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Non-Destructive Testing (NDT) Method for Defect Detection in Glass Fibre Reinforced Plastic/Polymer (GFRP/GRP) Composite Materials Structures: A Review

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ABSTRACT

Various industries are considering metal product in lieu composite materials. Structural engineers appreciate glass fibre reinforced plastic/polymer (GFRP/GRP) because to its high modulus of elasticity, ratio of strength to weight, and corrosion resistance features. It has been discovered that structural engineering defects to be leading cause for the catastrophic consequences. This paper provides an overview of available NDT methods that can be employed to assess the quality of GFRP/GRP composite materials. The most common NDT method used by researchers and practitioners is also discussed, along with the advantages, disadvantages, characteristics, and potential applications of these materials. The review will lead the research using ultrasonic testing as a potential method employing low-frequency transducers with multielement architecture. This study will lead industry players, GFRP/GRP manufacturers, researchers, and NDT practitioners towards the development of technical standards for ultrasonic testing on GFRP/GRP in Malaysia.

1. Introduction

Composite materials are frequently used in the manufacture of key components and industrial equipment in sectors such as contemporary military ships [5], warehousing facilities [10] the manufacturing of pipes and tubes [26,57], aeronautics [16,36], nuclear engineering [62], natural goods [38] and oil platforms [4] are commonly produced. GFRP/GRP is one of the examples of composite materials. According to [39] and [44], GFRP/GRP has been used for over fifty years a structural material due to excellent modulus of elasticity, strength-to-weight ratio, and resistance to corrosion characteristics [13]. As seen in Figure 1, GFRP/GRP pipes comprise of a liner layer, an inner reinforced layer, a core layer, an outer reinforced layer, and a surface veil.

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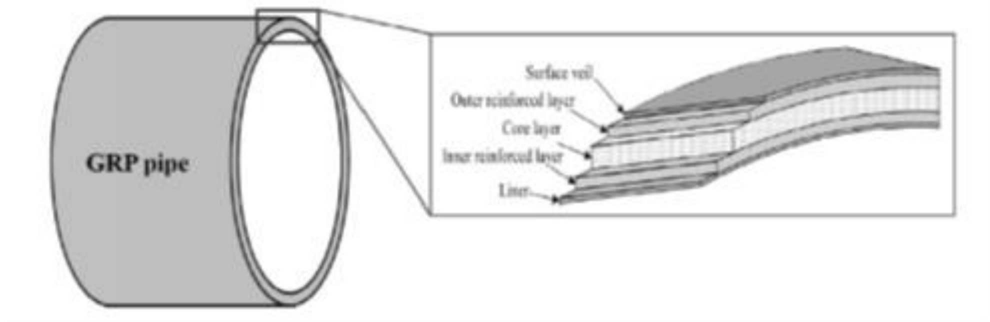
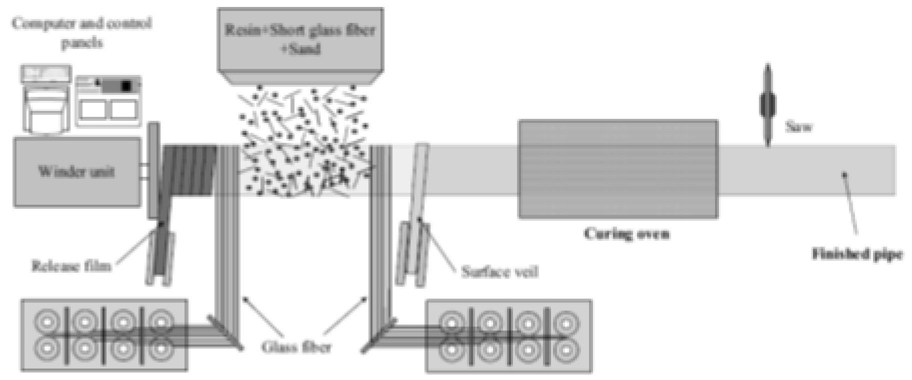
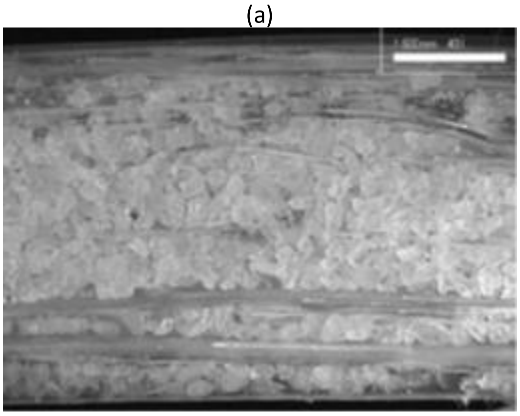


Fig. 1. An illustration of a configuration example for a GFRP/GRP pipe [65]

As an alternative for metals, these composites are extensively utilised in a range of applications [11]. Rising manufacturing demand for composites has led to enhancements in their manufacture, Figure 2(a) illustrates the production of GFRP/GRP by the continuous filament winding method, which distributes glass fibres, sand, and polyester resin progressively and continuously onto a rotating and translating cylinder-shaped mandrel. As seen in Figure 1 and Figure 2 [65], the interface between glass fibres and matrix or sand and matrix in the core layer exhibits a reasonably high adhesive state. However, the difficulty of this production lies in the fact that it must contend with such issues as the texture of the resin being inconsistent, voids forming, and delamination occurring, all of which might eventually cause the material to fail [22].



(a)



(b)

Fig. 2. (a) An example of a continuous filament winding equipment production process for GFRP/GRP pipes and (b) A cross-section of GFRP/GRP pipe, highlighting the different layers [64]

2. GFRP/GRP Composite Defects

There are three categories of flaws for which NDT is used:

i. Inherent defects: defects that occurred during production of the base or raw material.
ii. Processing defects: defects that occurred during the production of a material or component.
iii. In-service defects: defects that occurred throughout the service life of the material or component.

Recent research by Nsengiyumva *et al.,* [51] and Wang *et al.,* [63] highlights the broad usage of composites as a result of their remarkable mechanical qualities. Hence, NDT is essential for identifying and locating defects in these materials before to their failure, which saves money, avoids catastrophic failure, and improves the efficiency of repair and maintenance operations. As shown in Table 1, NORSOK M-622 (2005) provides an overview of the various NDT methods that may be used to detect manufacturing and transportation defects in GFRP/GRP pipe or tank systems.

