must be cleaned from any contaminant that will affect it during inspection. Finally, after getting the result from the flaw detector screen, the wave formation that was displayed was used to compare from different angles that are used for defect detection.

3.2.1 Calibration

3.2.1 (a) Ultrasonic Testing (UT)

Before testing, the equipment needs to be calibrated. This involves adjusting the equipment settings to ensure accurate measurement and interpretation of the ultrasonic signals. Calibration typically involves using reference standards with known flaw sizes to verify the accuracy of the equipment. This involves setting the appropriate parameters such as sound velocity, gain, and probe frequency based on the testing material and the desired inspection requirements. Apply a thin layer of grease as a couplant to the surface of the V2 block. This helps to ensure good acoustic coupling between the transducer and calibration block.

Firstly, after plugging in the flaw detector machine. Press the system menu and set the parameters. Then, press again to set dB and access the base to set velocity. Velocity depends on the type of material used. Furthermore, setting zero calibration to zero and then setting up the angle degree depends on the probe angle used during calibration. Then set up the range, thickness, and gate. Finally, move the probe angle until gets a higher wave. Then adjust the zero calibration to get an accurate position. Calibration block use is a V2 type. So, this calibration block has two radii which are 25mm and 50mm. and range can set up to 100.

3.2.1 (b) Phased Array Ultrasonic Testing (PAUT)

Every single beam that is utilized during the inspection needs to be calibrated to assess the distance and adjust for amplitude over the sound path that is used. This will cover the necessary adjustment for the impacts of wedge attenuation and wedge sound path change.

(i) Velocity Calibration

First, verify that all parameters in the focal law are accurate, including scan types, material specifications, focus depth, angle sweep, probe type, wedge type, and angle resolution. Choose the angle beam cursor and position it to display the 45-degree angle of refraction or the minimum angle for sectional scanning in the A-scan display. Utilize the 100mm radius on the IIW calibration block, adjust the sound path range to 300mm, and ensure the display shows the 2nd back wall echo (BWE) of the 100mm radius at a 200mm sound path distance (SPD). Fine-tune the probe for peak signal amplitude. Set the acquisition gate to cover the envelope signal and peak amplitude of the 100mm SPD, capturing it as the first calibration point. Repeat the "set acquisition" step for the 2nd BWE to complete velocity calibration. Verify that the material velocity falls within acceptable tolerance limits.

(ii) Wedge Delay Calibration

Correct for the delay between transducer firing and sound entering the test piece for all focal laws, similar to zero backwards in ultrasonic testing (UT). This can be achieved using a reflector of known depth or known sound path. Initially, position the probe on a basic calibration block to maximize the amplitude from the 1.5mmØ SDH at a 15mm depth. Set the sound path range to 50mm and place the acquisition gate around the SDH signal. Set the gate start and width such that each focal law's SDH measurement can be obtained. Acquire the SDH signal for each focal law by moving the probe forward and backwards. Move the probe gently, use a guide to avoid skew, and make several passes over the reflector to get an accurate curve. Once all focal laws are calibrated and fall within tolerance, accept the calibration, and the wedge delay calibration is concluded. Ensure that the wedge delay indication remains within the gated region throughout the calibration process.

(iii) Sensitivity (Gain) Calibration

The sensitivity (gain) calibration standardizes the amplitude response of a specific reflector across all focal laws (angles), ensuring that the reflector's amplitude appears consistently at the same screen height regardless of the angle (focal law) used for inspection. Start by placing the probe on a calibration block to achieve the maximum amplitude at a specific depth. Set the sound path range and position the acquisition gate around the SDH signal. Set the gate start and width appropriately to enable the SDH measurement to obtain each focal law. Commence acquiring the SDH signal for each focal law by moving the probe forward and backwards. Once all focal laws are calibrated and fall within the established tolerance, accept the calibration, marking the completion of the wedge delay calibration. Examine the calibrated distances and sensitivities by varying the focal laws from 45 to 70 degrees.

3.2.2 Scanning

3.2.2 (a) Ultrasonic Testing (UT)

The transducer is placed on the surface of the material. The location and orientation of the probe depend on the specific testing requirements and the geometry of the material. The setting parameter is just like the calibration step but during inspection can adjust a few parameters such as zero and delay to get a more accurate result. Below is an illustration figure for crack defects using different probe angles.

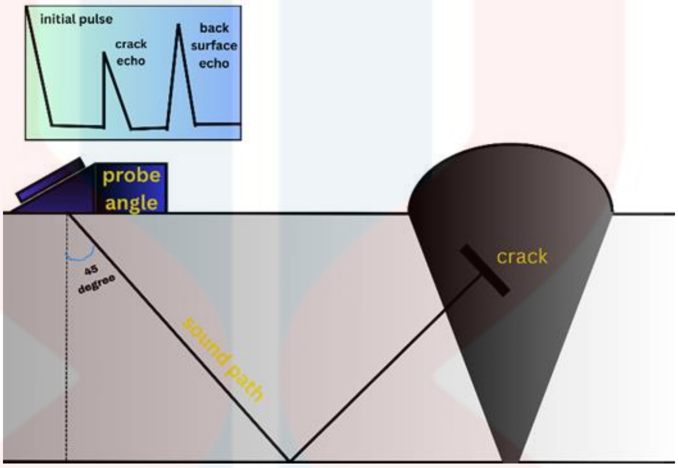


Figure 3.3: illustration of detection using a 45˚probe angle.

