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ADVANCE AND REVIEW OF COMPOSITE MATERIAL NON-DESTRUCTIVE TESTING TECHNIQUES

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Abstract

A review of non-destructive testing (NDT) procedures for the assessment of composites is given. The review takes into account the capabilities of the most popular techniques used in composite NDT applications, including Visual Testing (VT or VI), Ultrasonic Testing (UT), Thermography, Radiographic Testing (RT), Electromagnetic Testing (ET), Acoustic Emission (AE), and Shearography Testing, as well as the benefits and drawbacks of each technique. Additional techniques are categorised based on their inherent qualities and applicability. Typically, an NDT evaluator performs the evaluation using just one non-destructive test method. Using just one test technique is allowed if the scope of the job is simple. A mixture of several test methods is necessary because there are situations when a single test method does not give sufficient information about the material integrity Following that, approaches were grouped according to their inherent qualities and applicability. Non-destructive testing is frequently used in power plants, the aerospace, nuclear, military, and defence industries, as well as storage tank inspection, pipe and tube inspection, and the characterisation of composite flaw. The extent of NDT use for composite materials is the primary emphasis of this paper.

Introduction

Non-destructive methods are a significant category among the many different methods available for evaluating materials or components. Identification and characterisation of damages on the exterior and inside of materials without rupturing or otherwise changing the material are the tasks of non-destructive evaluation (NDE) or non-destructive testing (NDT) [1]. NDT stands for non-destructive testing, which is the evaluation and inspection of materials or components for characterization or identifying defects and flaws in comparison with some criteria without changing the original attributes or injuring the object being tested. NDT techniques offer an affordable way to test a sample for a single investigation or to check the entire material as part of a production quality control system.[2].

Non-destructive testing is a technique used to examine a material's integrity for surface, internal, or metallurgical faults without compromising the material's ability to be destroyed or its suitability for use [3]. The most crucial responsibilities in testing composite materials are played by a wide range of non-destructive testing techniques. Applications for composite NDT can be found in a variety of fields, including manufacturing, the production of pipes and tubes, storage tanks, aerospace, military and defence, the nuclear industry, and the characterization of composite faults. Damage to composite materials can occur during material processing, component manufacture, or in-service operations; the most frequent flaws are cracks, porosity, and delamination. [4] In the field of composite nondestructive testing (NDT), a wide range of methods are employed, including radiographic testing, visual testing (VT) or visual inspection (VI), ultrasonic testing, thermographic testing, infrared thermography testing, acoustic emission testing (AE), acoustic-ultrasonic testing, electromagnetic testing, shearography testing, optical testing, liquid penetrant testing, and magnetic particle testing. In order to determine the most effective method, this paper analyses numerous NDT techniques for defect characterisation and identification in material and composites.

2 Methods of Non-Destructive Testing Composites categories

1. **Contact vs. Non-Contact Techniques**

The two primary categories of NDT techniques are contact and non-contact techniques, and both have unique uses in analyzing and testing composites. Most NDT techniques require good contact between the sensor and tested composite surface to obtain reliable data. Contact methods are traditional ultrasonic testing, eddy current testing, magnetic testing, electromagnetic testing, and penetrant testing. Another approach to speed up the data collection process is to eliminate the need for physical contact between the sensor and tested structure. Noncontact methods are through transmission ultrasonic, radiography testing, thermography, shearography, and visual inspection (2). Optical methods (e.g. Thermography, holography or shearography) are mostly noncontact. Table 1 categorized NDT methods to contact methods and

Table 1: Contact & Non-Contact NDT Methods

Contact Methods	Non-Contact Methods
Traditional ultrasonic testing	Through transmission Ultrasonic
Eddy current testing	Radiography testing
Magnetic testing	Thermography
Electromagnetic	Infrared Testing
Penetrant testing	Holography
Liquid penetrant	Shearography
-	Visual inspection

2. Structural integrity and physical properties

Different methods can be used to test composites. When determining the appropriate approach to use, it is crucial to give those variables adequate consideration. These criteria include efficiency and safety. The technique picked should also reduce the expense of the process.

