ISSN 2229-5518

Recent Trends In Industrial And Other Engineering Applications Of Non Destructive Testing: A Review

Sanjay Kumar & Dalgobind Mahto

Abstract- The field of NDT is a very broad, interdisciplinary field that plays a critical role in inspecting that structural component and systems perform their function in a reliable fashion. Certain standards has been also implemented to assure the reliability of the NDT tests and prevent certain errors due to either the fault in the equipment used, the miss application of the methods or the skill and the knowledge of the inspectors. Successful NDT tests allow locating and characterizing material conditions and flaws that might otherwise cause planes to crash, reactors to fail, trains to derail, pipelines to burst, and variety of less visible, but equally troubling events. However, these techniques generally require considerable operator skill and interpreting test results accurately may be difficult because the results can be subjective. This paper presents the reviews of different works in the area of NDT and tries to find out latest developments and trends available in industries and other fields in order to minimize the total equipment cost, minimize damages and maximize the safety of machines, structures and materials.
Keywords: *Non destructive* testing, *Objectives*, *Literature Review*, *Summary of Literature Review and Conclusion*.

1. Introduction

Non-Destructive Testing (NDT) is defined by the American Society for Non-destructive Testing (ASNT) as: "The determination of the physical condition of an object without affecting that object's ability to fulfil its intended function. Non-destructive testing techniques typically use a probing energy form to determine material properties or to indicate the presence of material discontinuities (surface, internal or concealed)." The application of physical principles for detecting in homogeneities in materials without impairing the usefulness of the materials has brought into being a technique known as "non-destructive testing". Actually, the methods and techniques used in NDT measure physical properties or non-uniformity in physical properties of materials as well. Variations or non uniformities in physical properties may or may not affect the usefulness of a material, depending upon the particular application under consideration. Non destructive testing is the testing of materials, for surface or internal flaws or metallurgical condition, without interfering in any way with the integrity of the material or its suitability for service. The technique can be applied on a sampling basis for individual investigation or may be used for 100% checking of material in a production quality control system.

2. Non Destructive Testing Methods

The common NDT methods are:

1. Visual and optical Testing
2. Ultrasonic Testing
3. Electromagnetic Testing
4. Thermographic Testing
5. Radiographic Testing
6. Liquid Penetrant Testing
7. Magnetic particle Testing
8. Acoustic Emission testing
9. Magnetic Resonance Imaging Testing
10. Near-Infrared Spectroscopy
11. Optical Microscope Testing

Sanjay Kumar M.Tech student, Green Hills Engineering College, Solan, India. E-mail : er.sanjaysharma749@gmail.com
Dr. Dalgobind Mahto, Professor In Mechanical engineering department. Green Hills Engineering College, Solan, India. E-mail : mahto123@rediffmail.com

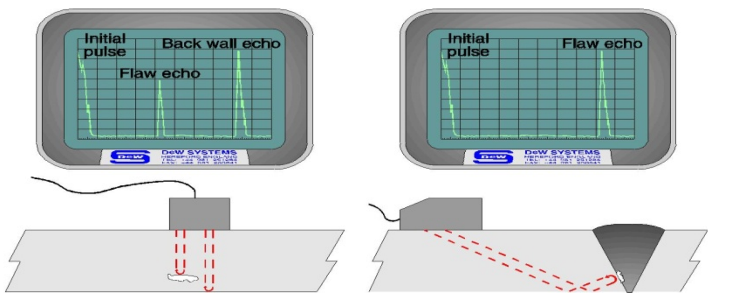
2.1 Visual and optical testing

Visual inspection is particularly effective detecting macroscopic flaws, such as poor welds. Many welding flaws are macroscopic: crater cracking, undercutting, slag inclusion, incomplete penetration welds, and the like. Likewise, VI is also suitable for detecting flaws in composite structures and piping of all types. Bad welds or joints, missing fasteners or components, poor fits, wrong dimensions, improper surface finish, large cracks, cavities, dents, inadequate size, wrong parts, lack of code approval stamps and similar proofs of testing.

2.2 Ultrasonic testing

This technique is used for the detection of internal and surface (particularly distant surface) defects in sound conducting materials. The principle 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 have the ability to travel a considerable distance in homogeneous elastic material, such as many metals with little attenuation. For example the velocity in steel is 5900 metres per second, and in water 1400 metres per second. Ultrasonic testing employs an extremely diverse set of methods based upon the generation and detection of mechanical vibrations or waves within test objects. The standard method of presenting information in ultrasonic testing is by means of a cathode ray tube, 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. The system is synchronised electronically so that at the instant the probe receives its electrical pulse the spot begins to traverse the screen. An upward deflection (peak) of the line on the left hand side of the screen is an indication of this occurrence.

ISSN 2229-5518



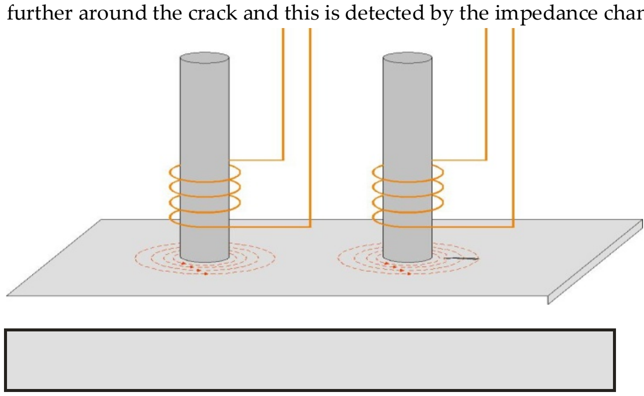
Schematic diagram of ultrasonic detection of slag in steel section using a normal probe.