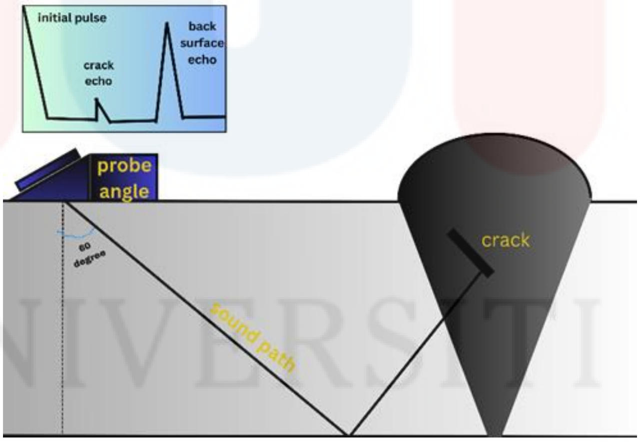


Figure 3.4: Example of detection using 60˚probe angle.

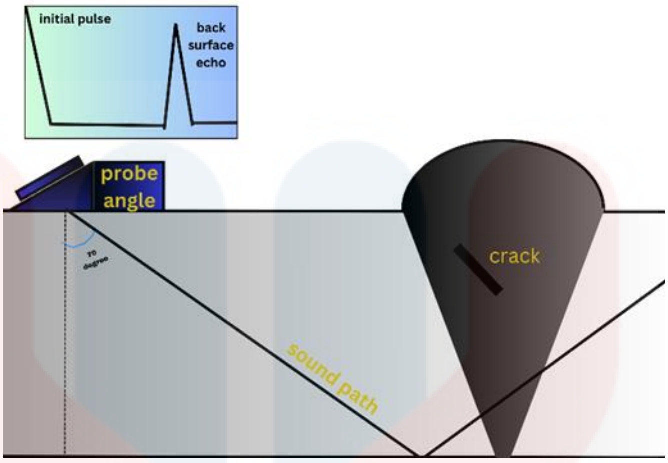


Figure 3.5: Example of detection using 70˚probe angle.

3.2.1 (b) Phased Array Ultrasonic Testing (PAUT)

A transducer, comprised of multiple small elements that can be individually controlled, is employed to generate ultrasonic waves. These elements are electronically excited in a regulated manner, forming a manipulability wavefront to achieve specific beam characteristics. Phased array technology enables the electronic control of the ultrasonic beam's angle and direction. By adjusting the timing and amplitude of signals sent to each transducer element, the beam can be steered and focused at varying depths and angles within the inspected material. The ultrasonic beam is systematically scanned across the material, leveraging precise control over its direction and focus to cover specific areas effectively with a single probe. Upon encountering a boundary or defect within the material, the ultrasonic waves are partially reflected to the transducer, whose elements double as receivers, detecting the reflected waves.

3.2.3 Post Cleaning

The remaining couplant shall be wiped from the surface after the examination. Choose a cleaning process that does not adversely affect the part.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Wave Analysis

Analysis of the displayed wave on the flaw detector screen is conducted for each type of defect under examination.

4.1.1 Crack

Usually, cracks are linear and irregular or jagged. In normal indications, damping in the transducer causes the right side of the signal to drop off quickly. However, because cracks are jagged, multiple returns occur, causing the screen signal to be much wider, thus producing a distinctive indication on the UT screen. Another effective way to determine that an indication is a crack is by the way the crack indication "walks" across the screen. As the sound beam starts to move across the crack, the spread of the sound beam causes the leading edge of the sound cone to reflect sound back well before the signal reaches its maximum. This results in a short or low-amplitude signal appearing on the right side of the screen.

As the transducer approaches the crack, more of the sound beam reflects, causing the signal height to increase and move towards the left side of the screen as the sound path becomes shorter. When the centreline of the sound beam, where the sound strength is greatest, reaches the base of the crack, the signal is usually at maximum strength. As the centreline clears the crack and the trailing edge passes the crack, the signal height decreases and moves to the left side of the screen until it disappears. Essentially, we see a wide short signal that grows in height as it moves to the left and then decreases in height until it disappears.

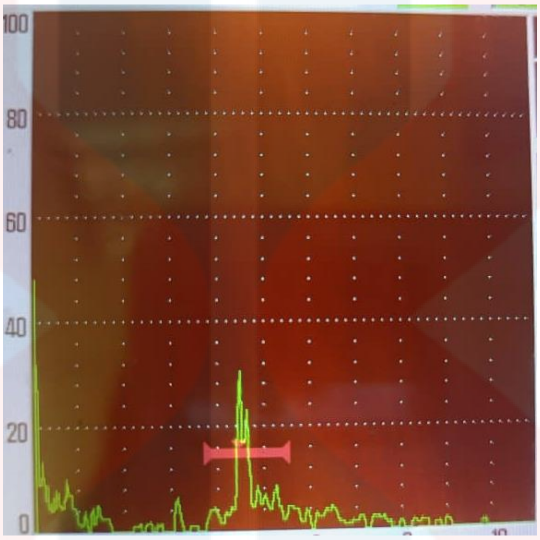


Figure 4.1.: A-scan representation for crack

4.1.2 Lack of Fusion

Lack of fusion is usually best seen ultrasonically in the second leg from the same side of the weld. Because the sound beam is coming up from the bottom surface, it tends to hit the lack of fusion more nearly perpendicular to the flat surface which gives the best reflection. So, the echo standing tall.