The main causes of failures in composites are material defects. Damages from material composite failure might appear as matrix cracking, fibre fracture, fibre debonding, and fibre pull-out (5). Advanced non-destructive testing (NDT) techniques are used in the systematic process of structural integrity to locate and quantify damage. [6]

Category	Applications
Estimating the mechanical and physical properties, as well as identifying material flaws in composite materials	Dynamic mechanical analysis measurement (DMA) [7]) The proportion of the fibre [8]) The mechanical stiffness and strength [9]) The elastic constants [10]) The amount of material (El-Sabbagh et al. 2013) Failure to initiate damage and ensuing damage evolution [11] Delamination [12], laminate construction [13], resin curing state [14], and fiber/matrix interface [15] conditions
For the purpose of evaluating the integrity of composite structural components	Finding fractures and debonding [16], mechanical rubbing [17], fibre pullout [18], and fibre breakage [19]

There are many available nondestructive procedures or processes. These techniques can be applied to metals, polymers, ceramics, composites, cermets, and coatings to detect cracks, internal voids, surface cavities, delamination, incomplete faulty welds, and any other sort of flaw that might result in premature failure. Typical NDT test protocols are listed in Table 1.

NDT Method versus Inspection Type

According to the literature review, there are many different kinds of inspections to evaluate composites, and for each of them, numerous research methodologies have been offered. The suggested methods in the literature for identifying damage in aircraft composite structures, evaluating aircraft composites, and keeping track of the health of aerospace composite structures are ultrasonic testing [20] thermographic testing [20], vibration methods [21], infrared thermography [22], shearography [23], and XCT [24].

Visual Testing (VT) – [VI - Visual Inspection] : Because it can save time and money by lowering the quantity of other testing or, in some cases, by eliminating the necessity for other types of testing altogether, visual testing (VT) - (VI - Visual Inspection) should be the most fundamental sort of NDT that many instances use. The visual inspection's speed is its most significant benefit. The process's relative affordability is visual inspection's additional benefit. Although visual inspection does not require any special equipment, it has several inherent drawbacks.

Ultrasonic Testing (UT) A transmitter and receiver circuit, a transducer tool, and display devices make up an assessment system. The position of the fracture, the extent of the fault, its direction, and other features might be determined based on the information conveyed by the signal [25]. Ultrasonic testing has benefits such as quick scan times, effective flaw detection abilities, and field usability. The difficulty of setup, the level of expertise required to effectively scan a part, and the requirement for test samples to ensure accurate testing are drawbacks. When evaluating the same part design repeatedly on an assembly line, this form of testing is ideal. In different applications, pulse echo and through transmission methodologies to ultrasonic NDT are typically used. High frequency sound is used in both of these methods. Both of these methods employ high frequency sound waves between 1 and 50 mhz to find intrinsic faults in a substance [26]. Testing with ultrasound iVs done in three different ways: transmission, reflection, and back scattering. Each of these employs a variety of coupling substances, transducers, and frequencies [27]. Wave propagation speed and amplitude (or energy) loss are the two most frequently utilised indicators of characteristics. Some of the testing techniques discussed here only evaluate a single property, but more flexible techniques may evaluate two or three [28]. The majority of applications just take the pulse velocity into account and link it to various parameters. A few more properties of a material can be discovered by taking energy loss into account [29]. Numerous authors have researched the pulse attenuation analysis technique. [30] Three factors that effect attenuation are geometry, absorption, and scattering. Scattering originates from tiny discontinuities like grain boundaries.

Thermography testing : Testing using thermography: Testing using thermography is also known as thermal imaging. The heat fluctuation caused by faults that are positioned further below a component's surface tends to be smaller than that caused by faults that are located close to the surface, which could affect a material's thermal conductivity. For thin parts, thermography inspection is used for this reason. Generally speaking, this type of inspection cannot find faults whose diameter is less than their depth in the component. Thermal radiation in the area is changed by a defect, such as a delamination or impact damage [31] There are many advantages and disadvantages to this form of evaluation. One advantage is that it can inspect the wide surface of a part. In contrast to many other methods of inspection, it does not require coupling, which is the second advantage. This enables the inspection of components that can only be examined from one side.