Table 1
Summary of several NDT methods for GFRP/GRP pipe and tank systems [50]

Types of manufacture defects in GFRP/GRP composite materials	Cause	Consequence	Recommended NDT method
Incorrect dimension	Improper fabrication a poorly shaved joint poorly conceived design.	Joint is not properly sealed. Joint may induce structural stress if pushed up	Visual testing/ inspection Radiographic testing method Ultrasonic testing Acoustic emission testing
Impact	Transport errors or mishandling.	Pipe failure	a) Visual testing/ inspection b) Pressure testing c) Acoustic emission testing
Incorrect lay-up in lamination	Lack of quality control and poor construction.	Inadequate straightening may lead in joint failure.	a) Visual testing/ inspection b) Radiographic testing method c) Acoustic emission testing
Improper adhesive curing and lamination	Outdoor weather conditions, including humidity and temperature. Incorrect controller settings or heating pad overlap absence improper placement of materials that produce a cooling effect in the pipe. out-of-date or incorrect materials.	The joint weakening	a) Visual testing/ inspection b) Ultrasonic testing c) Acoustic emission testing
Misaligned joint	Dimensional inconsistency resulting from movement during curing and distortions.	a) Sucking in air, leading in cavities b) Underperforming as a result of residual stress	a) Visual testing/ inspection b) Ultrasonic testing c) Acoustic emission testing
Void	Failure to properly repair damage may be the result of a poor adhesive. insufficient surface preparation. Movement during the curing process.	The joint weakening	a) Visual testing/ inspection b) Pressure testing c) Acoustic emission testing

3. Variety of NDT Methods for GFRP/GRP Composite Materials

Practitioners, researchers, and academics make use of NDT, non-destructive inspection (NDI), and non-destructive examination (NDE). All terminology and acronyms are intended to analyse, test, or assess materials, components, or assemblies for discontinuities or changes in qualities that do not affect the component's or system's functionality [2,3,37,38]. This indicates that NDT methods can be utilised piece-by-piece for component level study or on the entire material for full quality assurance throughout the manufacturing process [48]. According to a review of the literature and existing standards such as [29] and [50], there are several NDT methods for assessing composite materials, many of which have been recommended and authorised by experts. The following describes the NDT method used for GFRP/GRP.

3.1 Visual Testing/Inspection

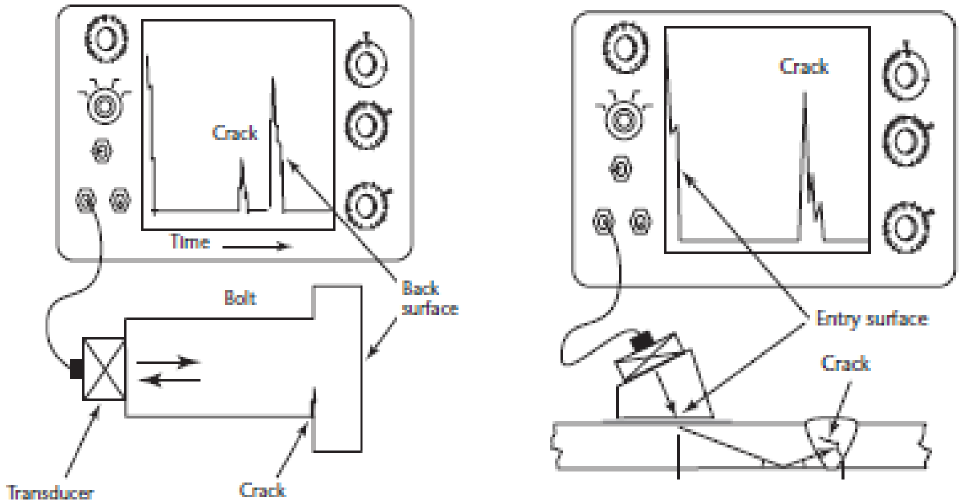
Typically, a visual testing/examination/inspection is done to assess the existence of surface defects and the object's compliance to standards. This may be done directly by the inspector using the inspector's eyes or indirectly using optical instruments as shown in Figure 3 [3].

Fig. 3. Visual testing/inspection is an example of inspecting the inside or outside of a product using optical equipment [3]

According to previous sources, visual testing/examination/inspection remains the preferred method when the resin is visible, since large regions inside the laminate may be properly evaluated [6]. But this method may be constrained by factors such as a component's size, shape, surface roughness, complexity, and difficult to detect discontinuities, such as subsurface and microscopic defects. In order to correctly assess symptoms of defects such as inadequate bonding, the inspector must have a thorough understanding of the test item, be competent with the visual equipment, and be familiar with the advanced NDT approach used, as detailed in several pertinent books, journals, articles and standards [3,6].

3.2 Ultrasonic Testing

This method, as shown in Figure 4 and Figure 5 has been the topic of a number of studies and publications, and it often used high-frequency sound energy for inspection [1,3,6,20,32,38,56]. As due to some publications, the pulse echo (PE) technique is well-suited for GFRP/GRP inspections between 8 mm and 25 mm in thickness, with lower frequencies generally ranging between 0.25 and 2.25 MHz [29,50]. Before performing the tests, it may be required to calibrate the frequency of the transducer and other acoustic instrument parameters. Numerous articles and journals have emphasized, the material must be appropriate for sound transmission since the reflected pulses in GFRP/GRP have more complicated waveforms and are resistant to materials with significant anisotropy and acoustic attenuation [1,3,6,7,20,32,38].



(a) (b)

Fig. 4. (a) Normal beam inspection with normal probe, and (b) Angle beam inspection with angle probe [3]

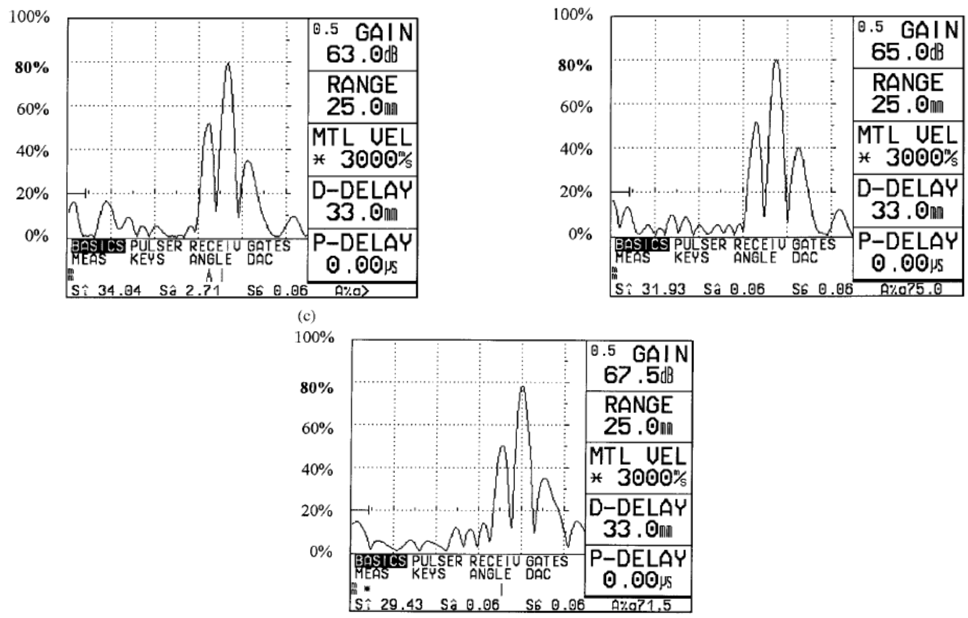


Fig. 5. 16 mm thick GRP composite using A-scan signal results from a conventional 0.5 GHz single crystal ultrasonic testing transducer [48]