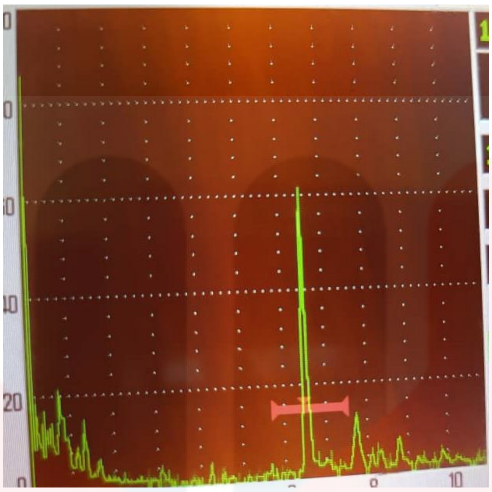


Figure 4.2: A-scan representation for lack of fusion

4.2 Wave Interpretation

Interpretation of waveform formation to determine the size and location of the defect including identifying the point of origin and endpoint where the wave is generated.

4.2.1 Calculation

The calculation of ultrasonic testing (UT) is performed using trigonometric formulas because the movement of waves in UT is based on trigonometry (Figure 4.3).

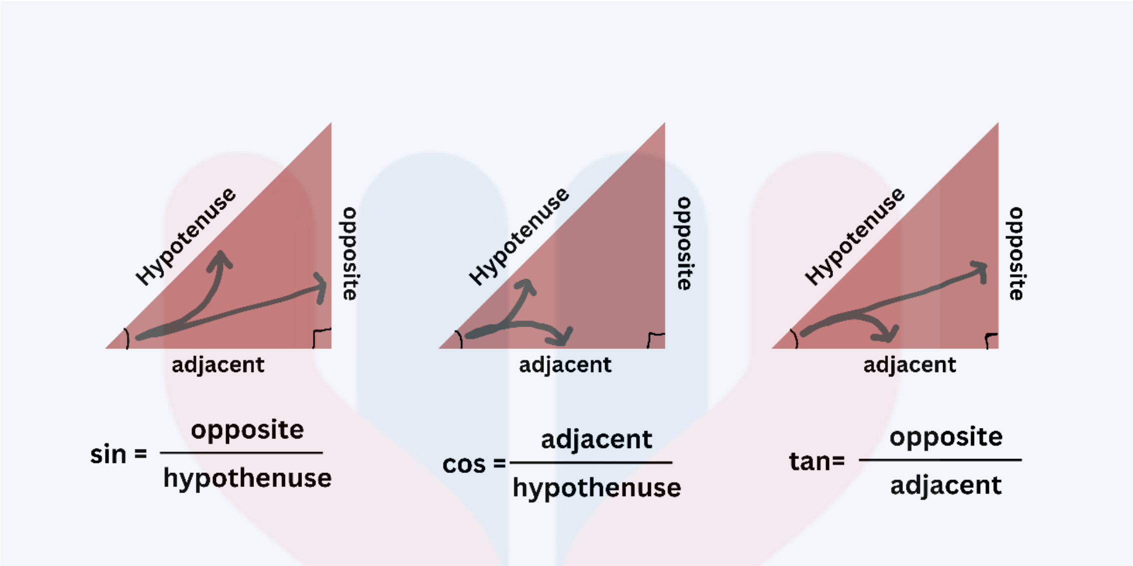


Figure 4.3: Formula of trigonometry

4.2.1 (a) Crack

According to Table 4.1, the defect depth for the crack type of defect obtained through trigonometric calculations with a probe angle of 45 degrees is 11.87 mm, while the surface distance from probe angle is 34.14 mm.

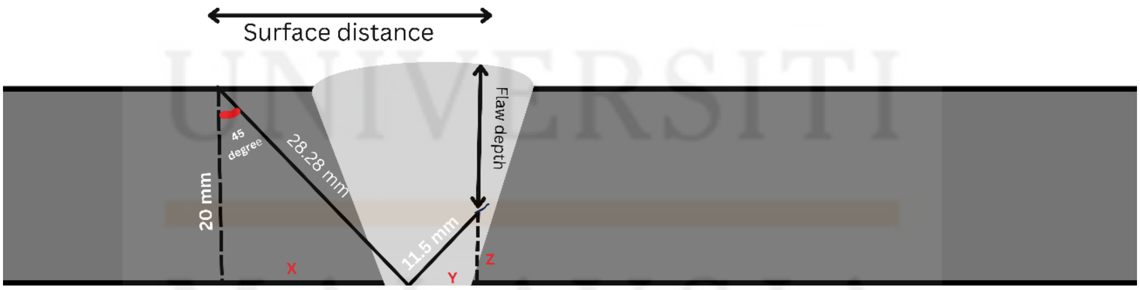


Figure 4.4: Illustration probe angle 45º of crack

Table 4.1: Calculation of defect depth and surface distance of crack using 45º

Probe Angle	Defect Depth (mm)	Surface Distance(mm)
45°	$\tan 45° = \frac{z}{8.13\ mm}$ $= 8.13\ mm$ $depth = 20\ mm - 8.13\ mm$ $= 11.87\ mm$	$\sin 45° = \frac{x}{28.28mm}$ $= 20\ mm\ (1st\ distance)$ $\cos 45° = \frac{y}{11.5\ mm}$ $= 8.13\ mm\ (2nd\ distance)$ $S.D = 20\ mm + 8.13\ mm$ $= 34.14mm$