Radiographic Testing (RT) is the most popular testing technique [1]. A delamination that creates an air pocket is the most frequent type of damage to composites; a delamination can only be observed in RT if its orientation is not perpendicular to the x-ray beam. There are numerous varieties of radiography, and each has a particular use. When the pieces are in the middle between being somewhat thick and thin, conventional radiography is most helpful. Low voltage radiography is employed for thin parts between 1 and 5 mm, and -ray radiography is effective for thick parts. Large voids, inclusions, trans-laminar cracks, uneven fibre distribution, and fibre misorientation like fibre wrinkles or weld lines can all be found using these forms of radiography. [26]. Another kind of radiography penetrates the composite with -rays. Because gamma rays have shorter wavelengths than other radiation, they are suitable for radiographs of thick sections. Another type of radiography used to identify microscopic matrix cracks and delaminations in a material is penetrant-enhanced [32] Unfortunately, this approach is less common because it poses risks when handling radioactive materials. This method is suitable for finding internal flaws or imperfections in ferrous and non-ferrous metals as well as other substances. Both electrically generated X-rays and radioactive isotope-emitted gamma rays are penetrating radiation that is variably absorbed by the material it passes through; the greater the thickness, the greater the absorption [3].

Electromagnetic Testing (ET) Electromagnetic testing (ET) techniques use electricity and magnetism to find and assess flaws, corrosion, and other problems in materials. ET creates magnetic fields, electric currents, or both inside a test object and then monitors the electromagnetic reaction. Eddy Current Testing (EC), Remote Field Testing (RFT), Magnetic Flux Leakage (MFL), and Alternating Current Field Measurement are examples of electromagnetic (EM) procedures (ACFM). The underlying physics in each of these methods is fundamentally different since the fields are described by various classes of partial differential equations (pdes).

Acoustic Emission (AE) Acoustic Emission (AE) is an effective method of imperfection analysis. This mechanical vibration generated by material defects such as matrix micro cracking, fiber-matrix debonding, localized delamination, or fiber pullout and breakage [33]. The stress waves that result from these types of defects spread out concentrically from their origin and are detected by an array of highly sensitive peizoelectrics. Two characteristics set the acoustic emission technique apart from the majority of other NDE methods. The signal's point of origin is the first distinction. This approach detects the "sound" produced by energy released in the object rather than providing energy to the object. The way AE handles dynamic processes in a material is the second distinction. It is important to be able to tell the difference between developing and stationary faults.

Acousto-Ultrasonic testing combines acoustic and ultrasonic testing techniques and is used specifically to assess the severity of internal flaws and inhomogeneities in a composite. Based on its superior economy, flexibility, and sensitivity, the acoustic/ultrasonic testing class has a lot of potential for nondestructive testing. No method currently in use, however, is sensitive or trustworthy enough to detect something. It is a practical technique since it makes non-critical defects visible and evaluable. The second benefit is that it serves as a reliable indicator of cumulative impact or fatigue damage to a structure. The setup and pre-calculations that are required before any testing are the drawback of this form of examination. The second drawback is that this kind of testing is ineffective for identifying specific, significant faults like delamination or voids [34].

Shearography Testing A laser optical technique is shearography testing. Shearography has the benefit that the failure of composite materials typically results from stress concentrations, and the degree of strain concentrations surrounding a specific defect makes determining the criticality of defects simple [35]. Shearography has the additional benefit of being less vulnerable to noise than many other nondestructive testing methods. This is advantageous since it enables less experienced users to examine and assess a part's suitability without needing substantial training. Shearography has a significant drawback in that it is very difficult to characterise defect types other than delamination. As a result, it is occasionally used in conjunction with other kinds of non-destructive evaluation procedures that can aid in the detection of specific flaws.

