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REVIEW ON RECENT DEVELOPMENTS IN NON-DESTRUCTIVE TESTING TECHNIQUES FOR ENGINEERING APPLICATIONS

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Abstract

Newer production and technologies and materials demands advanced non-destructive testing methods for quality and inspection of materials for internal flaws, particularly when critical safety is needed for certain applications. The recent developments in NDT providesystem engineers with challenging opportunities for bettersolutions for NDT. Thisstudyprovides information about non-destructive testing techniques for various engineering applications. This review covers the capabilities of most common techniques in NDT applications such as Visual Inspection, Ultrasonic Testing, Thermography, Radiographic Testing, Electromagnetic Testing, Acoustic Emission, and ShearographyTesting. The suitability of each method is decided based on advantages and disadvantages of different techniques.Application areas covered by Non-destructive testing arevarious power plants, nuclear industries, aircraft industries, military and defense industries, Inspection of storage tank, etc. This paper is mainly focused on the scope of NDT application for engineering applications.

Keywords: *NDT, Radiographic Testing, Shearography Testing, Composites*

1. Introduction

NDT plays important role in deciding quality and reliability of the product. Various techniques are available to evaluate materials or components and non-destructive techniques are important class of them with many application areas. The non-destructive testing helps in identifying flaws on the surfaces and interior part of the products without affecting properties.Selecting appropriate, cost effective and reliable NDT technique for the quality testingof productsto find defects and flaws in comparison with standards without changing the original attributes or affecting the object being tested.Damage in composite materials can arise during processing of material, fabrication of the part or in-service activities among which cracks, porosity and delamination are the most common defects.Nondestructive testing methods are cost effective means of testing of a sample for investigation or may be applied on the whole material for checking in a production quality control system.

Various NDT methods play major roles in testing of composite materials. The applications of composite NDT may include manufacturing of pipe and tube, storage tanks, aerospace industry, military and defense, nuclear industries.Numerous methods are used in the composite Nondestructive testing field, including ultrasonic testing, thermo graphic testing, infrared thermography testing, Radiographic testing, Visual inspection, acoustic emission testing, Shearography testing, Dye penetrant inspectionand Magnetic particle inspection.This review mainly focused onNondestructive testing methods for composites and other engineering applications and discussion about their advantages and limitations.

2. Non-Destructive Testing Methods

Various nondestructive testing techniques are used for metals, plastics, ceramics, composites, and coatings for identifying surface cracks, internal flaws, surface cavities, delamination, incomplete welds and any type of defect which would lead to premature failure.

Visual Inspection- This is mainly effective for detecting macroscopic defects in poor welds. Most of the welding defects are macroscopic in nature such as crater cracking, undercutting, slag inclusion, incomplete penetration welds, Similarly, Visual Inspection is also used for detecting flaws in composite structures and piping of different types. Improper welds or joints, missing fasteners or components, poor fits, improper dimensions, improper surface finish, small and large cracks, cavities and dents,

Radiography Testing-This technique is expensive as compared with other techniques. Thick sections consume a substantial amount of time and energy cost associated is also high. Radiography method has benefit over some of the other NDT methods in that the radiography provides a permanent reference for the internal soundness of the object that is radiographed. The x-ray emitted from a source has capability to penetrate metals as a function of the accelerating voltage in the x-ray tube. If any irregularities and flaw such as void present in the components are radiographed, more x-rays will pass in that area and the film under the part in turn will have more exposure or spot light than in the non-void areas. The sensitivity of x-rays is approximately 2% of the materials thickness. A thin crack does not show unless the x-rays ran parallel to the plane of the crack. It is observed that Gamma radiography is identical to x-ray radiography in function. However this technique is less popular because it has a limitation of hazards during the handling of radioactive materials. This technique is suitable for the detection of internal defects in ferrous, non-ferrous metals and other materials. X-rays are generated electrically, and Gamma rays emitted from the radio-active isotopes, are penetrating radiation which is differentially absorbed by the material through which it passes; the greater the thickness, the greater the absorption.