Schematic diagram of the use of an angle probe to detect defects not directly under the probe. Such as in weld inspection.

Fig. 1 An Illustration of Ultrasonic Flaw Detection.

2.3 Electromagnetic testing

Electromagnetic Testing (ET), as a form of NDT, is the process of inducing electric currents or magnetic fields or both inside a test object and observing the electromagnetic response. If the test is set up properly, a defect inside the test object creates a measurable response. The main applications of the eddy current technique are for the detection of surface or subsurface flaws, conductivity measurement and coating thickness measurement. Eddy currents can be produced in any electrically conducting material that is subjected to an alternating magnetic field (typically 10Hz to 10MHz). The alternating magnetic field is normally generated by passing an alternating current through a coil. The coil can have many shapes and can between 10 and 500 turns of wire. The magnitude of the eddy currents generated in the product is dependent on conductivity, permeability and the set up geometry. Any change in the material or geometry can be detected by the excitation coil as a change in the coil impedance. The simplest coil comprises a ferrite rod with several turns of wire wound at one end and which is positioned close to the surface of the product to be tested. When a crack, for example, occurs in the product surface the eddy current must travel further around the crack and this is detected by the impedance change.



A - No Crack
- Circular pattern

B - Surface Crack
- Distorted Circle
- Currents go round and under the crack (Increased Impedance)

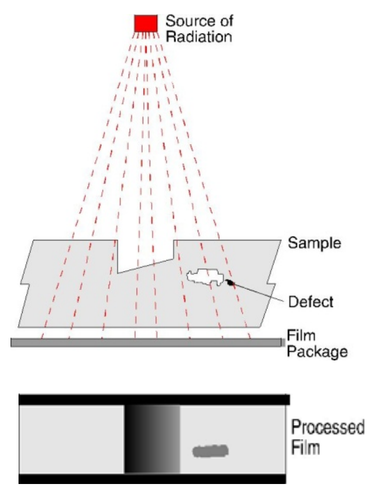
Fig. 2 An Illustration of Coil with single winding.

2.4 Thermographic testing

Infrared Thermography is the science of measuring and mapping surface temperatures. Infrared and thermal testing methods are characterized by the use of thermal measurements of a test object as it undergoes a response to a stimulus. Thermal imaging cameras are the most common sensing method. Passive imaging of machinery or electronics may be used to detect hot spots indicative of problems. Imaging of test objects after the application of energy can be used to monitor the flow of heat in the object, which is a function of material properties as well as boundaries. Flash thermography techniques have been very successful in imaging disbonds and delaminations in composite parts. Another significant recent advancement is the use of mechanical energy to stimulate localized heating at sub-surface discontinuities, such as cracks in metals, opening up a new field of application for the IR method. Infrared thermography, a nondestructive, remote sensing technique, has proved to be an effective, convenient, and economical method of testing concrete. It can detect internal voids, delaminations, and cracks in concrete structures such as bridge decks, highway pavements, garage floors, parking lot pavements, and building walls. An infrared thermographic scanning system can measure and view temperature patterns based upon temperature differences as small as a few hundredths of a degree Celsius. Infrared thermographic testing may be performed during day or night, depending on environmental conditions and the desired results. All objects emit electromagnetic radiation of a wavelength dependent on the object's temperature. The frequency of the radiation is inversely proportional to the temperature. In infrared thermography, the radiation is detected and measured with infrared imagers (radiometers). The imagers contain an infrared detector that converts the emitting radiation into electrical signals that are displayed on a colour or black & white computer display monitor.

2.5 Radiography testing

Radiography has an advantage over some of the other processes 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 an ability to penetrate metals as a function of the accelerating voltage in the x-ray emitting tube. If a void present in the object being radiographed, more x-rays will pass in that area and the film under the part in turn will have more exposure than in the non-void areas. The sensitivity of x-rays is nominally 2% of the materials thickness. Thus for a piece of steel with a 25mm thickness, the smallest void that could be detected would be 0.5mm in dimension. For this reason, parts are often radiographed in different planes. A thin crack does not show up unless the x-rays ran parallel to the plane the crack. Gamma radiography is identical to x-ray radiography in function. The difference is the source of the penetrating electromagnetic radiation which is a radioactive material such m Co 60. However this method is less popular because of the hazards of handling radioactive materials. This technique is suitable for the detection of internal defects in ferrous and non-ferrous metals and other materials. X-rays, generated electrically, and Gamma rays emitted from 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.



Schematic illustration of a typical exposure arrangement for radiography. The source of radiation can be either an X-ray tube or a radioactive isotope.

The resultant radiograph shows the subject as seen from the source.

Fig. 3 An Illustration of radiography testing.