Dye Penetrate Testing: This method relies on a liquid's capacity to be pulled into a fault in a "clean" surface by capillary action. Metals (such as aluminium, steel, titanium, copper, etc.), glass, various ceramic materials, rubber, and plastics are among the materials that are frequently investigated using DPT or LPI. All non-ferrous and ferrous materials can be tested for penetrability using the penetrant used in dye penetration testing, however magnetic-particle inspection is frequently employed for ferrous components due to its ability to detect subsurface materials. DPT is used to find flaws in casting, forging, and welding surface flaws such hairline cracks, surface porosity, leaks in new products, and fatigue cracks on operating or in use components. LPI is based on capillary action, in which a fluid with low surface tension permeates into surface-breaking discontinuities that are both clean and dry. Penetrant might be brushed, sprayed, or dipped onto the test component or specimen. The excess penetrant is removed and a developer is added once enough time for penetration has passed. In DPT, the key benefit of utilising a developer is that it aids in drawing penetrant out of the fault so that an unseen or invisible indicator becomes evident to the inspector. Depending on the type of dye employed (fluorescent or nonfluorescent), inspection is carried out under ultraviolet or white light (visible). [3]

Magnetic Particle Inspection: This technique looks for faults in components by using magnetic fields and tiny magnetic particles, such iron filings. A ferromagnetic material, such as iron, nickel, cobalt, or any of their alloys, must be used to make the component being inspected in order for the inspection to be successful. This is the only criterion from the perspective of inspectability. The simplest method involves placing an electromagnet yoke on the surface of the component to be studied, pouring a kerosene-iron filling suspension on it, and then energising the electromagnet. So, just as iron particles spread on a split magnet would be drawn to and cluster at the magnet's pole ends, the iron particles would also be drawn to the edges of the crack that was acting as the magnet's poles. The foundation of magnetic particle inspection is the cluster of particles, which is far simpler to see than the actual break. The detection of surface and near-surface discontinuities in magnetic materials, namely ferrite steel and iron, is appropriate for this technology. [3]

Eddy Current Testing: Electromagnetic induction is the technique through which eddy currents are produced. A magnetic field forms inside and around the conductor when alternating current is delivered, as when copper wire is used as the conductor. This magnetic field grows during the process as the alternating current increases to its maximum and contracts during the process as the current is decreased to zero. A new or secondary electrical conductor will experience current induction if it is brought into close proximity to this shifting magnetic field. The characteristics of the material, such as voids, fissures, and variations in grain size, as well as the physical separation between the coil and the material, affect these currents. On a second coil that serves as a sensor, these currents cause resistance to build. In actual fact, a probe is placed above the surface of the part to be inspected or examined, and through the same probe, electronic equipment measures the eddy current in the work piece. Eddy current testing can be used to identify a variety of things, including cracks, measure material thickness, measure coating thickness, detect heat damage, determine case depth, measure conductivity to identify the material, and monitor heat treatment. [36].

3. Composite material nondestructive testing

Nowadays Due to their numerous remarkable features, composite materials hold enormous promise for their potential and expected uses in a range of industries, from aerospace to construction. This attention is not only being drawn to them because they are at the forefront of active material research. A variety of methodologies and techniques have been developed and modified over time as a result of the nondestructive testing and inspection or examination of composite structures, both for manufacturing quality assurance and for the identification of in-service damage. Since composite materials are frequently non-homogeneous and anistropic, fault detection calls for professional effort.[37] There are large variety of non-destructive testing procedures are available for composite material fault evaluation. Techniques including infrared thermography, acoustic emission, and ultrasonics are successfully used in composite materials. Ultrasonic method yields more accurate and trustworthy results. Moreover, this method poses no danger. The skill is necessary during the operation.