The defect depth for a probe angle of 60 degrees is 17.5 mm, with a surface distance of 30.31 mm. The defect depth for a probe angle of 60 degrees is deeper compared to the probe angle of 45 degrees (Table 4.2)

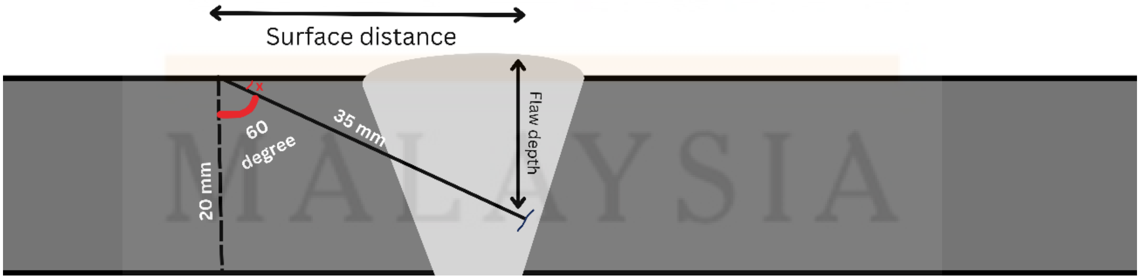


Figure 4.5: Illustration of probe angle 60º of crack

Table 4.2: Calculation of defect depth and surface distance of crack using 60º

Probe Angle	Defect Depth (mm)	Surface Distance(mm)
60°	$\cos 60° = \frac{depth}{35\ mm}$ $= 17.5\ mm$	$\tan 30° = \frac{17.5}{s.d}$ $= 30.31mm$

For a probe angle of 70 degrees, a defect depth of 19.95mm is obtained, with the defect located in the root area (Table 4.3). The surface distance for a 70-degree probe angle is greater compared to probe angles of 45 and 60 degrees.

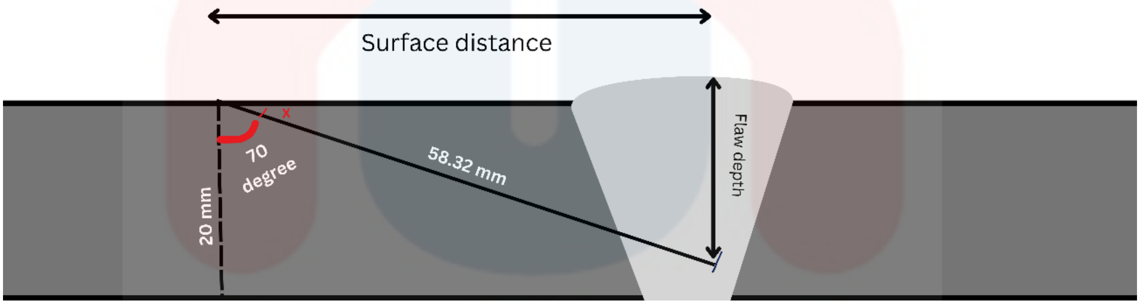


Figure 4.6: Illustration of probe angle 70º of crack

Table 4.3: Calculation of defect depth and surface distance of crack using 70º

Probe Angle	Defect Depth (mm)	Surface Distance(mm)
70°	$\sin 20° = \frac{depth}{58.32mm}$ $= 19.95\ mm$	$\sin 70° = \frac{s.d}{58.32\ mm}$ $= 54.80\ mm$

4.2.1 (b) Lack of Fusion

For the lack of fusion defect, at a probe angle of 45 degrees, the defect depth is 11.51 mm, while the surface distance is 28.49 mm (Table 4.4)

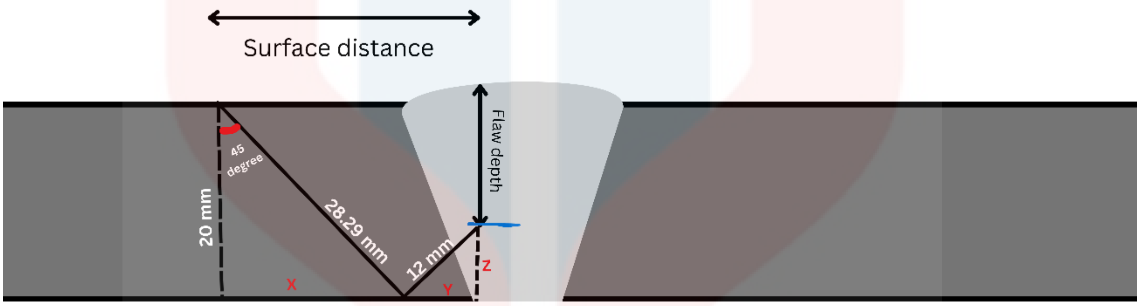


Figure 4.7: illustration of trigonometry of probe angle 45º (LOF)

Table 4.4: Calculation defect depth and surface distance of LOF using 45º

Probe Angle	Defect Depth (mm)	Surface Distance(mm)
45°	$\sin 45° = \frac{z}{12\ mm}$ $= 8.49\ mm$ $\text{f.d} = 20 - 8.49$ $= 11.51\ mm$	$\tan 45° = \frac{x}{20\ mm}$ $= 20\ mm\ (1st\ distance)$ $\cos 45° = \frac{y}{12\ mm}$ $= 8.49\ mm\ (2nd\ distance)$ $\text{S.D} = 20 + 8.49$ $= 28.49\ mm$

According Table 4.5, the defect depth for a 60-degree probe angle is 11.5 mm. This indicates that the defect depth for a 60-degree probe angle is the same as that for a

45-degree probe angle. However, the surface distance for the 60-degree probe angle is 49.36 mm.