2.6 Liquid penetrant testing

The technique is based on the ability of a liquid to be drawn into a "clean" surface breaking flaw by capillary action. Materials that are commonly inspected using LPI include the following; metals (aluminium, copper, steel, titanium, etc.), glass, many ceramic materials, rubber, plastics. The penetrant may be applied to all non-ferrous materials and ferrous materials; although for ferrous components magnetic-particle inspection is often used instead for its subsurface detection capability. LPI is used to detect casting, forging and welding surface defects such as hairline cracks, surface porosity, leaks in new products, and fatigue cracks on in-service components. LPI is based upon capillary action, where low surface tension fluid penetrates into clean and dry surface-breaking discontinuities. Penetrant may be applied to the test component by dipping, spraying, or brushing. After adequate penetration time has been allowed, the excess penetrant is removed and a developer is applied. The developer helps to draw penetrant out of the flaw so that an 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 (visible).

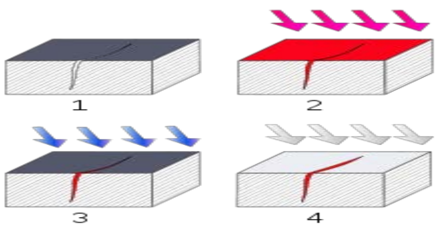


Fig.4 An Illustration of liquid penetration testing.

1. Section of material with a surface-breaking crack that is not visible to the naked eye.
2. Penetrant is applied to the surface.
3. Excess penetrant is removed.
4. Developer is applied, rendering the crack visible.

2.7 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 an inspect ability standpoint is that the component being inspected must be made of a ferromagnetic material such 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 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.

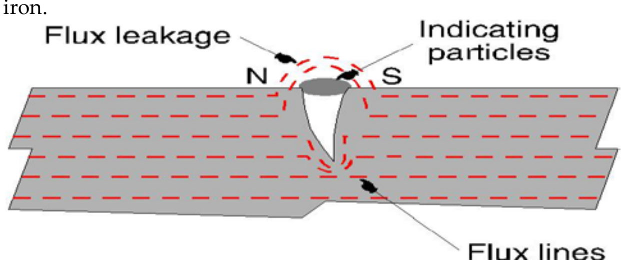


Fig. 5 An Illustration of the Principle of Magnetic Particle Inspection

2.8 Acoustic method

There are two different kind of acoustic methods: (a) acoustic emission; (b) acoustic impact technique.

(a). Acoustic emission

Acoustic emission (AE) is the sound waves produced when a material undergoes stress (internal change), as a result of an 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 generated when the energy in a material, or on its surface is released rapidly. The wave generated by the source is of practical interest in methods used to stimulate and capture AE in a controlled fashion, for study and/or use in inspection, quality control, system feedback, process monitoring and others.

(b). Acoustic impact technique

This technique consists of tapping the surface of an object and listening to and analyzing the signals to detect discontinuities and flaws. The principle is basically the same as when one taps walls, desktops or countertops in various locations with a finger or a hammer and listens to the sound emitted. Vitrified grinding wheels are tested in a similar manner to detect cracks in the wheel that may not be visible to the naked eye. This technique is easy to perform and can be instrumented and automated. However, the results depend on the geometry and mass of the part so a reference standard is necessary for identifying flaws.

2.9 Magnetic resonance imaging

Magnetic resonance imaging (MRI), nuclear magnetic resonance imaging (NMRI), or magnetic resonance tomography (MRT) is a medical imaging technique used in radiology to visualize internal structures of the body in detail. MRI makes use of the property of nuclear magnetic resonance (NMR) to image nuclei of atoms inside the body. MRI can create more detailed images of the human body than are possible with X-rays.

An MRI scanner is a device in which the patient lies within a large, powerful magnet where the magnetic field is used to align the magnetization of some atomic nuclei in the body, and radio frequency magnetic fields are applied to systematically alter the alignment of this magnetization. This causes the nuclei to produce a rotating magnetic field detectable by the scanner and this information is recorded to construct an image of the scanned area of the body. Magnetic field gradients cause nuclei at different locations to process at different speeds, which allows spatial information to be recovered using Fourier analysis of the measured signal. By using gradients in different directions, 2D images or 3D volumes can be obtained in any arbitrary orientation.

2.10 Near-infrared spectroscopy

Near-infrared spectroscopy (NIRS) is a spectroscopic method that uses the near-infrared region of the electromagnetic spectrum (from about 800 nm to 2500 nm). Typical applications include pharmaceutical, medical diagnostics (including blood sugar and pulse oximetry), food and agrochemical quality control, and combustion research, as well as research in functional neuroimaging, sports medicine & science, elite sports training, ergonomics, rehabilitation, neonatal research, brain computer interface, urology (bladder contraction) and neurology (neurovascular coupling).

Near-infrared spectroscopy is based on molecular overtone and combination vibrations. Such transitions are forbidden by the selection rules of quantum mechanics. As a result, the molar absorptivity in the near IR region is typically quite small. One advantage is that NIR can typically penetrate much farther into a sample than mid infrared radiation. Near infrared spectroscopy is, therefore, not a particularly sensitive technique, but it can be very useful in probing bulk material with little or no sample preparation.