Dye Penetrate Inspection- This inspectionis based on the capability of a liquid to be drawn into a "clean" surface breaking flaw by capillary action. Materials that are mostly inspected using DPI include metals (aluminum, steel, titanium, copper, etc.), glass, many ceramic materials, rubber, and plastics. The penetrant which is used in dye penetrate testing may be used to all non-ferrous and ferrous components; we also known that for ferrous components magnetic-particle inspection is frequently used instead of its subsurface detection capability. DPI is used to detect surface defects or flaws in casting, forging and welding such as micro cracks, surface porosity, leaks in new parts, and fatigue cracks on in-service or in operating components.The main benefit of using a developer in Dry Penetrant Inspection is that it helps to draw penetrant out of the defect or flaw so that an unseen or invisible indication becomes visible to the inspector. Inspection is performed under ultraviolet or white light, depending on the type of dye used fluorescent or non-fluorescent.

Ultrasonic Testing- This technique is used for the detection of internal defects in sound conducting materials. The principle of operation of ultrasonic testing is in some respects similar to echo sounding. A short pulse of ultrasound is generated by means of an electric charge applied to a piezoelectric crystal, which vibrates for a very short period at a frequency related to the thickness of the crystal. In flaw detection this frequency is usually in the range of 1 MHz to 6 MHz Vibrations or sound waves at this frequency they have the ability to travel a significant distance in homogeneous elastic material, such as many metals with very little attenuation. Ultrasonic testing employs an extremely diverse set of methods based upon the generation and detection of mechanical vibrations or waves within test components. Cathode ray tube is the standard means of presenting information in ultrasonic testing, in which horizontal movement of the spot from left to right represents time elapsed. The rate at which the spot moves is such that it gives the appearance of a horizontal line on the screen.

Magnetic Particle Inspection- This method uses magnetic fields and small magnetic particles, such as iron filings to detect flaws in components. The only requirement from is that the component being inspected must be made of a ferromagnetic material such as iron, nickel, cobalt, or some of their alloys, since these materials are materials that can be magnetized to a level that will allow the inspection to be effective. In its simplest application, an electromagnet yoke is placed on the surface of the part to be examined, a kerosene-iron filling suspension is poured on the surface and the electromagnet is energized. If there is a discontinuity such as a crack or a flaw on the surface of the part, magnetic flux will be broken from that place and a new south and North Pole will form at each edge of the discontinuity. Then just like if iron particles are scattered on a cracked magnet, the particles will be attracted to and cluster at the pole ends of the magnet, the iron particles will also be attracted at the edges of the crack behaving poles of the magnet. This cluster of particles is much easier to see than the actual crack and this is the basis for magnetic particle inspection. This method is suitable for the detection of surface and near surface discontinuities in magnetic material, mainly ferrite steel and iron.

Eddy Current Testing- Eddy currents are created by electromagnetic induction process. When alternating current is applied to the conductor, for example as in copper wire, a magnetic field generated in and around the conductor. During the process this magnetic field expands as the alternating current increases to maximum and collapses as the current is reduced to zero. If a new or secondary electrical conductor is brought into the close contact to this changing magnetic field, current will be induced in second conductor. These currents are influenced by the nature of the material such as voids, cracks, changes in grain size, as well as physical distance between coil and material. These currents form impedance on a second coil which is used as a sensor. In practice the surface of the component is to be tested by placing a probe above the surface, and electronic equipment monitors the eddy current in the work piece through the same probe. Eddy currents testing can be used to find out number of things such as crack detection, material thickness, coating thickness measurements, heat damage detection, case depth determination, conductivity measurements for material identification, heat treatment monitoring.

Acoustic Emission Testing- Acoustic emission is the sound waves created when a material undergoes stress, as a result of some external force. AE is a phenomenon occurring in for instance mechanical loading generating sources of elastic waves. This occurrence is the result of a small surface displacement of a material produced due to stress waves developed when the energy in a material or on its surface is released quickly. The wave which is developed by the source is of practical interest in techniques used to stimulate and capture AE in a controlled fashion, for study and inspection, examination, quality control, system feedback, process monitoring and others.Theimportant thing is that the acoustic emissions are detected with sensors consisting of piezoelectric ceramic elements. This method is particularly effective for continuous surveillance of load-bearing structures.

Shearography Testing is a testing and measuring technique similar to holographic interferometry. It utilizes coherent light or coherent sound waves to provide information about the quality of different materials in nondestructive testing, strain measurement, and vibration analysis. Shearography is largely used in production and development in aerospace industries, wind rotor blades, automotive industry, and materials research areas. Benefits of Shearography are the large area testing capabilities, non-contact properties, its relative insensitivity to environmental disturbances, and its good performance on honeycomb materials, which is a main challenge for traditional nondestructive testing methods. The important applications are in composite nondestructive testing, where typical defects are De -laminations, Wrinkles, Porosity, Foreign components. This is also used in industries such as Aerospace, Space, Boats, Wind power, Automotive, Tires, and Art conservatio

Thermography

Thermography mainly refers to the nondestructive testing of components, materials or systems through the imaging of the thermal patterns at the component surface. The thermography termmainly refers to all thermo graphic inspection techniques despite of the physical phenomena used for monitoring the thermal changes. For instance, the application of a temperature sensitive coating to a surface in order to measure its temperature is a thermographic inspection contact technique based on heat conduction where there is no infrared sensor involved.