3.3 Shearography Testing

This NDT method employs coherent laser light to generate a visual representation of a test item, strain measurement, and vibration analysis, similar to holographic interferometry as seen in Figure 6. To reveal the result, this method relies on the deformation of test specimens, which might lead in the failure of either the material or the specimens [27,28,53]. Optical tools are essential to this method. The greatest results may be achieved with the right illumination just above the specimen. Burkov *et al.,* [9] presented the results of a phase map honeycomb CFRP panel in Figure 7. To operate the equipment and examine the data, however, needed a person with extensive knowledge due to the complexity and difficulty of interpreting the findings.

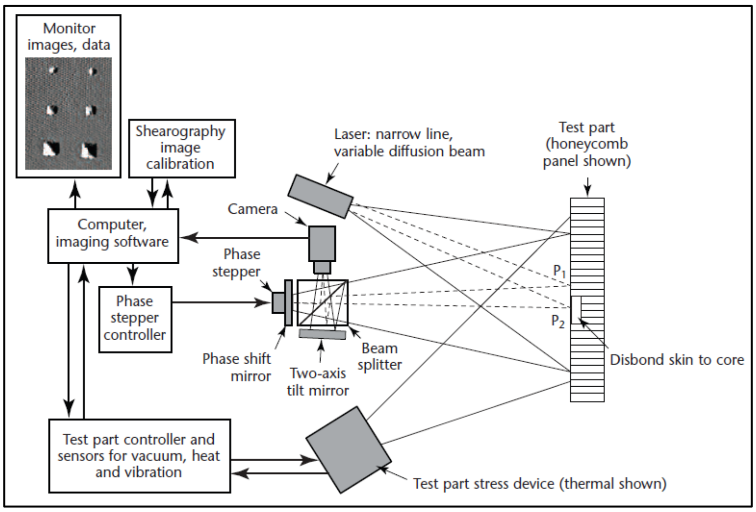


Fig. 6. Schematic diagram of digital shearography arrangement for analysis of composite structures [3]

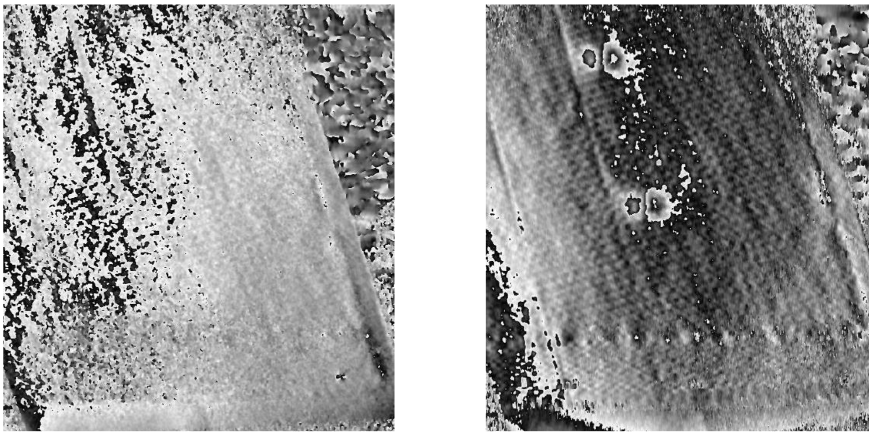


Fig. 7. The two images of shearography display result by Burkov *et al.,* [9] showing the phase map honeycomb CFRP panel

3.4 Pressure Testing

The pressure testing evaluation is conducted after a pipeline has been built but prior to its reinstatement into operation [29,50]. The objective of the test is to determine the pipeline's pressure, leakage, joint tightness, maximum capacity, and reliability. This examination takes place after a pipeline has been installed but prior to its reinstatement into operation. This test might result in a catastrophic failure or explosion, thus appropriate precautions must be taken. Figure 8 illustrates the experimental setup by [65] extended internal pressure test. The objective of this test is to evaluate the failure pressure and time to failure of a GRP pipe subjected to sustained internal pressure.

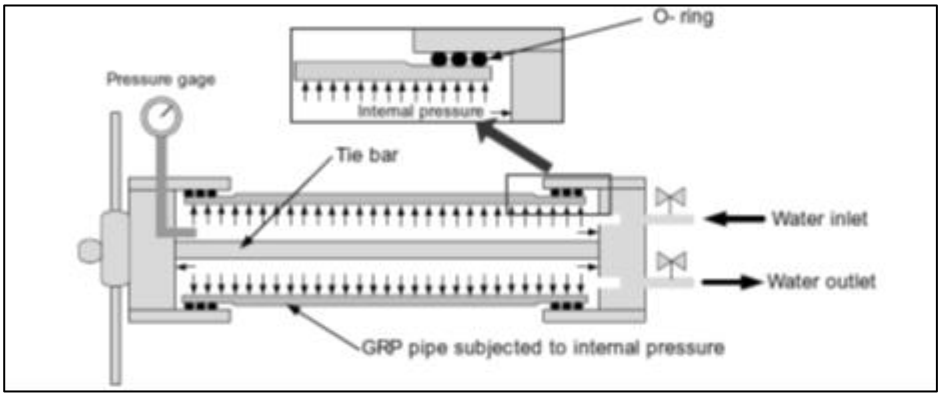
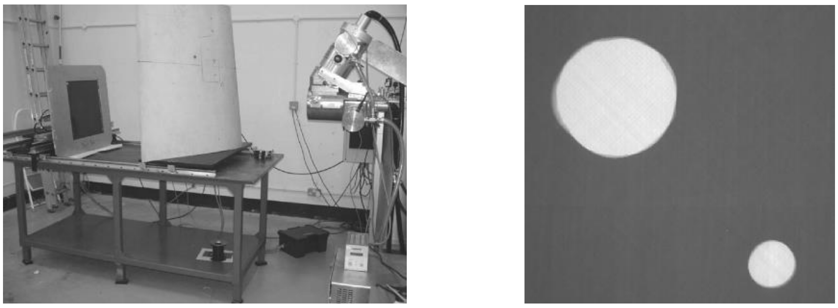


Fig. 8. A schematic illustration of an experiment conducted by [65] to determine the failure pressure and time to failure of a GRP pipe exposed to sustained internal pressure

3.5 Radiography Testing

This method employs x-rays or gamma rays to examine the interior structure of produced components for defects or irregularities. Example of this method set-up to examine the turbine blade by Jasiūnienė *et al.,* [30] as shown in Figure 9 (a) and (b). As mentioned in a number of articles and journals, restrictions on ionising radiation in this method require the development of a protective perimeter [3,8, 20,49].