2.11 Optical microscope

The microscope has a digital camera, and is attached to a computer. The optical microscope, often referred to as the "light microscope", is a type of microscope which uses visible light and a system of lenses to magnify images of small samples. Optical microscopes are the oldest design of microscope and were possibly designed in their present compound form in the 17th century. Basic optical microscopes can be very simple, although there are many complex designs which aim to improve resolution and sample contrast. Historically optical microscopes were easy to develop and are popular because they use visible light so that samples may be directly observed by eye. The image from an optical microscope can be captured by normal light-sensitive cameras to generate a micrograph. Originally images were captured by photographic film but modern developments in CMOS and charge-coupled device (CCD) cameras allow the capture of digital images. Purely digital microscopes are now available which use a CCD camera to examine a sample, showing the resulting image directly on a computer screen without the need for eyepieces.

3. Objectives

- Providing better quality of products.
- Reducing costs and increasing production.
- Detection of unwanted failures in the very beginning phase.
- Providing the ability to inspect the equipments in operational state.
- Reaching to higher levels of reliability.
- Gaining consumer satisfaction.
- Avoiding or reducing downtime and wastage of material.
- Thickness measurements.
- Evaluation of surface characteristics.
- Determining areas with high stress concentration.
- Prediction of material behaviour.
- To evaluate the properties of a material, component or system without causing damage.
- Internal characteristics of solid structures can be examined without permanently affecting the structure.

4. Literature survey

D. Bates et al [1] compares the use of different thermal non-destructive testing techniques to rapidly inspect carbon fibre composite aircraft components. Samples were prepared to simulate inclusions and barely visible impact damage in carbon fibre reinforced plastic laminate which represent faults in the manufacturing process and in-service environment respectively. The limits of material fault detection were then compared for transient and lock-in thermography and the results were verified with underwater ultrasonic c-scans.
Infrared thermography (thermal imaging) is an important and powerful technique for consideration when investigating any structural situation where a ready source of surface heating (or cooling) is available. The methods used are totally non-destructive and non-invasive, and can be highly cost-effective. D.J. Titman [2] explores a wide range of applications, particularly relating to structural investigation situations. Some guidance is given on optimum timing, conditions and viewing locations for the various situations described as well as limitations of the technique.
P Cawley [3] states that The NDT market is dominated by the 'big five' techniques: radiography, ultrasonic, eddy current, magnetic particle and penetrant testing. There is therefore a continuing drive to increase the speed of inspection, to reduce the preparation required and, if possible, to inspect without the need to shut down operation.
Jacek Jarmulak et al [4] present how the case-based reasoning methodology (where interpretation of new data is based on previous data-interpretation cases) can be used to tackle the problem of NDT data interpretation. The article presents the characteristics of CBR, which make it an interesting alternative to statistical classifiers and to expert systems.
Non destructive testing is an important method of insuring quality of the composites. Comparing with other non destructive testing methods, the ultrasonic inspection can be considered an effective method of checking the common defects and damages in composites, and its development of studying and application is introduced by Li Zhijun [5].
G. S. Park et al [6] describes the design method of a magnetic system to maximize the magnetic flux leakage (MFL) in a non-destructive testing (NDT) system. The defect signals in a MFL type NDT system mainly depend on the change of the magnetic leakage flux in the region of a defect.
The basis of the wave propagation and the principles of the hyperbolic triangulation are presented by P. Tschelisnig [7]. The state-of-the-art AE inspection system is explained with examples drawn from the TUV Vienna's 32-channel equipment and software. The AE tests performed at TUV Vienna and the results gained are discussed under the headings of integrity analysis and leakage tests.
Non-destructive testing provides the ability to differentiate different structures of materials or to measure internal and induced stresses, thus providing data for the calculation of reliability and potential lifetime [8]. Here, a closer monitoring of fast processes like crack propagation, especially under an impact load, may provide a better understanding of materials behaviour.
In Pulse Echo Ultrasonic testing piezoelectric transducers generate ultrasonic pulses, which are transmitted into the specimen to check for cracks and other defects [9]. Flaws in the specimen will reflect the signals back to be detected by the transducers. The amplitude and size of reflected pulses indicate the size and location of the flaw. Ultrasonics is limited in its capability to characterise near surface defects because of the interference between transmitted and received pulses in this area.
A new non-destructive testing (NDT) method for defect detection in concrete structures is presented by K. Mori et al [10]. The method is based on the dynamic response of flawed concrete structures subjected to impact loading. Conversely to similar NDT techniques, such as the impact-echo method, the present method uses non-contacting devices for both impact generation (a shock tube producing shock waves) and response monitoring (laser vibrometers measuring concrete surface velocity). According to the experimental and numerical results, it appears that the present method enables an effective detection of defects, particularly in the range of shallow defects.
The use of infrared thermography in the architectural restoration field is examined by Giovanni M. Carlomagnoet al [11]. Three samples, made of a support of marble, brick, or tuff, covered with a layer of plaster with inclusions to simulate detachments or cracks in frescoes, are considered. Different techniques: pulse thermography, lateral heating thermography, lock-in or modulated thermography and pulse phase thermography are employed to detect the flaws artificially created.
M.R Clark et al[12] shows that even with the low ambient temperatures experienced in Europe it is possible to use infrared thermography to identify correctly known areas of delamination in a concrete bridge structure and also to investigate the internal structure of a masonry bridge.
M.D. Beard et al [13] are aimed at the development of a portable non-destructive testing instrument for evaluating the condition of rock bolts. In applications such as coal mine roof reinforcement, the opportunities for rock bolt inspection are currently limited to destructive techniques such as the pull-out test.
Spectral Analysis of surface waves (SASW) in concrete structures consists of the generation, measurement and processing of dispersive

surface waves [14]. In SASW test, the surface of the media under consideration is subject to an impact using, for example, a 12-mm steel ball, to generate surface wave energy at various frequencies. Two vertical accelerometer receivers detect the energy transmitted through the testing media.