The aeronautical structures are also scanned using the shearography technology. In GRP pressure vessels, where inclusion is found using shearography, this is likewise applicable and helpful. Composite materials offer more anisotropy and superior specific stiffness, which can be tailored to the demands of structural loads. The use of composites is expanding, and it is currently used in applications across the transportation sector, including those for next-generation aeroplanes like the brand-new Boeing 787. In marine applications, composites are frequently employed, and they have revolutionised sports equipment including skis, tennis rackets, and golf clubs. [38]

Delaminations or disbonds (laminate-to-laminate or laminate-to-core), broken fibres from impact, fatigue damage that affects the zone of the composite material through microcracking, fibre delaminations, fibre breaks, and a general loss of mechanical modulus are typical manifestations of composite mechanical damage. Thermal damage from prolonged exposure to heat above resin cure temperatures as well as a combination of effects due to extreme operational conditions can also result in composite mechanical damage. A summary of potential flaws and damage observed in composite materials is shown in Table 2.

Table No. 2 Defects in composite [38]

Defects in Composites	
Delaminations	Missing Adhesive
Disbonds	Misoriented Fibers/ Ply
Porosity	Wavy Fibers
Contamination	Mislocated Ply/ Details
Improper Cure	Impact Damage
Resin Rich/Poor	Thermal Damage
Damaged Fiber	Thickness Variation
Voids	Dimensional Problem
Cracks	Interface Integrity

A quick growth and advancement in health monitoring applications, as well as future prognostics of the structural degradation, are supported by the combination of non-destructive testing techniques and the requirement for ongoing monitoring of the structural condition of composite materials. [38] All of these variables significantly affect the testing of composites using non-destructive techniques.

Conclusion

In order to provide a thorough analysis of NDT of composites, this study analysed NDT methods for composite evaluation by classifying their benefits and drawbacks as well as outlining NDT methods of composite materials. The non-destructive testing of composite materials has grown more important and challenging as a result of the fact that composite tools are typically employed in critical-safety applications, such as in the primary building of aeroplanes. When determining the appropriate approach to use, efficiency and safety considerations should be taken into account. The technique picked should also reduce the expense of the process. It is founded on techniques that depend on the use of physical values to ascertain a material's properties.

References

1] Lockard, C. D. (2015). Anomaly detection in radiographic images of composite materials via crosshatch regression. (1586713 M.A.), Mills College, Ann Arbor. Retrieved from proquest Dissertations & Theses Global database.

2] Newswire, P. (2013, 2013 Feb 07). Global Non-Destructive Testing (NDT) Equipment Market - By Technology (Ultrasonic, Eddy Current, Electromagnetic, Radiography, Thermography), Verticals (Manufacturing, Petrochemical, Aerospace, Automotive, Power Generation) & Geography (2013 - 2018), PR Newswire.

3]. S. Kumar, D. G. .Mahto. Recent trends in industrial and other engineering applications of non destructive testing: a review. International Journal of Scientific & Engineering Research. 2013 Sep;4(9).

4]. MR Jolly, A. Prabhakar, B. Sturzu, K. Hollstein, R.Singh, Thomas, P. Foote & A. Shaw. Review of Non-destructive Testing (NDT) Techniques and their Applicability to Thick Walled Composites. Procedia CIRP. 2015 Dec 31;38:129-36.

5]. Mckuur, G. (2006). Defect and Fracture Detection Using Acoustic Emission Monitoring: University of Cape Town.

6] Katunin, A., Danczak, M., & Kostka, P. (2015). Automated identification and classification of internal defects in composite structures using computed tomography and 3D wavelet analysis. Archives of Civil and Mechanical Engineering, 15(2), 436-448.

7] sturm, R., Grimberg, R., Savin, A., & Grum, J. (2015). Destructive and nondestructive evaluations of the effect of moisture absorption on the mechanical properties of polyester-based composites. Composites Part B: Engineering, 71, 10-16.