(a) (b)

Fig. 9. (a) A picture of an inspection setup using Radiographic Testing to check the turbine blade, as shown by Jasiūnienė *et al.,* [30], and (b) the picture display of a radiography image of an artificial defect manufactured in a turbine blade as identified by Jasiūnienė *et al.,* [30]

3.6 Acoustic Emission Testing

When a material deforms under stress, the emission of ultrasonic stress waves from localised sources is detected and monitored. According to a number of studies, journals and standards, acoustic emission testing is incapable of detecting existing flaws that do not develop or grow over time [3,19,20,60]. As seen in Figure 10, Gholizadeh *et al.,* [19] reviewed an example of an acoustic emission signal in the scientific publications by Marec *et al.,* [45]. In 1969, a study identified the limitations of this method [15]. During assessments, it is difficult to distinguish between the actual acoustic emission signals and the background noise. For a decent fracture prediction, the material must be loaded near to the proportionate limit of deformation before acoustic emission generation occurs. In their research using acoustic emission on wood and wood-based composites, Katunin *et al.,* demonstrated that small acoustic emission generated by anisotropic materials cannot be detected as acoustic emission signals due to the significant attenuation of acoustic emission waves during propagation, unless the appropriate transducers are used [32]. Figure 10 and 11 show examples setup of this project.

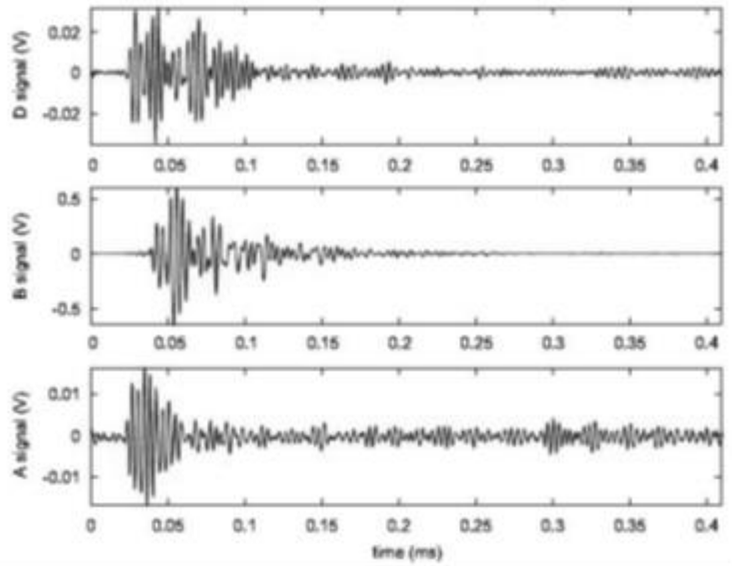


Fig. 10. Example of the acoustic emission signal of sheet moulding composite by Marec *et al.,* [45], as reviewed by Gholizadeh *et al.,* [19]

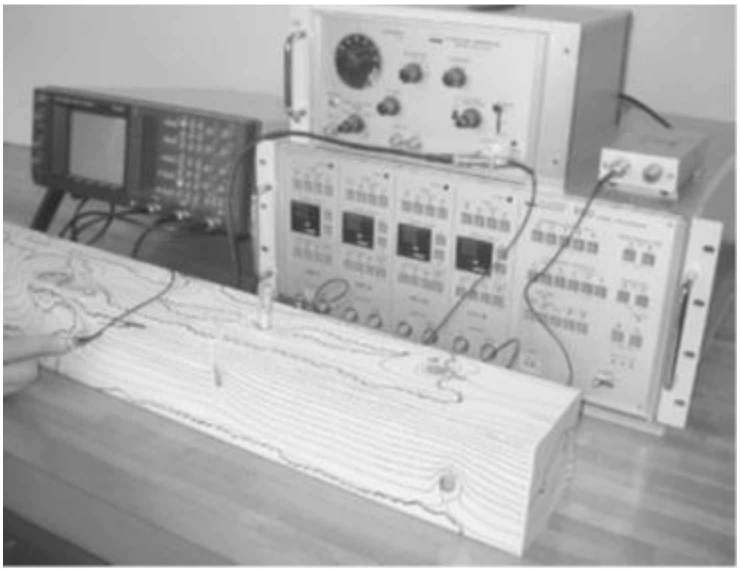
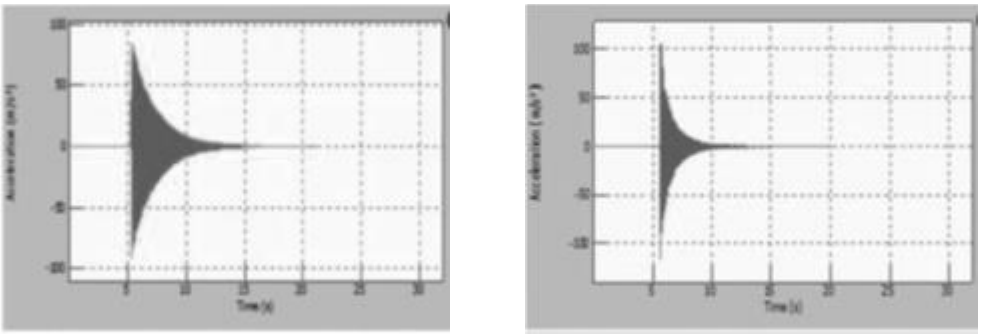


Fig. 11. Example of acoustic emission for their study on acoustic emission on wood and wood-based composites [33]

3.7 Vibration Testing

Damage is detected, localised, and quantified using a combination of dynamic analysis of the system and measurements of changes in the lower structural natural frequencies, which may be obtained at a single spot inside the structure. Example of a highly damping substance with the effect of reducing both the natural frequencies and the intensities of vibration is described in a number of scholarly articles [31,32,41,52,55]. The determination of existence small delamination in the sublayers of carbon fibre composite beam could be perform by using vibration testing and signal analysis [52]. In Figure 12 (a), the results of the vibration test using an OROS four-channel FFT analyzer reveal that the damping rate changes depending on the existence of delamination in Figure 12(b).