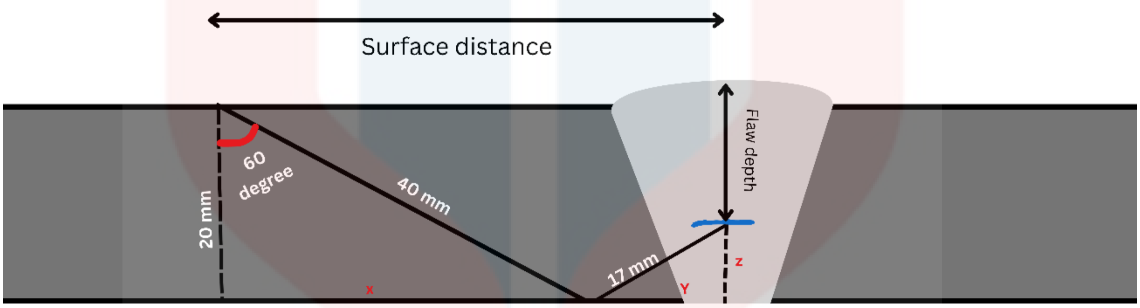


Figure 4.8: Illustration of trigonometry of probe angle 60º (LOF)

Table 4.5: Calculation defect depth and surface distance of LOF using 60º

Probe Angle	Defect Depth (mm)	Surface Distance(mm)
60°	$\sin 30° = \frac{z}{17\ mm}$ $= 8.5\ mm$ $\text{f.d} = 20 - 8.5$ $= 11.5\ mm$	$\tan 60° = \frac{x}{20\ mm}$ $= 34.64\ mm\ (1st\ distance)$ $\cos 30° = \frac{y}{17\ mm}$ $= 14.72\ mm\ (2nd\ distance)$ $\text{S.D} = 34.64 + 14.72$ $= 49.36\ mm$

For the 70-degree probe angle, the defect depth is 13.5 mm, and the surface distance is 72.79 mm. The difference in defect depth compared to the 60-degree and 45-degree probe angles is 2.0 mm (Table 4.6).

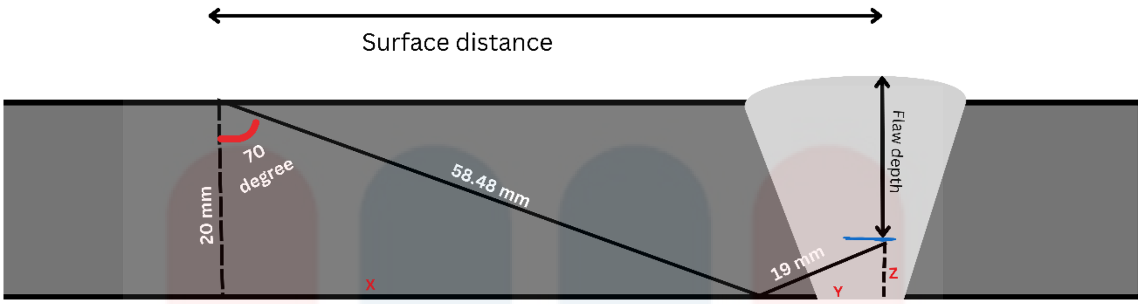


Figure 4.9: Illustration of trigonometry of probe angle 70º (LOF)

Table 4.6: Calculation defect depth and surface distance of LOF using 70º

Probe Angle	Defect Depth (mm)	Surface Distance(mm)
70°	$\sin 20° = \frac{z}{19\ mm}$ $= 6.5\ mm$ $\text{depth} = 20 - 6.5$ $= 13.5\ mm$	$\tan 70° = \frac{x}{20\ mm}$ $= 54.94\ mm\ (1st\ distance)$ $\cos 20° = \frac{y}{19\ mm}$ $= 17.85\ mm\ (2nd\ distance)$ $\text{S.D} = 54.94 + 17.85$ $= 72.79\ mm$

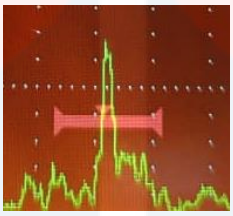
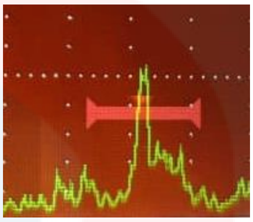
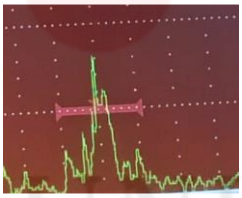
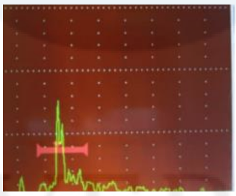
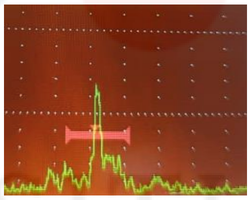
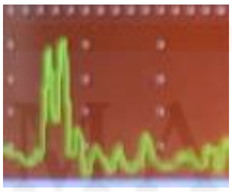
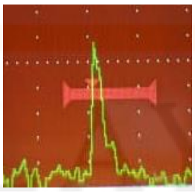
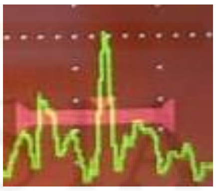
4.2.2 Size Defect

The amplitude method is used to measure size defects. Explanation about this method can refer to section 2.1.6.