The optimum elements of the suitably defined matrices of the magnetic variables, based on the measurement of families of minor hysteresis loops, are more sensitive than any of the traditional parameters obtained from the saturation-to-saturation loop [15]. In order to get the optimum elements, the samples do not have to be measured up to their saturation value, but to a pre-determined lower magnetization value only.

The development of non-destructive techniques (NDT) techniques for the in-service inspection of railroad wheels and gauge corners was the main activity of the NDT division. Firstly the inspection of the wheels rim and disk should be carried out without dismantling the wheels and using ultrasonic techniques [16]. On the other hand, the inspection of the railroad track surface at a train speed of about 70 km/h should be guaranteed using eddy current techniques.

Thermal non-destructive testing (NDT) is commonly used for assessing aircraft composites. In this work, certain applications of transient thermal NDT relating to the assessment of aircraft composites are presented by N.P. Avdelid et al [17]. Real-time monitoring of all features was obtained using pulsed thermography. However, in the composite repairs cases thermal modelling and pulsed-phase thermography were also used with the intention of providing supplementary results.

Pulsed eddy current techniques, which are believed to be potentially rich of information, are also sensitive to the effect. Gui Yun Tian et al[18] gives an approach using normalisation and two reference signals to reduce the lift-off problem with pulsed eddy current techniques is proposed. The technique can also be applied for measurement of metal thickness beneath non-conductive coatings, microstructure, strain/stress measurement, where the output is sensitive to the lift-off effect.

C. Hakan Gur et al. [19] investigate the effect of quenching and tempering on sound velocity of steels, and to contribute to the non destructive control and optimisation of the quenching/tempering systems. Microstructures of the samples were characterised by metallographic examinations and hardness measurements. The reference values were obtained for as-quenched and tempered structures by measuring sound velocities for both longitudinal and transversal waves.

Impulse-thermography is well suited for the detection of voids and honeycombing in concrete up to concrete covers of 10 cm and more [20]. For quantitative analysis, a computer program for numerical simulation of the heating up and cooling down processes was developed based on Finite Differences. With this program parameter studies have been performed for investigating the influence of environmental conditions, material parameters and geometry on the thermal behaviour.

Yi-mei Mao et al [21] gives a detection technique for locating and determining the extent of defects and cracks in oil pipelines based on Hilbert-Huang time-frequency analysis is proposed. The ultrasonic signals reflected from defect-free pipelines and from pipelines with defects were processed using Hilbert-Huang transform, a recently developed signal processing technique based on direct extraction of the energy associated with the intrinsic time scales in the signal.

A non-destructive method is described by Gary S. Schajer et al [22] to estimate fibber (grain) direction, moisture density, and dry density of an orthotropic material such as wood, from measurements of the complex attenuation of microwaves transmitted through the material. The complex attenuation in an orthotropic material has a tensor character, similar to other tensor quantities such as stress and strain.

Allen G. Davis et al [23] describes the use of non-destructive testing to examine the efficiency of tunnel lining grouting programmes, with particular emphasis on results obtained by the impulse response and impulse radar methods.

K. Kosmas et al [24] presents a laboratory developed Hall sensor for non-destructive testing of ferromagnetic surfaces, based on magnetic anomaly detection phenomena. The principle of operation is based on the detection of the magnetic flux leakage in the dimensional boundaries of a gap.

Bruce W. et al [25] bring together the most relevant published work on arrays for non-destructive evaluation applications, comment on the state-of the art and discuss future directions. There is also a significant body of published literature referring to use of arrays in the medical and sonar fields and the most relevant papers from these related areas are also reviewed.

Impulse-thermography is an active method for quantitative investigations of the near surface region of various structures [26]. It has recently been applied and optimised to applications in civil engineering. By using either an internal or external heat source, parts of the structure under investigation are heated up and the transient heat flux is observed by recording the temperature change at the surface as a function of time.

Carosena Meola et al [27] study was focused on the aid provided by lock-in thermography for non-destructive evaluation of aerospace materials and structures. The experimental analysis was performed by testing several specimens, which were made of different materials employed in the fabrication of aircraft (composites, hybrid composites, sandwiches, metals) and which included the most commonly encountered kinds of damage (delamination, impact damage, fatigue failure).

Christoph Kohl et al [28] present the results of measurements carried out in the laboratory at BAM and on-site at several bridges using reconstructed and fused radar and ultrasonic echo data sets. In this context different scanning systems, developed for the on-site application of NDT-methods (e.g. reinforced concrete bridges) are introduced.

