

Non-Destructive Technnique That Uses Sound Waves To Detect Flaws in Materials

Lindo Rivaldi Butar-Butar¹, Kiki Dwi Putra², Brandon³, Fardin hasibuan⁴

Lindorbutarbutar@gmail.com, kikidwiputra05@gmail.com, brandonbrandon100200@gmail.com, fardin.hasibuan123456@gmail.com

^{1,2,3,4}Mechanical Engineering, Universitas Riau Kepulauan, Indonesia

*Corresponding author: Lindorbutarbutar@gmail.com

Paper History

Received: January 31st, 2025

Received in revised form: February 09th, 2025

Accepted: August 15th, 2026

Publish: August 31th, 2026

ABSTRACT

Non-destructive testing (NDT) is a crucial method for assessing the structural integrity of materials without causing damage. Among the various NDT techniques, the use of sound waves—such as ultrasonic testing—stands out for its precision and flexibility. This technique utilizes high-frequency sound waves to penetrate materials and detect defects such as cracks, voids, and inclusions. The method operates based on the interaction of sound waves with material boundaries, where imperfections reflect the waves, generating distinct signals. Advanced ultrasonic testing can provide detailed information on the size, location, and orientation of defects, enabling accurate material condition assessment. This abstract highlights the significance of sound wave-based NDT in industries such as aerospace, construction, and manufacturing to ensure safety, reliability, and cost efficiency. Further advancements in this technique can enhance accuracy and maintain structural integrity in critical applications.

KEY WORDS: *Non-Destructive Testing (NDT); Ultrasonic Testing (UT); Sound Waves; Material Integrity; Defect Detection; Structural Inspection; Crack Detection; Aerospace; Construction; Manufacturing.*

1.0 INTRODUCTION

Non-destructive testing (NDT) techniques play a crucial role in ensuring the safety, reliability, and integrity of materials and structures without causing damage to the tested components. Among various NDT methods, sound wave-based techniques, such as ultrasonic testing (UT), have become a cornerstone of modern material evaluation. This method utilizes high-frequency sound waves to detect defects, measure material thickness, and perform other analyses.

Ultrasonic testing operates by transmitting sound waves into a material and analyzing the reflected signals to identify inconsistencies such as cracks, voids, or inclusions. This technique is widely recognized for its accuracy and reliability

in material assessment. It has the capability to penetrate deep into different materials and is adaptable across various industries, including aerospace, manufacturing, and energy. By utilizing sound waves, technicians and inspectors can evaluate the safety and performance of critical components while minimizing downtime and ensuring operational stability.

A. Introduction

1. Ultrasonic Testing: Overview
2. Importance of non-destructive testing in maintaining product quality.
3. Basic principles of ultrasonic wave interaction with materials.
4. Advantages of ultrasonic testing over other methods.
5. Recent Developments in Ultrasonic Technology
6. Innovations in transducers and testing instruments.
7. Application of artificial intelligence in ultrasonic data

B. Analysis.

1. Current trends in ultrasonic testing applications in various industries.
2. Basic Theory Section
3. Ultrasonic Wave Generation and Propagation
4. Ultrasonic wave formation mechanism.
5. Types of ultrasonic waves (longitudinal, transverse).
6. Factors affecting wave velocity and attenuation.
7. Ultrasonic Wave Interaction with Defects
8. Mechanism of reflection, refraction, and diffraction of waves.
9. Types of defects that can be detected (cracks, pores, inclusions).
10. Relationship between defect size and ultrasonic signal

C. Test Method Section

1. Pulse-Echo Scanning Technique
2. Working principle and application of the technique.
3. Types of probes and couplings.
4. Analysis of A-scan, B-scan, and C-scan data.
5. Transmission Techniques
6. Measurement of attenuation and wave velocity.
7. Applications in thickness measurement.
8. Resonance Techniques
9. Measurement of coating and thin material thickness.

D. Data Analysis Section

1. Interpretation of Ultrasonic Signals

- Identification of defect types based on signal characteristics.
- Effect of noise and interference on signals.
- Calibration of Ultrasonic Systems
- Applicable calibration standards.
- Calibration procedures to ensure measurement accuracy

E. Application Section

- Ultrasonic Testing in Manufacturing Industry
- Applications in testing welds, castings, and composite materials.
- Ultrasonic Testing in Energy Industry
- Inspection of pipes, pressure vessels, and turbine

F. Components.

- Ultrasonic Testing in Other Industries
- Applications in aerospace, automotive, and civil.