4.2.2 (a) Crack

The largest detectable size for a crack defect is 11 mm, achieved using a 60-degree probe angle. Meanwhile, the second-largest size is indicated by a 70-degree probe angle, measuring 6 mm, followed by a 4 mm size for the use of a 60-degree probe angle (Table 4.7).

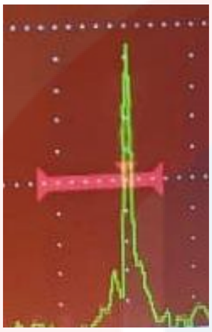
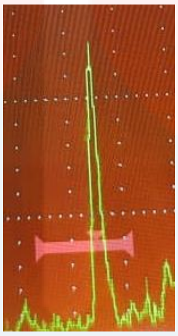
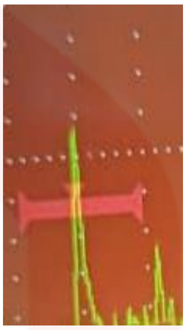
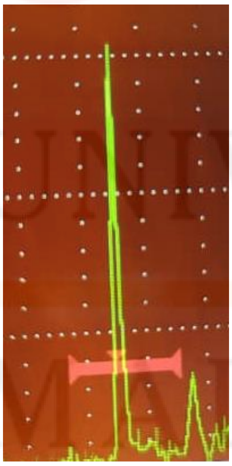
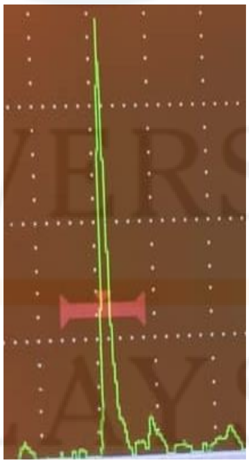
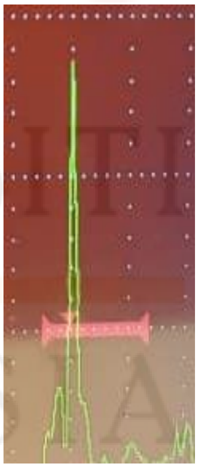
Table 4.7: Size of crack defect with different probe angle

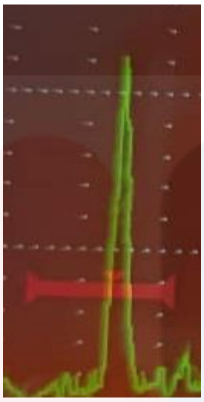
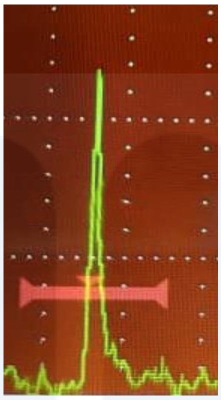
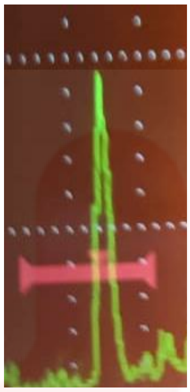
Probe Angle	Echo Formation			Size (mm)
45°	 Range: 62 mm	 Range: 64 mm	 Range: 66 mm	$size\ defect$ $= 66 - 62$ $= 4\ mm$
60°	 Range: 50 mm	 Range:55 mm	 Range: 61mm	$size\ defect$ $= 61 - 50$ $= 11\ mm$
70°	 Range: 68 mm	 Range: 70 mm	 Range: 74 mm	$size\ defect$ $= 74 - 68$ $= 6\ mm$

4.2.2 (b) Lack of Fusion

The largest detectable size for a crack defect is 15 mm, attained when employing a 60-degree probe angle. In contrast, the size is recorded as 10 mm for both 70-degree and 60-degree probe angles (Table 4.8).

Table 4.8: Size lack of fusion defect with different probe angle

Probe Angle	Echo Formation			Size (mm)
45°	 Range: 50 mm	 Range: 55 mm	 Range: 60 mm	$size\ defect$ $= 60 - 50$ $= 10\ mm$
60°	 Range: 45 mm	 Range: 52 mm	 Range: 60 mm	$size\ defect$ $= 60 - 45$ $= 15\ mm$

70°	 Range: 54 mm	 Range: 56mm	 Range: 64 mm	$size\ defect$ $= 64 - 54$ $= 10\ mm$

4.3 Effect of Probe Angle

The use of different probe angles has an impact on defect detection. Each probe angle is placed at a different location on the sample surface. This is done to generate wave formations for the detected defects. If the probe angles for all three angles are located in the same position, it is possible that the 45-degree and 70-degree probe angles may not be able to detect any defects within the weld metal. Therefore, when examining the wave interpretation in section 4.2, it can be observed that each use of a probe angle has a different surface distance. Each probe angle can detect defects but may have varying defect sizes.

4.4 Data Analysis (PAUT)

PAUT represents the result by three types of data representation. A-scan, B-scan, and S-scan.