The diagnosis based on the propagation of guided ultrasonic waves along the pipes offers an attractive solution for the fault identification and classification. Francesca Cau et al [29] studied this problem by means of suitable Artificial Neural Network models. Numerical techniques have been used to simulate the guided wave propagation in the pipes. In particular, the finite element method has been used to model different kinds of pipes and faults, and to obtain several returning echoes containing the faults information.

In the first project material degradation due to thermal aging is investigated, in the second project neutron exposed specimens from national surveillance programmes of nuclear power plant (NPP) pressure vessels were characterised in the hot cell of the research reactor in Patten [30]. Fatigue specimens especially prepared in LCF tests were measured by electromagnetic and micro-magnetic non-destructive testing and evaluation techniques.

The steel cord rubber belt is one of the most important parts of a conveyor. The durability of the belt depends mainly on the steel cord durability. When a conveyer belt is in use the ropes of the cord can be broken or corroded [31]. Rope splice damage is also possible. A scanner with set of eddy current probes installed at the belt under the test surface is significantly lighter than a magnetic one and can work in the gap up to 10-20 mm between the probes and the belt.

D. Bracun et al [32] presents a laser-based method for three-dimensional (3D) measurements of the shape of an electrode indentation. The method is based on the illumination of the indentation with structured light and the detection of the image of the illuminated indentation by means of a digital camera. Image processing algorithms are employed to determine the 3D shape of the indentation.

Janez Marko Slabe et al[33] treats the results obtained in simultaneous measurements of Acoustic Emission (AE) with PZT AE sensors and of deformations with resistance measuring rosettes carried out during and immediately after laser cutting-out of a deep-drawn sheet product, i.e., mudguard. It was found that the main source of AE during laser cutting was the cutting gas jet.

In ultrasonic non-destructive testing it is very difficult to detect flaws in materials with coarse-grain structure. The ultrasonic signals measured on these materials contain echoes which are very similar to fault echoes. These echoes arise from grains which are contained in the material. For the detection of flaws various methods for suppressing echoes from grains have to be used. Vaclav Matz et al [34 used the method for filtering ultrasonic signals based on discrete wavelet transform. For the classification of ultrasonic signals in A-scan we used a pattern recognition method called support vector machines. In this study we classify signals with fault echoes, echo from weld and back-wall echo. Ultrasonic signals were measured on materials used for constructing aeroplane engines.

Defects need to be banned and dimensional measurement of complex geometries with high resolution is required. In addition, throughput is high and production cycles may last only a few seconds. These objectives call for non-destructive testing that keeps step with the production cycle [35]. Production and quality measurement techniques therefore play an important role in providing customers with more economical and reliable products. We briefly compare various NDT techniques and demonstrate the feasibility of X-ray tomography as a technique suitable for the dimensional measurement of complex structures with sub-µm resolution.

Dye Penetrant Inspection (DPI) and Magnetic Particles Inspection (MPI) are two of the most commonly used NDT techniques in industry. Both techniques do rely heavily on human judgment and visual capability to identify any faults or defects on the specimen at the end of the process. Despite the fact that human plays an important role on the reliability of the NDT test results, very little research work has been carried out to study the ergonomics and human factors in using these NDT methods. Several human factors which could affect the reliability of the tests are discussed and some recommendations are also provided to improve the tests [36].

The designed software can be used to calculate mechanical and physical properties of an unknown sample if the chemical composition and hardness value of that sample is available, where the effect of every element in the unknown sample on its mechanical and physical properties can be deduced from the comparison between the data of the same element in the standard samples [37]. In this work, tensile strength, elongation, and microscopic structure of 15 standard steel samples of low and medium carbon steel were determined by using destructive testing methods.

Non-destructive testing (NDT) was carried out using ultrasonic pulse velocity (UPV) and impact rebound hammer (IRH) techniques to establish a correlation with the compressive strengths of compression tests. The resulting correlation curve for each test is obtained by changing the level of compaction, water/cement ratio and concrete age of specimens. The resulting calibration curves for strength estimation were compared with others from previous published literature [38].

Satellite nozzles are manufactured from C/SiC, using the Liquid Polymer Infiltration (LPI) process. In this article the applicability of different non-destructive analysis methods for the characterisation of C/SiC components will be discussed [39]. Synchrotron radiation using tomography on small samples with a resolution of 1.4 µm, i.e. the fibre scale, was used to characterise three dimensionally fibre orientation and integrity, matrix homogeneity and dimensions and distributions of micro pores.

E. Bayraktar et al [40] gives a comparative study on the new developments in non-destructive controls of the composite materials and applications in the manufacturing engineering and also reviews essentially the performance and advantages of X-rays computed tomography (XR-CT) medical scanner about its usage at multiple scales (macro, micro, meso and nano), the method and also the terminology.

Rodrigo Benenson et al [41] address the problem of autonomous navigation of a car-like robot evolving in an urban environment. Such an environment exhibits a heterogeneous geometry and is cluttered with moving obstacles.

An approach for the analysis of gamma ray incoherent scattering on free and binding electrons is presented for Non destructive Testing (NDT) [42]. The method is based on computational simulation and backscattering gamma ray measurements for carbon steel walls. The results of thickness measurements for steel walls are described by the theory of the energy transfer model.

Lattice defects and microstructure in homogeneities like vacancies, dissolved atoms dislocations and precipitations are normally not discussed as defects but they are influence parameters which mainly predict the macroscopic properties, the physical properties as well as the mechanical ones[43]. In order to keep these properties constant in materials production more and more material characterization by NDT is integrated in the production processes.