G. Conclusion Section

- Summary of Findings
- Advantages and limitations of ultrasonic testing.
- Future development trends.
- Suggestions for Further Research
- Development of new testing techniques.
- Improvement of accuracy and efficiency of data analysis.

2.0 METHODOLOGY

Non-Destructive Testing (NDT) methods have become essential for ensuring the safety, reliability, and structural integrity of materials and components without causing permanent damage. Among the various NDT techniques available, ultrasonic testing (UT), which utilizes high-frequency sound waves, has emerged as an effective and reliable method for detecting internal discontinuities in materials. This technique is widely applied because it can provide accurate information about the location, size, and characteristics of defects. This paper discusses the principles, working mechanisms, methodologies, applications, advantages, and limitations of sound wave-based NDT, with particular emphasis on ultrasonic testing and its applications in industries such as aerospace, construction, and manufacturing.

1. Principles of Sound Wave-Based NDT

Ultrasonic testing is a method that uses high-frequency sound waves to pass through a material in order to detect variations in acoustic impedance, which are caused by imperfections like cracks, voids, or inclusions.

2. Working Principles

Sound waves are introduced into the material using a transducer. These waves travel through the material and reflect back when they encounter discontinuities. The reflected waves are captured and analyzed to determine the presence and characteristics of flaws.

3. Types of Waves Used

Longitudinal Waves: Move in the same direction as the wave propagation. Shear Waves: Move perpendicular to the direction of the wave and are sensitive to specific types of flaws. Surface Waves (Rayleigh Waves): Travel along the surface and are

particularly effective at detecting surface defects.

4. Methodologies

Pulse-Echo Method this method involves sending a single pulse of sound waves into the material and measuring the echoes returned from flaws or boundaries.

5. Through-Transmission Method

Two transducers are used, one as a transmitter and the other as a receiver. Flaws are identified by the attenuation of transmitted waves.

6. Phased Array Ultrasonic Testing (PAUT)

An advanced method that uses multiple transducers to focus and steer sound waves, allowing detailed imaging of flaws.

7. Applications

Aerospace Industry

Inspection of aircraft components, including wings and fuselage, to ensure structural integrity.

8. Construction Industry

Assessment of concrete structures for voids, cracks, and delamination.

Manufacturing Sector

Quality control of welds, pipes, and metal sheets in production lines.

9. Advantages of Sound Wave-Based NDT

Non-Destructive: Materials remain intact.

Highly Accurate: Capable of detecting small defects.

Versatile: Applicable to various materials, including metals, composites, and ceramics.

Portable Equipment: Suitable for field testing.

Real-Time Results: Immediate analysis and decision-making.

10. Limitations

Requires skilled operators for accurate interpretation.

Limited penetration in highly attenuative materials.

Surface conditions may affect the accuracy of results.

3.0 RESULT

The testing results of the SRF04 ultrasonic sensor are presented in Table 1. The test was conducted by comparing the distance or height displayed by the ultrasonic sensor with the results of manual measurements. The measurement range used in this experiment was 0–60 cm. This comparison was carried out to evaluate the accuracy and consistency of the ultrasonic sensor in detecting changes in distance.

Table 1. Testing Results of Ultrasonic Sensor SRF04

No.	0 – 60 Scale Display (cm) in lab view	Manual Height Measurement (cm)	Error Value (RMS) Delta Value	Ultrasonic Sensor Indicator
1	0	0	0	0
2	5	5.3	0.3	395

3	10	15.4	0.3	690
4	15	20.4	0.4	985
5	20	25.5	0.4	1280
6	25	30.3	0.5	1575
7	30	35.4	0.1	1870
8	35	40.5	0.4	2165
9	40	46	0.5	2460
10	45	51.5	1	2755

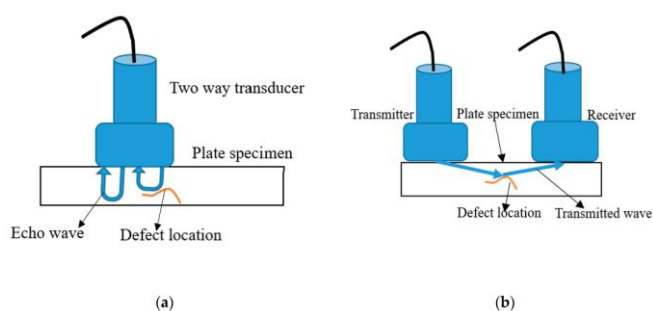


Figure 1: An ultrasonic testing diagram comparing pulse-echo and through-transmission methods for detecting defects in plate materials.