8] El-Sabbagh, A., Steuernagel, L., & Ziegmann, G. (2013). Characterisation of flax polypropylene composites using ultrasonic longitudinal sound wave technique. Composites Part B: Engineering, 45(1), 1164-1172. Doi: http://dx.doi.org/10.1016/j.compositesb.2012.06.010

9] Ray, B. C. (2006). Temperature effect during humid ageing on interfaces of glass and carbon fibers reinforced epoxy composites. Journal of Colloid and Interface Science, 298(1), 111-117. Doi: http://dx.doi.org/10.1016/j.jcis.2005.12.023

10] Rojek, M., Stabik, J., & Wróbel, G. (2005). Ultrasonic methods in diagnostics of epoxy–glass composites. Journal of Materials Processing Technology, 162, 121-126.

11] Talreja, R. (2008). Damage and fatigue in composites–a personal account. Composites Science and Technology, 68(13), 2585-2591.

12] Ghadermazi, K., Khozeimeh, M. A., Taheri-Behrooz, F., & Safizadeh, M. S. (2015). Delamination detection in glass–epoxy composites using step-phase thermography (SPT). Infrared Physics & Technology, 72, 204-209. Doi: http://dx.doi.org/10.1016/j.infrared.2015.08.006

13] Sarasini, F., & Santulli, C. (2014). 10 - Non-destructive testing (NDT) of natural fibre composites: acoustic emission technique. In A. Hodzic & R. Shanks (Eds.), Natural Fibre Composites (pp. 273-302): Woodhead Publishing.

14] Aggelis, D. G., & Paipetis, A. S. (2012). Monitoring of resin curing and hardening by ultrasound. Construction and Building Materials, 26(1), 755-760. Doi: http://dx.doi.org/10.1016/j.conbuildmat.2011.06.084

15] Kersemans, M., De Baere, I., Degrieck, J., Van Den Abeele, K., Pyl, L., Zastavnik, F., . . . Van Paepegem, W. (2014). Nondestructive damage assessment in fiber reinforced composites with the pulsed ultrasonic polar scan. Polymer Testing, 34, 85-96.

16] Giurgiutiu, V. (2016). Chapter 5 - Damage and Failure of Aerospace Composites. In V. Giurgiutiu (Ed.), Structural Health Monitoring of Aerospace Composites (pp. 125-175). Oxford: Academic Press.

17] Gostautas, R., Ramirez, G., Peterman, R., & Meggers, D. (2005). Acoustic Emission Monitoring and Analysis of Glass Fiber-Reinforced Composites Bridge Decks. Journal of Bridge Engineering, 10(6), 713-721.

18] Short, G., Guild, F., & Pavier, M. (2002). Delaminations in flat and curved composite laminates subjected to compressive load. Composite structures, 58(2), 249-258.

19] Narita, F., Shindo, Y., Takeda, T., Kuronuma, Y., & Sanada, K. (2014). Loading Rate-Dependent Fracture Properties and Electrical resistancebased Crack Growth Monitoring of Polycarbonate Reinforced with Carbon Nanotubes Under Tension. Journal of Testing and Evaluation, 43(1).

20] Katunin, A., Dragan, K., & Dziendzikowski, M. (2015). Damage identification in aircraft composite structures: A case study using various nondestructive testing techniques. Composite structures, 127(0), 1-9. Doi: http://dx.doi.org/10.1016/j.compstruct.2015.02.080

21]Loutas, T. H., Panopoulou, A., Roulias, D., & Kostopoulos, V. (2012). Intelligent health monitoring of aerospace composite structures based on dynamic strain measurements. Expert Systems with Applications, 39(9), 8412-8422. Doi: http://dx.doi.org/10.1016/j.eswa.2012.01.179

22] Meola, C., & Carlomagno, G. M. (2014). Infrared thermography to evaluate impact damage in glass/epoxy with manufacturing defects. International Journal of Impact Engineering, 67(0), 1-11. Doi: http://dx.doi.org/10.1016/j.ijimpeng.2013.12.010

23] Růžek, R., Lohonka, R., & Jironč, J. (2006). Ultrasonic C-Scan and shearography NDI techniques evaluation of impact defects identification. NDT & E International, 39(2), 132-142. Doi: http://dx.doi.org/10.1016/j.ndteint.2005.07.012