(a) (b)

Fig. 12. (a) Diagram of time vs acceleration for a carbon fibre composite with no flaws in, and (b) Diagram of time vs acceleration for a carbon fibre composite with no delamination in. This test was conducted by Nayak *et al.,* [52]

In addition, the data is presented in tabulated form as shown in Table 2. Clearly, the data indicate that the natural frequency of a delaminated composite beam is lower than that of a beam without delamination. Nayak *et al.,* [52] also present the FFT plots of online vibration tests, as shown in Figure 13 and 14, for a beam without delamination and one with delamination, respectively; these plots depict super harmonics and side bands. According to Glowacz *et al.,* [21], the noise contamination and suitable mounting placement of vibration sensors are essential for the use of this method. Nevertheless, this method is expensive and takes additional time to evaluate the acoustic and vibrational data.

Table 2
Comparison of natural frequencies of beam without delamination and beam with delamination provided by Nayak *et al.,* [52]

Mode	Natural frequencies (in Hertz)	
	Beam without delamination	Beam with delamination
1st mode	20.9238	19.9245
2nd mode	120.7035	118.7534
3rd mode	263.6757	258.9843

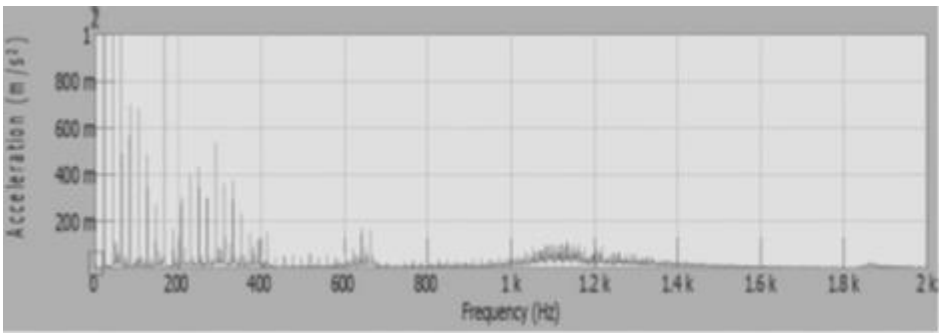


Fig. 13. FFT representation of a composite beam without delamination by Nayak *et al.,* [52]

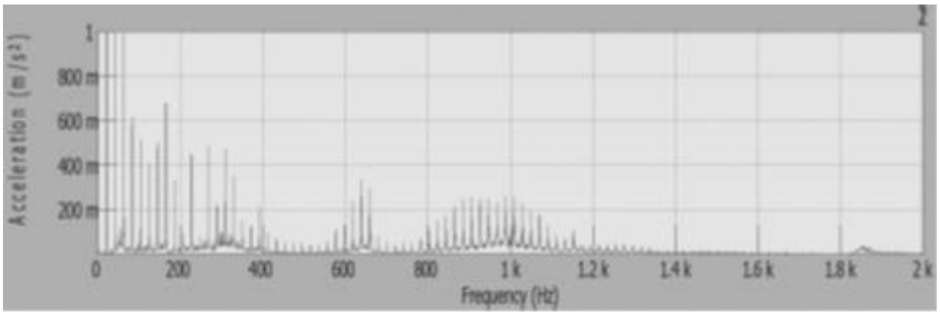


Fig. 14. FFT representation of a composite beam with delamination by Nayak *et al.,* [52]

3.8 Eddy Current Testing

This electromagnetic method, according to Cheng *et al.,* [12], involves introducing a coil carrying an electrical current close to a conductive substance. As shown in Figure 15, in accordance with Faraday's law, the examined material will create inductive currents in response to the applied electromagnetic fields, which flow normal to the incoming magnetic fields. To decrease the applied field, they may create magnetic fields in opposite to the main fields, resulting in a change in coil impedance, in accordance with Lenz's law.

A number of studies, publications, standards, and journals stated this method of inspection use electromagnetic induction to detect surface and sub-surface flaws, measure coating thickness, identify materials, and determine the heat treatment phase of material properties [3,14,20,23,40].

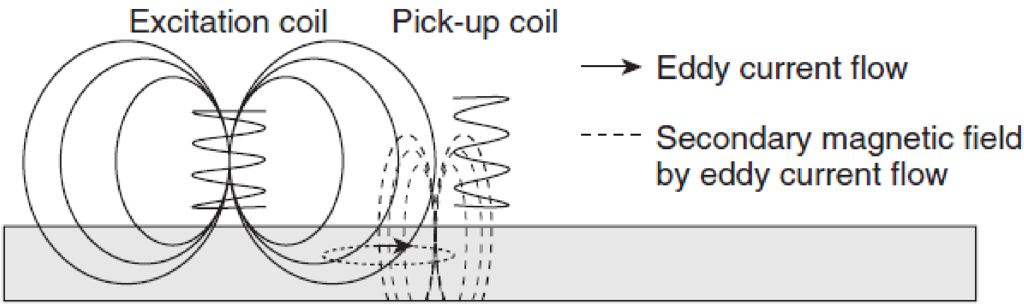


Fig. 15. Principle of Eddy Current testing method as illustrated by Heuer *et al.,* [25]

Heuer *et al.,* [25] stated that this method can be applied to low-conducting materials such as carbon fibre reinforced plastic (CFRP). According to Heuer *et al.,* [25], Mizukami *et al.,* [47], and Gäbler *et al.,* [18], this method can also be used on GFRP/GRP composite materials, however high-frequency eddy current method is required for both composite materials. Numerous studies presenting the eddy current method of composite materials in data visualisation can be seen in Figure 16 [25]. During eddy current testing of composites, it is difficult to distinguish between delamination and interlaminar fractures, and this method is also restricted to composites containing carbon or other conductive fibres.