The current dynamic process in computing, microelectronics, smart sensors and automation provide NDT system engineers with challenging opportunities for improved NDT solutions. Peter Bieder et al [44] focus on the quantification of inspection results with respect to flaw type, flaw location and flaw size, at high inspection speeds.

U.C. Hasar et al [45] shows microwave reflection and transmission properties measured from various sides of hardened mortar and concrete specimens with different water to cement ratios. These properties are important in predicting/measuring accurate electrical properties of cement-based materials which can eventually be utilized in structural health monitoring, public safety, and propagation-related research.

Pulsed thermography, an infrared non-destructive evaluation (NDE) technique, is proposed by M. Genest et al [46] for the detection of disbond and monitoring of disbond growth in bonded graphite repairs. Correlated results with ultrasonic pulse echo c-scan inspections and destructive testing show good disbond detection capability with accuracy similar to that of ultrasonic inspection.

Zoltán Orbán et al [47] present methods of inspection and testing for masonry arch railway bridges. An overview of a selection of available non-destructive, minor-destructive and monitoring methods is given and their efficacy for the assessment of masonry arch bridges is discussed.

S. Chaki et al [48] deals with a guided ultrasonic wave procedure for monitoring the stress levels in seven-wire steel strands (15.7 mm in diameter). The mechanical and geometrical characteristics of the prestressed strands were taken into account for optimizing the measurement configuration and then the choice of the guided ultrasonic mode at a suitable frequency.

A.A. Shah et al [49] present findings on nonlinear ultrasonic testing of concrete. The study was focused on testing cubic concrete specimens. It consisted of the non-destructive evaluation of concrete cubes using nonlinear ultrasonic technique with different frequency transducers. The transducer used at the wave-transmitting end had a broadband frequency of 100 kHz.

Ahmed Haddad et al [50] examine the applicability of eddy current techniques in-process for monitoring of powder density particle size and the time necessary to structure variation. An eddy current based monitoring system developed to measure metal powder density is expanded for monitoring metal powder diameter in metal compounds.

The assessment of creep damage in steels employed in the power generation industry is usually carried out by means of replica metallography, but the several shortcomings of this method have prompted a search for alternative or complementary non-destructive techniques, ranging from ultrasonic to electromagnetic methods, hardness measurements and nuclear techniques. A critical review [51] of the main results obtained to date in the secondary and tertiary stages of creep is presented in this paper, and the advantages and disadvantages of each method are discussed.

Pulsed eddy current (PEC) testing is a new emerging and effective electromagnetic non-destructive testing (NDT) technique. The main purpose [52] of this study is to identify surface defects and sub-surface defects using features-based rectangular pulsed eddy current sensor. The further study of PEC rectangular sensor proposed in author's previous work has been made to classify the different types of defects in specimen. In different directions of sensor scanning, peak waves of pick-up coil are studied.

Maryam Sargolzahi et al [53] deal with the application of various test methods for monitoring the progression of alkali–silica reaction (ASR) in laboratory concrete mixtures. The effectiveness of each method is reported. Mechanical properties were assessed with conventional destructive test and with non-destructive tests (ultrasonic pulse velocity, dynamic modulus of elasticity and nonlinear acoustics). Petrographic examination was performed to confirm damage associated with ASR.

The purpose of this study is non-destructive determination of residual stresses in the welded steel plates by Magnetic Barkhausen Noise (MBN) technique [54]. A MBN-stress calibration set-up and a residual stress measurement system with scanning ability were developed. To control the accuracy and the effectiveness of the developed system and procedure, various MBN measurements were carried out. The MBN results were verified by the hole-drilling method. Microstructural investigation and hardness measurements were also conducted.

J. HOŁA et al [55] presents a survey of state-of-the-art non-destructive diagnostic techniques of testing building structures and examples of their applications. Much attention is devoted to acoustic techniques since they have been greatly developed in recent years and there is a clear trend towards acquiring information on a tested element or structure from acoustic signals processed by proper software using complex data analysis algorithms.

Highly automated processes ensure high quality on a constant level, if it is connected with a high degree of (automated) monitoring and control. Meanwhile, continuous process and quality monitoring by non-destructive testing (NDT) [56] is an accepted procedure to early diagnosis of irregular process conditions, followed by an NDT-based feedback control and optimization. Consequently, the development of process integrated NDT is an important scientific task.

Yong-Kai Zhu et al [57] provides a review of the main optical NDT technologies, including fibre optics, electronic speckle, infrared thermography, endoscopic and terahertz technology. Among them, fibre optics features easy integration and embedding, electronic speckle focuses on whole-field high precision detection, infrared thermography has unique advantages for tests of combined materials, endoscopic technology provides images of the internal surface of the object directly, and terahertz technology opens a new direction of internal NDT because of its excellent penetration capability to most of non-metallic materials.