4.0 DISCUSSION

The discussion of ultrasonic testing results is based on the principle of sound wave propagation and echo reflection within the tested material. In ultrasonic testing, high-frequency sound waves are transmitted into the material through a transducer. When these waves encounter a discontinuity, such as a crack, void, or change in material boundary, a portion of the wave is reflected back toward the transducer. The time required for the reflected wave to return can then be used to determine the depth or position of the discontinuity. The relationship between the echo travel time, material depth, and sound velocity can be expressed by the following equation:

$$t = 2d / v \quad (1)$$

Where:

- t = Time taken for the echo to return (s)
- d = Depth of the flaw or material (m)
- v = Velocity of sound in the material (m/s)

Explanation:

- Sound Wave Propagation:** A transducer emits high-frequency sound waves into the material.
- Reflection:** When sound waves encounter a discontinuity (e.g., a crack or void), part of the wave reflects back to the transducer.
- Measurement:** By measuring the time (t) it takes for the echo to return and knowing the velocity (v) of sound in the material, the distance (d) to the flaw can be calculated.

This equation assumes that sound waves travel in a straight line, which is typical in straightforward situations. However, for more complex shapes, adjustments based on the angle of incidence and material properties may be required.

Non-Destructive Testing (NDT) techniques are widely used in various industries to evaluate the integrity, quality, and reliability of materials, components, and structures without causing permanent damage. Among the different NDT methods, techniques based on sound waves, particularly Ultrasonic Testing (UT), are widely recognized for their effectiveness in detecting internal flaws that may not be visible through conventional visual inspection, such as cracks, voids, inclusions, lack of fusion, and other discontinuities. Ultrasonic Testing is an NDT method that utilizes high-frequency sound waves, generally ranging from approximately 0.5 MHz to 15 MHz, depending on the type of material, component geometry, and inspection requirements.

In this method, a piezoelectric transducer converts electrical energy into high-frequency mechanical vibrations and introduces ultrasonic waves into the test material. As the waves propagate through the material, they interact with its internal structure, boundaries, and discontinuities. When the ultrasonic waves encounter a defect or an interface with a different acoustic impedance, a portion of the sound energy is reflected back toward the transducer, while the remaining energy continues to propagate through the material. The reflected signals, known as echoes, are detected by the transducer and converted into electrical signals that are subsequently processed and displayed by the ultrasonic instrument. The travel time and amplitude of these echoes can then be analyzed to determine

the location, depth, and characteristics of potential flaws. The effectiveness of ultrasonic testing depends on several important components, including transducers, couplants, and display or data acquisition systems. Transducers are responsible for converting electrical energy into ultrasonic energy during transmission and converting returning ultrasonic energy back into electrical signals during reception. Couplants, such as gels or liquids, are applied between the transducer and the surface of the test material to eliminate air gaps and improve the transmission of ultrasonic energy into the material. Meanwhile, display and data acquisition systems are used to visualize, process, and analyze the received ultrasonic signals, enabling inspectors to evaluate the condition of the material and identify potential defects accurately. Through the combination of ultrasonic wave generation, propagation, reflection, detection, and signal analysis, UT provides a reliable and efficient approach for assessing material integrity while maintaining the original condition of the inspected component.

Advantages of Ultrasonic Testing

- High Sensitivity:** Can detect very small flaws.
- Deep Penetration:** Suitable for thick materials.
- Immediate Results:** Provides real-time analysis.
- Non-invasive:** Leaves the material intact and undamaged.
- Portable Equipment:** Modern systems are highly compact and mobile.

Common Applications

- Industrial Manufacturing:** Quality assurance of welds, castings, and forgings.

2. Aerospace: Inspection of structural components for fatigue cracks.
3. Oil & Gas: Monitoring of pipelines and pressure vessels.
4. Medical Applications: Ultrasonography for diagnostic imaging, extending the principles of UT to biological tissues.