Infrared thermography on the other hand, is a nondestructive, nonintrusive, noncontact mapping of thermal patterns or "thermograms", on the surface of objects through the use of some kind of infrared detector.It can be used to find defects in shafts, pipes, and other metal or plastic parts. It can alsouse to detect objects in dark areas. It has some medical application, essentially in physiotherapy.Thermography makes use of infrared imaging to detect flaws within the component. An Infra-Red camera records temporal distribution of the surface temperature after the component has been heated. Flaws disturb the heat flow and hence can be detected [6].Thermal NDT techniques broadly use active thermography.Here, heat waves are sent by using an internal or external source. This allows depth measurement, thickness measurement, and size of internal flaws.In addition to this, Pulse and Lock-In Thermography is used for NDT applications worldwide for flaw imaging [1].Pulsed Thermography is a class of thermography in which a stimulus is applied through a flash pulse, generally Xenon lamps. A selection of active-sources, various types of IR camera, and a range of analytical tools are available for response monitoring of the objects to the active-sources commonlyused NDT methods are shown in Table 1 [16].

Table 1Commonly used NDT Methods

Sr	NDT method	Capabilit	Limitations

N o.		**y of NDT method**	**of NDT method**
1	Visual inspection	Macroscopic surface flaws	Small flaws are difficult to detect, no subsurface flaws.
2	Microscopy inspection	Small surface flaws	Not applicable to larger structures; no subsurface flaws
3	Radiographic testing	Subsurface flaws	Smallest defect detectable is 2% of the thickness; radiation protection. No subsurface flaws not for porous materials
4	Dye penetratetesting	Surface flaws	No subsurface flaws not for porousMaterials
5	Ultrasonictesting	Subsurface flaws	Material must be good conductor ofsound.
6	Magnetic particletesting	Surface / near surface and layer flaws	Limited subsurface capability, only forferromagnetic materials.
7	Eddy currenttesting	Surface and near surface flaws	Difficult to interpret in some applications; only for metals
8	Acoustic emission testing	Can analyze entire structure	Difficult to interpret, expensive Equipment's
9	Shearographytesting	Disbands, Delamination, Wrinkles, Porosity, Foreign objects, and Impact damages	The Possibility of Damaging Material, Results are Complex to Interpret
10	Thermography	Allows measurement of depth, thickness, and size of internal flaws.	Most cameras have ±2% accuracy or worse in measurement of temperature and are not as accurate as contact methods. Methods and instruments are limited to directly detecting surface temperatures.

3. Literature Review

Yang Zhan-Feng et al [18] describes the nonlinear ultrasonic testing method for micro-damage of TATB based Polymer Bonded Explosive. This technique is used to evaluate the flaws inside explosive parts. For PBX specimen examination, the linear wave theory based method such as the ultrasonic Pulsed Echo method or transmission method is used. From the research we find out that the materials damage and property degradation are always come with some kind of non-linear mechanical behavior's, result in the non-linear ultrasonic transmission, like creating of the higher-order harmonic wave. In the research of micro-damage and performance of PBX parts the non-linear ultrasonic technique is used can be meaningful, which will give a new technique for the evaluation of the micro-damage and its expansion regularity as well as the reliability of explosives storage. During this inspection we found that the Ultrasonic linear parameters such as gain or velocity were not changed during the whole fatigue cycle loading process. Concluding to this work author proposed that the ultrasonic linear parameters are not sensitive to accumulation and development of micro-damage, which was very sensitive but not similar to ultrasonic nonlinear coefficient.

S. Kumar et al [14] stated that these testing techniques typically use a probing energy form to determine material properties or to indicate the presence of material discontinuities. It was found that most of the NDT methods are primarily used in many places such as in the aerospace industry, manufacturing industries and likely to be used for evaluating civil work and infrastructures. From this research paper, it is concluded that there is a need of more research work which is carried out so that these techniques are applicable for field use for civil infrastructure. This work reviews the dissimilar or different works in the area of NDT and trying to find out most recent developments and trends available in industries in order to reduce damages, minimize cost and maximize the safety operation.