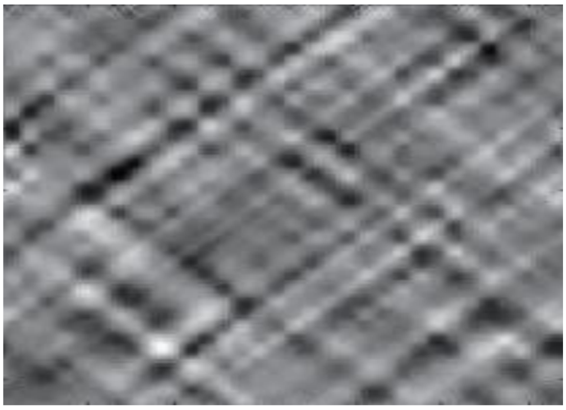


Fig. 16. Data visualisation using eddy current method presenting fiber oriented at 45° [25]

3.9 Differential Scanning Calorimetry (DSC) and Barcol Hardness Testing

This thermo-analytical method may be used to analyse a variety of non-metallic and polymeric materials. Specific heat capacity, glass transition temperatures, phase transitions, and melting points are the most often measured and used physical properties for characterisation. It is necessary to take precautions to guarantee that the testing site is free of contaminants [29,48]. Several previous studies spotted to use this method to the GFRP/GRP composite material shown in Figure 17 in order to study the mass variation and energy changes experienced by the composite materials as a function of temperature and time [50,55]. However, the figure only indicates the mass and heat flow variations as a function of temperature, not the identification and categorization of defect types.

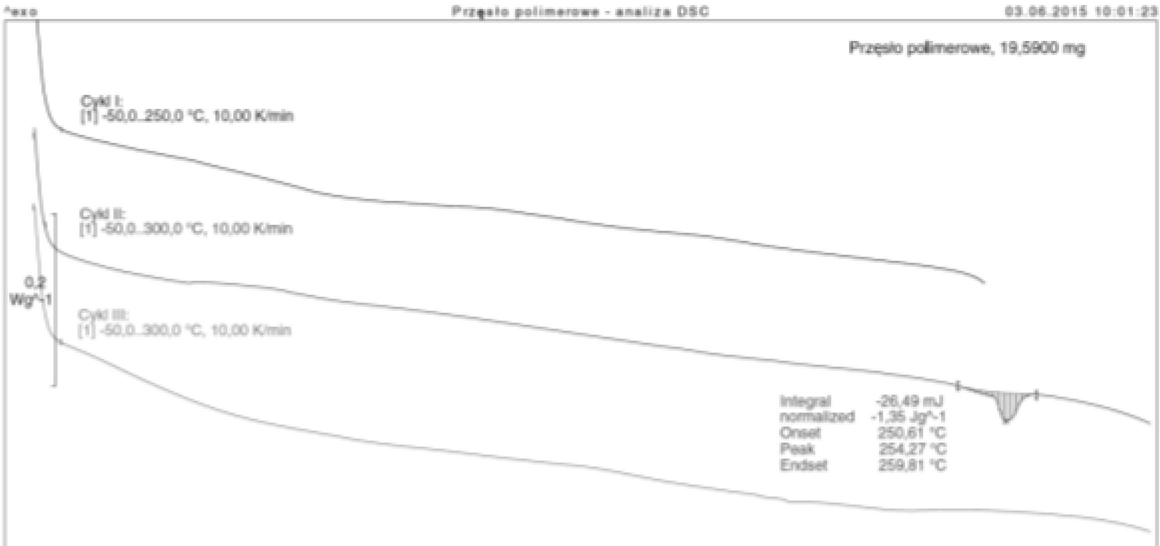
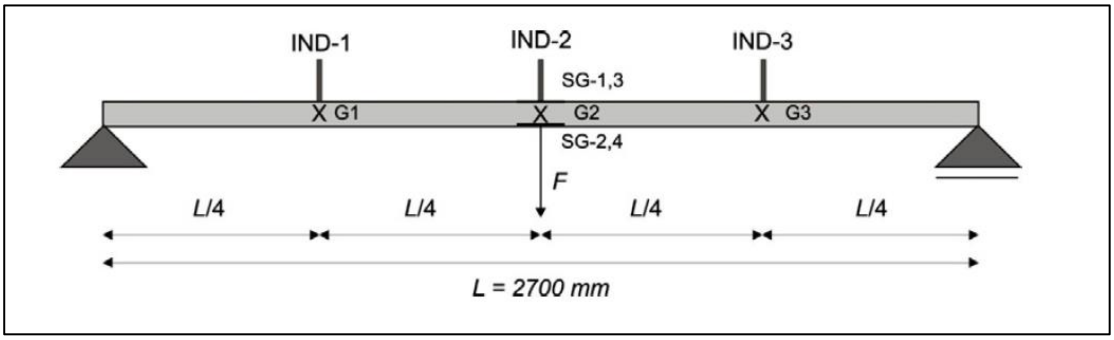


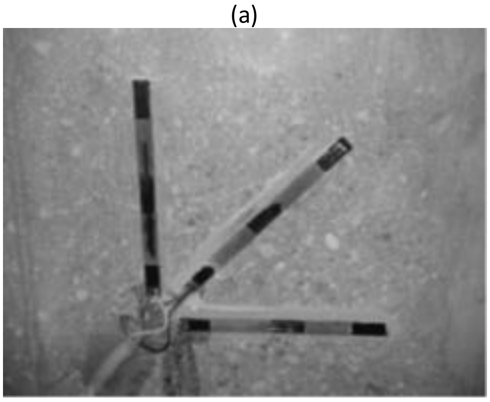
Fig. 17. example of DSC result tested by [58] on GFRP/GRP composite material

3.10 Strain Gauge Testing

Deformation evaluation is a condition monitoring method [41]. As shown in Figure 18 (a), Kovačič *et al.,* [34] used this approach to test on bridge construction with the purpose of determining vertical displacements and strains. A 2700 x 75 x 80 mm reinforced concrete beam was produced for load testing. As seen in Figure 18 (b), the strain gauge sensor was securely attached to the reinforcing bars of the bridge in this study. During the attachment process, problems such as air bubbles under the strain gauge, poor bonding at the edges, unreliable solder connections, and flux residue must be prevented. The results of this method correspond to the signal processing shown in Figure 19 (a) and (b). A disadvantage of the method is that it must be regularly calibrated to maintain proper operation and accurate readings, particularly at extreme temperatures [3].