24] Bull, D. J., Spearing, S. M., Sinclair, I., & Helfen, L. (2013). Three-dimensional assessment of low velocity impact damage in particle toughened composite laminates using micro-focus X-ray computed tomography and synchrotron radiation laminography. Composites Part A: Applied Science and Manufacturing, 52(0), 62-69. Doi: http://dx.doi.org/10.1016/j.compositesa.2013.05.003

25] Lu, Y. (2010). Non-destructive Evaluation on Concrete Materials and Structures using Cement-based Piezoelectric Sensor. (3457480 Ph.D.), Hong Kong University of Science and Technology (Hong Kong), Ann Arbor. Retrievedfromhttp://search.proquest.com/docview/880396184?Accountid=28930 proquest Dissertations & Theses Global database.

26] Garney, G. (2006). Defects found through non-destructive testing methods of fiber reinforced polymeric composites. (1438996 M.S.), California State University, Fullerton, Ann Arbor. Retrieved from http://search.proquest.com/docview/304910161?Accountid=28930 proquest Dissertations & Theses Global database.

27] Stonawski, O., & Engineering, S. I. U. A. C. M. (2008). Non-destructive Evaluation of Carbon/carbon Brakes Using Air-coupled Ultrasonic Inspection Systems: Southern Illinois University at Carbondale.

28] Ducharne, B., Guyomar, D., Sébald, G., & Zhang, B. (2015). 10 - Modeling energy losses in power ultrasound transducers. In J. A. Gallegojuárez & K. F. Graff (Eds.), Power Ultrasonics (pp. 241-256). Oxford: Woodhead Publishing.

29] Karabutov, A. A., & Podymova, N. B. (2014a). Quantitative analysis of the influence of voids and delaminations on acoustic attenuation in CFRP composites by the laser-ultrasonic spectroscopy method. Composites Part B: Engineering, 56(0), 238-244.

30] El-Sabbagh, A., Steuernagel, L., & Ziegmann, G. (2013). Characterisation of flax polypropylene composites using ultrasonic longitudinal sound wave technique. Composites Part B: Engineering, 45(1), 1164-1172. Doi: http://dx.doi.org/10.1016/j.compositesb.2012.06.010

31] Meyendorf, N.G.H., P.B. Nagy, and S. Rokhlin (2013), Nondestructive Materials Characterization: With Applications to Aerospace Materials: Springer Berlin Heidelberg.

32] Ataş, A., & Soutis, C. (2013). Subcritical damage mechanisms of bolted joints in CFRP composite laminates. Composites Part B: Engineering, 54(0), 20-27. Doi: http://dx.doi.org/10.1016/j.compositesb.2013.04.071

33] Arumugam, V., Kumar, C. S., Santulli, C., Sarasini, F., & Stanley, A. J. (2011). A Global Method for the Identification of Failure Modes in Fiberglass Using Acoustic Emission. Journal of Testing and Evaluation, 39(5).

34] Schroeder, J. A., Ahmed, T., Chaudhry, B., & Shepard, S. (2002). Non-destructive testing of structural composites and adhesively bonded composite joints: pulsed thermography. Composites Part A: Applied Science and Manufacturing, 33(11), 1511-1517.

35] Hung, Y. Y., Yang, L. X., & Huang, Y. H. (2013). 5 - Non-destructive evaluation (NDE) of composites: digital shearography. In V. M. Karbhari (Ed.), Non-Destructive Evaluation (NDE) of Polymer Matrix Composites (pp. 84-115): Woodhead Publishing.

[36]. Web.Itu.Edu.Tr/~Arana/Ndt.Pdf.

37]]. I.V. Kaushal , A.Sai Kiran, A Review Of Non Destructive Testing Methods For Composite Materials , IJMETMR, Jan 24, 2014. [33]. Web.Itu.Edu.Tr/~Arana/Ndt.Pdf.

38]]. BB. Djordjevic. Nondestructive test technology for the composites. InThe 10th International Conference of the Slovenian Society for nondestructive testing 2009 Sep (pp. 259-265).