MR Jolly et al [11] describes the most reliable and cost effective non-destructive testing technique for the thick walled carbon fibre component that can detect small cracks and other flaws and may be used in continuous flow production at an acceptable cost. From this research work we observed that delamination is the main type of flaw that exists within the component which lead to in-homogeneity within the composite part. Delamination size larger than 1 mm has to be detected. In Radiography technique the object is penetrated with short wavelength electromagnetic radiation. The total amount of radiation that passes through the component is captured by a detector. The absorption is a function of density and thickness of the material. Another method called Computed Tomography is used for thick walled carbon fibre component. This technique is used to generate an exact three-dimensional cross sectional image of the entire part. Defects that can be detected using this technique are delamination, porosity, fibre cracks or impact damages. Thermography testing makes use of infrared imaging to detect flaws within the component. Although Computed Tomography equipment is significantly more expensive than Ultrasonic Technique and thermography equipment, it is an established system having high reliability and a much better traceability.

Chunguang Xu et al [3]describes the non-destructive testing of residual stress using ultrasonic critical refracted wave in longitudinal direction. As we found that residual stress has significant effect on the performance of the mechanical parts, especially on its strength, fatigue life and corrosion resistance and dimensional stability. Residual stresses occur in many manufactured components and machineries. A wide variety of different methods has been developed to measure or determine residual stress for different types of components in order to obtain reliable assessment. Based on acoustic elasticity theory, the testing principle of ultrasonic longitudinal critical refracted wave method is analyzed. From this research paper we found that Ultrasonic LCR wave method has the characteristics of high resolution, high penetration and no harmful effect to the human body, and that is the most promising technology in the development of residual stress testing. Also by utilizing the ultrasonic detector, we carried out experimental research on residual stress testing of welded joint of oil pipeline. The residual stress in oil pipeline welds joint and several other mechanical components are tested. Through experiments, it is cleared that the accuracy, practicability of the ultrasonic LCR wave method.

S. Gholizadeh [15] reviewed the non-destructive testing methods for the evaluation of composites. Composite tools are mostly used for critical safety applications in aircraft construction. So to know the incipient faults in composites, the NDT techniques are very much essential. They uses different methods such as visual inspection technique, ultrasonic inspection, Thermography and more for evaluating faults in composite material. The best Nondestructive inspection method choice is depends upon the safety of operation and cost incurred during the operation.

Tirupan Mandal et al [17] describes the non-destructive testing of cementstabilized materials (CSMs) using ultrasonic pulse velocity instrumentation. In this flexural strength and modulus tests were conducted on CSMs and their constrained modulus were noted and recorded. The effect and outcome of compaction, curing time, and binder content was assessed. Results which we got from the ultrasonic pulse velocity tests shows that with decrease in density of the specimen, constrained modulus and P-wave velocity reduces, whereas, with increase in binder content and curing time of the specimen, the constrained modulus and P-wave velocity increases. Thus nondestructive inspection is proposed as a suitable and expedient method for determining the flexural properties of CSMs in comparison to destructive methods such as third-point bending beam tests.

Gabriel Dan Tasca et al [7] described research regarding ultrasonic examination of complex parts. Nondestructive evaluation process established and recognized in order to observe cracks and de-laminations that occur below the surface in titanium parts and in particularly in complex parts. Although X-rays method might be an apparent choice, but they are not effective in most of the cases, mostly when the flaw or defect has the same density as the surrounding material. We also know from this paper that the ultrasonic data can be used to give a better understanding of the failure mechanisms in this material. Automated Ultrasonic Testing has been used whenever detailed inspection of critical structures or components is required, such as in nuclear power plant. In addition to this AUT is also applied to other fields such as in the Process or production industry.

4. Conclusion

This review paper describes different NDT methods for engineering applications with their benefits and limitations for composite and other materials. Due to the fact that composite tools are mostly used in critical safety applications such as in aircraft industries, the non-destructive testing of composite materials has become more crucial and demanding. For analyzing the best NDT Method factors such as efficiency and safety should be used. Furthermore, the method chosen should reduce the cost associated in the operation. It is based on techniques that depend on the use of physical values to determine the characteristics of materials. In addition to this non-destructive tests use physical principles to identify and evaluate flaws or defects.

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