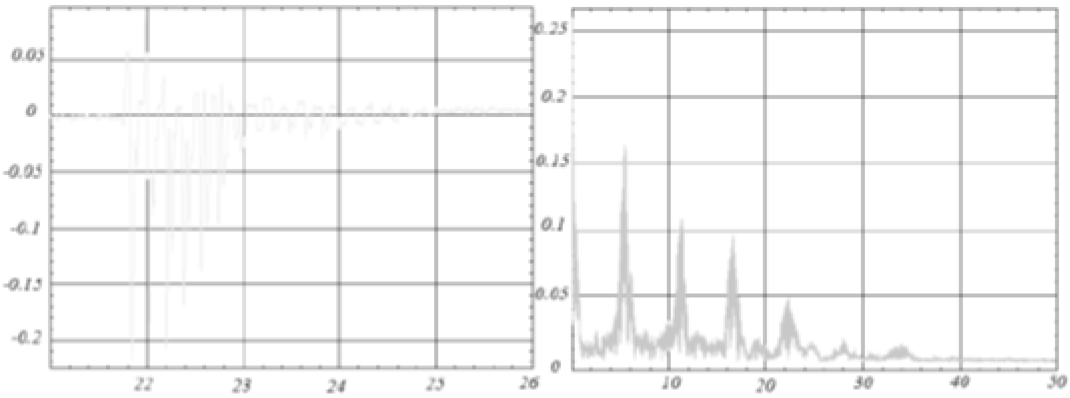


(a)

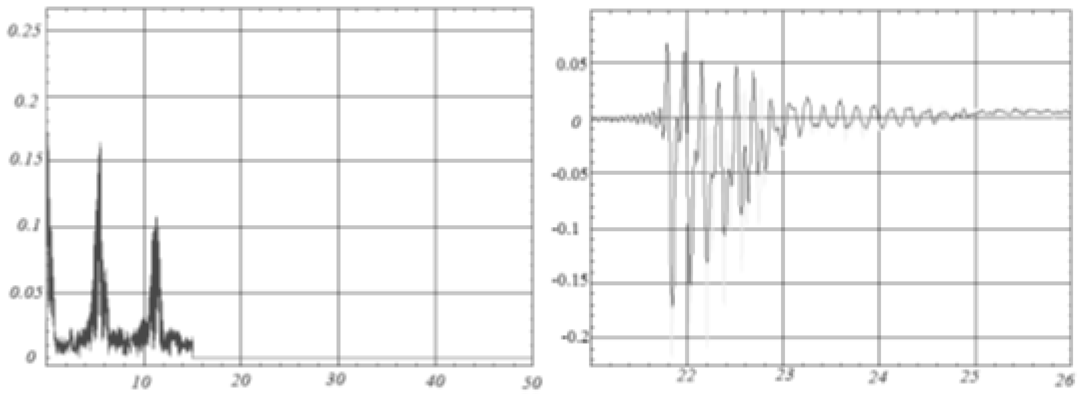


(b)

Fig. 18. (a) Example of concrete beam tested using strain gauge, and (b) Strain gauge sensors installed on bridge reinforcing bars by Kovačič *et al.,* [34]



(a)



(b)

Fig. 19. The result of the strain gauge signal processing examined by Kovačič *et al.,* [34], displaying the raw signal and the corrected signal in (a), indicates that the corrected signal has a less extreme peak than the original signal in (b)

3.11 Thermographic Testing

This method identifies temperature fluctuations and thermal behaviour of industrial equipment, electronic devices, and materials using the method of infrared detection. As in production, they are the most crucial aspects of maintenance [3,29,50]. Loganathan *et al.,* [38] investigated the assessment of randomly-oriented short natural fiber-reinforced phenolic composites using the infrared thermographic method. As indicated in Figure 20, the results of this investigation recorded the temperature and time changes of the tested materials continuously. As a result of the dissipation of energy, the peak of the temperature-time graph indicated the formation of macrocracks and matrix cracking [38]. However, if temperatures fall within a small spectrum, infrared imaging may misinterpret camera data, making objects unrecognizable [20,24,32,42,46,64].

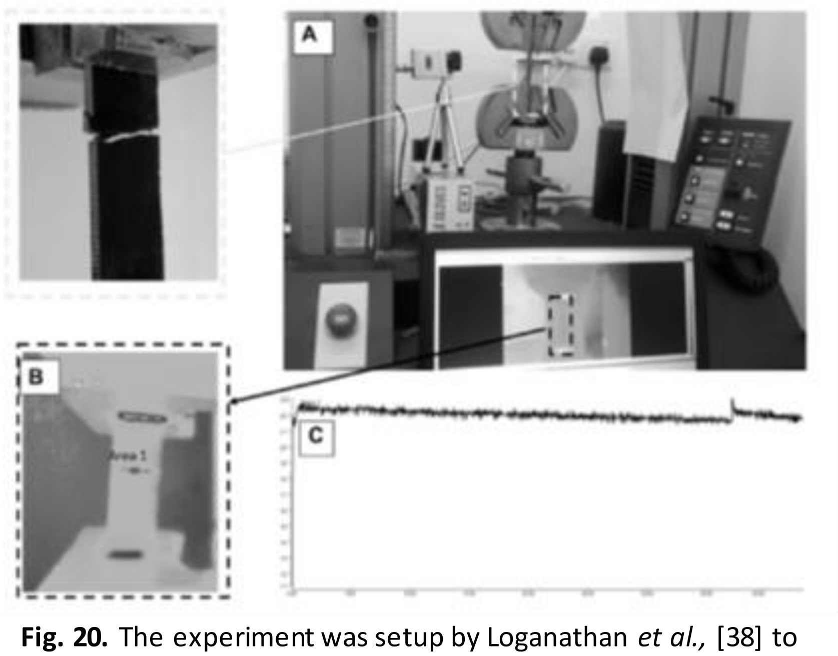


Fig. 20. The experiment was setup by Loganathan *et al.,* [38] to test the tensile sample of randomly-oriented short-natural-fiber-reinforced phenolic composite material

4. Summary of NDT Methods for GFRP/GRP Composite Materials

Based on a review of the relevant articles, books, and established NDT standards on CFRP/GRP composites materials, there are a number of proposed NDT methods that may be applied to test these composites, including visual testing, ultrasonic testing, shearography testing, pressure testing, radiographic testing, acoustic emission testing, vibration testing, eddy current testing, differential scanning calorimetry (DSC)/Barcol hardness testing, and thermographic testing. The discriptions, advantages and disadvantages of applying various NDT methods on CFRP/GRP composite materials are summarized and listed in Table 3.