4.4.1 Lack of Fusion (LOF)

Figure 4.10 shown a defect known as LOF. This defect is a type of planar defect. Through A-scan presentation, it can be interpreted as a lack of fusion due to the formation of waves that are vertical and straight. Identifying sidewall LOF poses a significant challenge, as the typical bevel angles in welded joints often do not align well with those used in ultrasonic testing. Consequently, the unfused sidewall may not produce a sufficiently strong signal amplitude for detection. Moreover, sidewall LOF may not be visible in the initial scan from the side of the defect or may appear as a permissible indication during a subsequent scan. Therefore, it is essential to inspect the weld from both sides whenever the part configuration allows. Even if signals seem acceptable but are detected along the weld's side, it might be necessary to adjust the wedge angles and re-scan the area to ascertain the presence of sidewall LOF. The location of the defect can be identified through the S-scan displayed. Through S-scan, this defect is identified as a lack of side wall fusion.

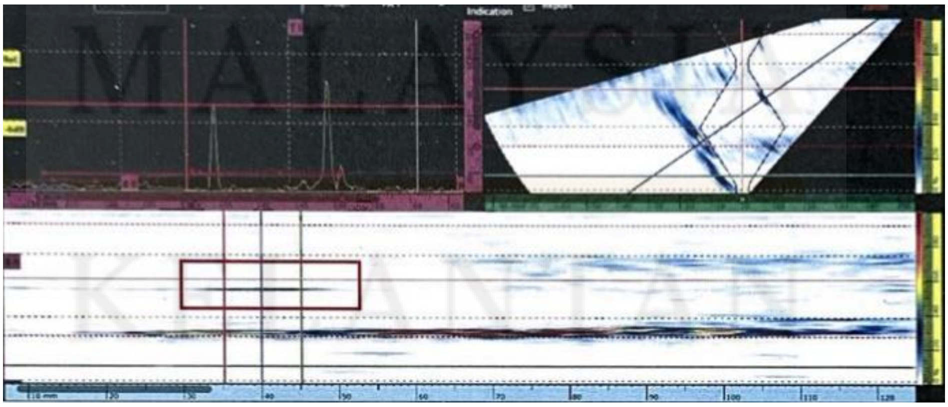


Figure 4.10: Data representation lack of fusion

4.4.2 Crack

Figure 4.11 shows a crack-type defect. A crack is also a planar defect. Through A-scan presentation, it can be interpreted as a crack due to the resulting wave formation. If the width of the UT screen is set at one full distance, the crack should start appearing right to the right of the midpoint and then descend from the screen close to a quarter of the distance between the main burst and the midpoint. If the crack starts from the scanning surface, the signal should run in from the right side of the screen and descend right to the right of the midpoint. This is a generalization, and the exact location will depend on the thickness of the material and will vary due to different sound paths. Therefore, it allows the operator to skip the crack in the first leg if the signal is very close to the scanning surface so that it appears as part of the main burst. The location of the defect can be determined through the displayed S-scan. In the S-scan, this defect is identified as a toe crack.

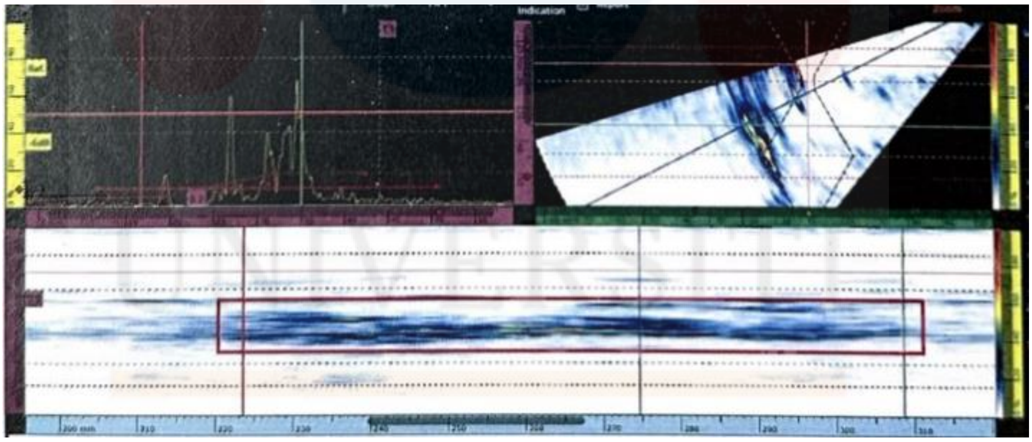


Figure 4.11: Data representation crack

4.4.3 Slag Inclusion

Figure 4.12 illustrates a defect known as a slag inclusion. Slag inclusion is also considered a volumetric defect. Through A-scan presentation, they can be interpreted as slag due to the distinctive wave formation they produce. To illustrate, when the transducer encounters a slag inclusion, the irregular shape causes the sound beam to strike it at various points simultaneously, resulting in a signal characterized by multiple peaks. As the transducer advances, the beam's centreline interacts with the contours more intensely, leading to fluctuations in the amplitude of each peak as the beam encounters reflection points. Consequently, the signal exhibits a pattern of alternating peaks, which fluctuate in height and subtly shift left or right as the scanning progresses. This distinct signal pattern, featuring alternating peaks, can be effectively demonstrated by halting the transducer when multiple peaks are maximized and then gently tilting it sideways at that position. Through S-scan, volumetric defects can be observed in significant numbers, but they are not porosity; rather, they are slag inclusions.