Challenges and Limitations

1. Surface Preparation: Requires smooth and clean surfaces for optimal results.
2. Skill Dependency: Requires trained technicians for effective use and interpretation.
3. Geometry Limitations: Complex shapes can distort sound waves, complicating the inspection.
4. Material Limitations: Some materials, such as coarse-grained metals, may scatter sound, reducing resolution.

Other Sound Wave-Based NDT Techniques

1. Acoustic Emission Testing (AET):
 - a. Detects transient stress waves generated by the rapid release of energy within materials.
 - b. Useful for monitoring real-time structural health.
2. Resonance Testing:
 - a. Analyzes material response to specific sound wave frequencies to identify defects or inconsistencies.
3. Impact-Echo Testing:
 - a. Suitable for concrete structures, where sound waves are analyzed to assess internal voids or cracks.
 - b. Suitable for concrete structures, where sound waves are analyzed to assess internal voids or cracks.

5.0 CONCLUSION

Sound wave-based non-destructive techniques (NDT), such as ultrasonic testing, are invaluable for assessing the structural integrity of materials without causing harm. These methods provide high precision, deep penetration, and real-time results, making them crucial for ensuring the safety and reliability of components in industries like manufacturing, aerospace, and oil & gas. While challenges exist, such as the need for skilled operators and material-specific limitations, technological advancements like phased-array ultrasonics and automated inspection are enhancing their effectiveness. Overall, sound wave-based NDT plays a vital role in modern industries by preventing failures, improving quality control, and extending the lifespan of critical structures.

ACKNOWLEDGEMENTS

We express our heartfelt appreciation to all individuals and organizations who have contributed to the development and application of non-destructive techniques using sound waves for flaw detection in materials. A special thanks goes to the researchers, engineers, and technicians whose commitment has driven the innovation and improvement of ultrasonic testing and related methods. We also recognize the support of academic institutions and industry leaders in offering vital resources, training, and research facilities that continue to push this field forward. Lastly, we extend our gratitude to the

regulatory bodies and professional organizations that set standards and ensure the safe and effective use of non-destructive testing techniques globally.

REFERENCE

- [1] ASTM International. (2020). *Standard guide for ultrasonic testing of materials* (ASTM E114). Retrieved from <https://www.astm.org>
- Bai, Y. & Bai, Q. (2010). *Subsea Engineering Handbook*: Elsevier.
- [2] Blitz, J., & Simpson, G. (1995). Ultrasonic methods of non-destructive testing. Springer Science+Business Media.
- Koto, J., Khair, A. & Selamat, A. (2015). Ultra deep water subsea pipeline design and assessment, *Proceeding of Ocean, Mechanical and Aerospace -Science and Engineering*, 2, 38-43.
- [3] European Committee for Standardization. (2010). Non-destructive testing: Characterization and verification of ultrasonic instruments (EN 12668-1:2010).
- [4] Hellier, C. J. (2013). *Handbook of nondestructive evaluation*. McGraw-Hill Education.
- [5] Khan, M. A., & Sharma, A. K. (2020). Recent developments in ultrasonic NDT technologies for composite materials. *Ultrasonics*, 108*, 106316. <https://doi.org/10.1016/j.ultras.2020.106316>
- [6] Krautkrämer, J., & Krautkrämer, H. (1990). *Ultrasonic testing of materials*. Springer-Verlag.
- [7] Lizzul, A., & Petrucci, G. (2018). Acoustic emission and ultrasonic testing in non-destructive material evaluation. *Materials Today: Proceedings*, 5*(14), 27191–27198. <https://doi.org/10.1016/j.matpr.2018.09.095>
- [8] Scruby, C. B., & Drain, L. E. (1990). *Laser ultrasonics: Techniques and applications*. Taylor & Francis.
- [9] Maldague, X. P. V., & Moore, P. O. (2001). *Nondestructive testing handbook, vol. 7: Ultrasonic testing*. American Society for Nondestructive Testing (ASNT).
- [10] Zhang, J., Liu, B., & Guo, H. (2019). Advances in ultrasonic testing for flaw detection in metallic materials. *Journal of Materials Research and Technology*, 8*(3), 3235–3245. <https://doi.org/10.1016/j.jmrt.2019.01.098>