Table 3
The descriptions, advantages and disadvantages of applying various NDT methods on CFRP/GRP composite materials

NDT Method	Description	Advantages	Disadvantages
Visual testing	Performed directly with the inspector's eyes or indirectly using optical devices	This inspection is often used.	a) The inspector must have extensive knowledge about the visual equipment. b) Method limitations include a part's size, shape, surface roughness, complexity, and flaws that are hard to find, such as internal and small defect.
Ultrasonic testing	Used high-frequency sound waves to inspect for defect.	a) Can detect surface, subsurface, and internal defect within material b) Can test on diverse materials and thicknesses with the suitable transducer frequency.	The material must be suitable for sound transmission
Shearography Testing	Similar to holographic interferometry, this nondestructive testing technique employs coherent laser light to provide a visual representation of a test item, as well as strain measurement and vibration analysis.	This method can be applied to large areas contactlessly and automatically.	Due to the complexity and difficulty of interpreting the results, a person with substantial understanding was needed to operate the equipment and review the data.
Pressure testing	To verify the pipeline's integrity after installation and prior to commissioning throughout its service life.	Can determine the pressure, leakage, tightness of the joints, maximum capacity, and reliability of the pipeline.	This test could cause a catastrophic failure or explosion, so the right precautions need to be taken
Radiographic testing	X-rays or gamma rays are used in this method to check the	a) It facilitates the inspection of	In this method, limits on ionizing radiation require the creation of a protective perimeter.

	internal structure of manufactured parts for defects	assembled components. b) Little surface preparation is required.	
Acoustic emission testing	The emission of ultrasonic stress waves from localized sources is detected and monitored when a material deforms under stress.	Allows inspectors to examine the whole load record of a material without causing damage.	It is challenging to distinguish between actual acoustic emission signals and background noise.
Vibration testing	The deployment of mechanical motion to a component, product, system, or structure to study its reaction or degeneration over time.	Enables the inspector to prioritize the health of assets, assess and diagnose the detected asset, and take the appropriate remedial action at the appropriate moment	Costly and time-consuming approach for interpreting acoustic and vibrational inputs.
Eddy current testing	A fluctuating magnetic field in a conductor will induce eddy currents, which are effectively electrical current loops in the conductor, according to Faraday's law of induction.	Use electromagnetic induction to detect surface and sub-surface defects, measure coating thickness, identify materials, and define the heat treatment phase of material properties.	Can only be used to measure conductive materials
Differential Scanning Calorimetry (DSC) and Barcol Hardness Testing	This method is a thermo-analytical method used to analyze a broad range of non-metallic and polymeric materials.	Specific heat capacity, glass transition temperatures, phase transitions, and melting points are the physical parameters measured and used for characterisation.	a) Analyze the mass and heat flow fluctuations as a function of temperature, but do not identify and classify defect types. b) do not identify and classify defect types.
Strain gauge testing	The method used to assess fluctuations in the dimensions of a structure's surface.	Its mobility, low cost, and reusability	The method is that it must be regularly calibrated to give dependable performance and accurate readings, particularly in severe conditions.
Thermography testing	Using infrared detection, this method identifies temperature variations and thermal behavior of industrial equipment, electrical devices, and materials.	Assist manufacturers in limiting or eliminating heat damage, so extending the time before equipment must be replaced and decreasing the frequency with which it must be changed.	Infrared imaging may misunderstand camera data if temperatures fall inside a small spectrum, leaving objects unrecognizable.

5. NDT Research on GFRP/GRP Composites

Fotsing *et al.,* [17] present a measurement technique that employs an optical system and deflectometry technique in their study. This technique is unique in that the intensity of the reflected light may be mapped in real time. This study focuses specifically on surface crack anomalies in composite samples. The output or image display may be altered by the light intensity and composite sample curvature of this technique.

In the present study, Arun Prakash *et al.,* [1] used ultrasonic testing method to examine the mechanical properties of three different types of glass fibre reinforced polymer (GFRP/GRP) plates. Due to the anisotropic structure of GRP materials and composites, ultrasonic energy may be diminished as a result of significant acoustic attenuation. Using a transducer with a single element may reduce the probability of detection (POD) of GRP materials.

Sutthaweekul *et al.,* [61] report a nondestructive testing (NDT) application employing a microwave open-ended waveguide probe to discover and characterise internal defects in coated GFRP/GRP pipes by producing a flat bottom hole (FBH) using the microwave method. If the flat bottom hole (FBH) image is not displayed appropriately, the operator's evaluation and interpretation of the image may be inaccurate. Using electromagnetic induction, Matsunaga *et al.,* [43] determined the rate of water absorption by glass fibre reinforced polymers. However, this method can only be used to determine the water absorption rate of polymers reinforced with glass fibres.

To determine the efficiency of defect detection in a GFRP/GRP sample, Rani and Mulaveesala [54] present three distinct frequency modulated thermal wave imaging techniques, frequency modulated thermal wave imaging (FMTWI), Barker coded thermal wave imaging (BCTWI), and digitised frequency modulated thermal wave imaging (DFMTWI). The data analysis approaches need specific knowledge and skill. Reasons such as the varying emissivities of different materials, reflections from nearby surfaces, and other factors may make it difficult to produce high resolution.

Krstulović-Opara *et al.,* [35] introduced pulsed infrared thermography as a method for assessing osmosis processes and other indications of structural damage, such as blistering and delamination, in glass fibre reinforced plastic (GRP) structures. As determined by the research, this method required to apply a heat flow to a structure, damaged and other structural anomalies have different temperature dynamics than undamaged material.

6. Conclusion

The review indicates that GFRP/GRP composite materials play a key role in several industries. The product better modulus of elasticity, strength-to-weight ratio, and corrosion resistance contribute to its rising manufacturing demand and extensive use as an alternative for metals in a wide variety of industrial applications. The highlighted the advantages, disadvantages and describing NDT methods in a comprehensive review of the relevant established studies and standards using NDT methods for GFRP/GRP materials in industry. Several NDT researchers and practitioners have used contemporary NDT methods and techniques to inspect GFRP/GRP composite materials. Several of them employed a variety of NDT methods and techniques to identify defects in GFRP/GRP composite materials, some of which were able to detect the defect and assess it qualitatively, while others were able to detect the defect quantitatively. By doing this review, it is anticipated that new research directions that might be followed to solve the limits of standard NDT methods would be identified.

This study will focus on advanced ultrasonic testing technique. Several studies employ the pulse echo (PE) technique as a benchmark for GFRP/GRP inspections between 8 mm and 25 mm in thickness, with lower frequencies typically ranging from 0.25 to 2.25 MHz. According to a variety of studies and journals, the material must be suitable for acoustics since the reflected pulses in GFRP/GRP have more complex waveforms and are resistant to materials with significant anisotropy and acoustic attenuation. Hence, a low frequency probe with a frequency of 1.5MHz is suitable for a range of GRP pipe inspections. In majority of reviewed research, an ultrasonic technique with a single-element transducer was used. This indicates that multielement architecture probes have the potential to significantly enhance ultrasonic testing and inspection by increasing the probability of detection (POD).

Typically, standard ultrasonic testing method only permits the A-scan display of data. This study will provide its results through a B-scan (cross-sectional scan), C-scan (top-down view), and a three-dimensional representation of the indication. Ultrasonic acquisition process known as Full Matrix Capture (FMC) obtains all the A-scans (amplitude time series) and the A-scans data are synthesized using the Total Focusing Method (TFM) for image reconstructions to provide the optimal image quality for defect detection and characterization of GFRP/GRP composite materials.

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