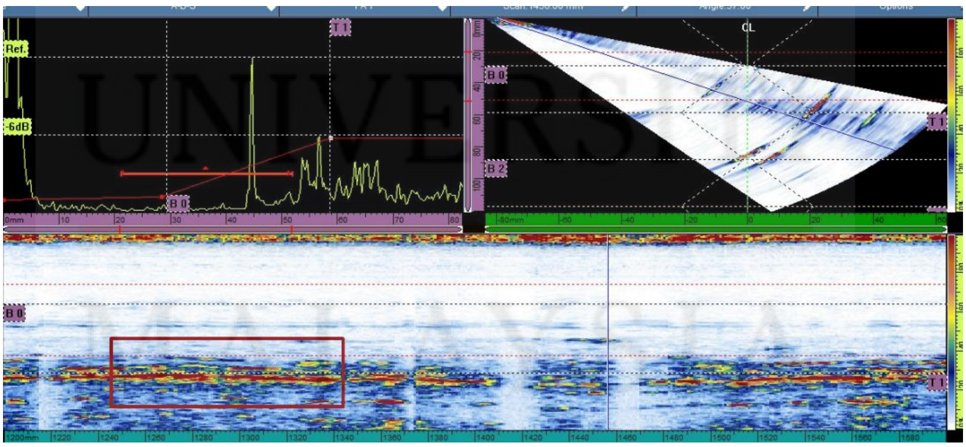


Figure 4.12: Data representation slag inclusion

4.4.4 Porosity

Figure 4.13 illustrates the porosity type of defect. Porosity is also a volumetric defect. Through A-scan presentation, it can be interpreted as porosity due to the resulting wave formation. Bias-shaped pores, like gas pores, are point sources, and sound waves are only reflected from them at a point where the sound wave strikes the hole perpendicular to its circumference. Since the pores have negligible length and their diameter is usually a very small percentage of the cross-sectional area of the sound wave, the signal returned from the pore is very slight, resulting in a highly discrete screen signal often with low amplitude. The effect of the sound waves reflected from the spherical shape provides distinct characteristics on the screen for porosity. The overall result is a single, narrow, and sharp signal that appears on the screen only at one location and then quickly disappears. There are some exceptions to this; if the pore is large or close to the surface being scanned, the signal may shift slightly to the left, usually 1 to 2 minor lines, before disappearing.

Again, the pore is a point source, and when the signal reaches its maximum, the observer will see that a slight forward or backward movement of the transducer, or slight oscillation of the transducer to the right or left, will cause the signal to disappear. In cases of clustered porosity or closely spaced pores, the screen display may show several very closely spaced signals that could be mistaken for slag inclusions. However, it is often possible to separate these individual signals, which will exhibit very tight or narrow traces and the location of each signal at one location without significant lateral movement, which generally does not occur with slag inclusions. Through S-scan, porosity defects can be observed in a circular shape. C-scan indicates that the existing porosity exhibits a type of linear porosity.

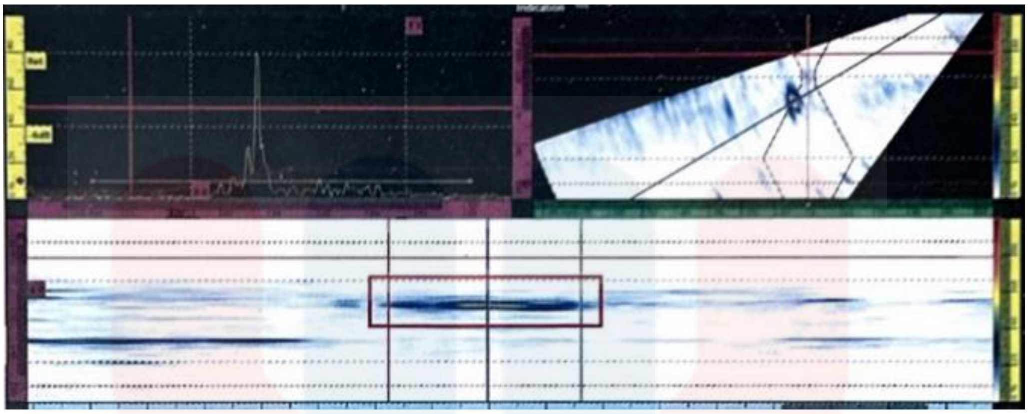


Figure 4.13: Data representation of porosity

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The aim of this study where to know the weld defect detection using Ultrasonic Testing (UT) and Phased Array Ultrasonic Testing (PAUT). The objectives were achieved, and the result obtained can be concluded:

i. The use of different probe angles of UT can affect the result of wave formation for the same defect in weld inspection.
ii. A suitable probe angle during weld inspection can enhance the detection of finer details in each defect.
iii. The location of a defect in a weld specimen can be one of the reasons for employing different probe angles.
iv. PAUT employs a single probe angle with a more feature-rich design compared to conventional UT.
v. PAUT can display a three-dimensional image of defects through sectorial scanning (S-scan) and B-scan for representation.

5.2 Recommendations

Ultrasonic Testing (UT) and Phased Array Ultrasonic Testing (PAUT) are non-destructive testing (NDT) methods that have been developed for several decades. They are employed to ascertain the presence of flaws or defects in materials. However, studies on the impact of probe angle in UT and PAUT inspections are infrequently reported. Consequently, several suggestions can be proposed for future inspections, including an increased focus on studying the effects of probe angles in UT and PAUT. From this research, it is recommended to determine the optimal angle for inspections based on material thickness and the location of the defect being sought. The use of PAUT may be preferable over UT due to its advanced features incorporated into the probe design. Nevertheless, UT is more suitable for beginners who wish to learn about inspections before delving into the complexities of PAUT.

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APPENDIX A

Ultrasonic Equipment

Practicing Ultrasonic Testing

APPENDIX B

Run examination at ReliaCraft Consultancy Sdn Bhd