Surface defects in metals are not necessarily confined to orientations normal to the sample surface; however, much of the previous work investigating the interaction of ultrasonic surface waves with surface-breaking defects has assumed cracks inclined at 90° to the surface. B. Dutton et al [58] explores the interaction of Rayleigh waves with cracks which have a wide range of angles and depths relative to the surface, using a non-contact laser generation and detection system. Additional insight is acquired using 3D model generated using finite element method software

Javier Garcia Martin et al [59] gives an overview of the fundamentals and main variables of eddy current testing. It also describes the state-of-the-art sensors and modern techniques such as multi-frequency and pulsed systems. Recent advances in complex models towards solving crack-sensor interaction, developments in instrumentation due to advances in electronic devices, and the evolution of data processing suggest that eddy current testing systems will be increasingly used in the future.

Cast irons look like 'composites' made of a steel matrix and graphite filler. The standard description of matrix and graphite structure properties, e.g., after EN 945 is not satisfactory. Physical description of its structure can be better carried out using rigidity and hardness of matrix [60]. The expression of this description in a plane using bi-dimensional vector of tension strength or yield strength offers new useful relations to manufacturing metallurgy.

Vijay R. Rathod et al [61] proposed research experimentation has been established in Central Foundry Forge Plant (CFFP) of Bharat Heavy Electrical Ltd. India (BHEL). The proposed image segmentation techniques are introduced to detect and assess the weld flaws from the weldments and calculate the features such as length, width, area, perimeter, major axis length, minor axis length, orientation and resolution. Software has fully written in Mat lab.

A novel ultrasonic non-destructive technique (NDT) based on application of a transmission tomography of guided ultrasonic waves is proposed for floor inspection of large storage tanks and detection of non-uniformities, such as corrosion [62]. The technique needs access only to the outer edge of the tank floor and does not require emptying the tank. Estimation of the attenuation of different wave modes propagating in steel plates and determination of the losses in the lap welds showed that most suitable is S0 Lamb wave mode which possesses smallest losses and consequently enables investigation of tank floors up to average diameter 20-30 m.

Antonio J. Salazar et al [64] reports the influence of surface roughness on the characterisation, through the use of ultrasonic signals, of AISI-SAE 4340 steel samples. The samples were prepared with varying surface roughnesses, applied through mechanical methods and measured using a Mitutoyo Surfest-211. A normal incidence direct contact pulse-echo method was applied, using transducers of 5, 7.5 and 10 MHz, all with a 0.375 inch diameter.

Sharad Shrivastava et al [65] deals with the existing research gap in medical field by the application of non-destructive testing technique. They give a general idea about the various non-destructive testing techniques used in biomedical field. It also covers the disadvantages of various techniques and how these disadvantages can be taken care by Acoustic emission and Acousto–ultrasonic technique

Christian Garnier et al [66] evaluate the efficiency of these NDT methods in the detection of in site defects resulting from Barely Visible Impact Damages (BVID) or in-service damages to complex surfaces such as wings or rods. The size and position of all the defects were determined by GVI (General Visual Inspection). The evaluation of the three NDT techniques enabled conclusions to be drawn regarding defect detection and size.

NDT techniques that provide surface and internal information of the blade are necessary. I. Amenabar et al [67] inspect the detection capabilities and performance of ultrasonic, shearography, thermography and X-ray CT techniques for the inspection of wind turbine blades with delamination defects have been analyzed.

F. Van den Abeele et al [68] gives the philosophy of risk based inspection is introduced and recent advances in non destructive testing (in particular ultrasonic and electromagnetic techniques) are reviewed. Then, the use of fracture mechanics based damage models is demonstrated to predict fatigue failure for offshore structures.

The capability of the new approach of AE acquisition in discriminating between different loading and damage states is shown and discussed by T.H. Loutas et al [69]. Interesting findings on the effect of the oil temperature upon AE recordings only speculated theoretically so far are also presented. Both methods yielded interesting results and showed an ability to distinguish between healthy and defected gears.

Bo Li et al [70] study focused on the relationship between primary friction stir welding process parameters and varied types of weld-defect discovered in aluminium 2219-T6 friction stir butt-welds of thick plates, meanwhile, the weld-defect forming mechanisms were investigated.

Besides a series of optical metallographic examinations for friction stir butt welds, multiple non-destructive testing methods including X-ray detection, ultrasonic C-scan testing, ultrasonic phased array inspection and fluorescent penetrating fluid inspection were successfully used aiming to examine the shapes and existence locations of different weld-defects.

A. Lopes Ribeiro et al [71] show that a simple algorithm used to model the eddy current inspection of an aluminium plate can be used to preview the acquired voltage signals. Thus, the algorithm is suitable to work as a forward problem solver to determine the expected measurement signal obtained with a uniform excitation field probe including a giant magneto resistor sensor. The algorithm is based on a conformal transformation and is able to preview the shape of the electrical current lines when a metallic plate with a superficial straight crack is subject to a sinusoidal excitation field with constant amplitude and orientation in a bounded zone around the sensor element.

Umesh Singh et al [72] reviews magnetic particle crack detection (MPCD) in terms of principle, advantages, disadvantages and limitations. Different mine gear components are evaluated through MPCD technique and results are analyzed in terms of their suitability by applying acceptance/rejection norms followed by the mining industry in India. MPCD is now a widely acceptable technique in the world and has simplified inspection processes, leading to significant cost reductions and quality control enhancement and confidence.

Rodrigo Velázquez Castillo et al [73] analyze the relevance of Non Destructive Technique (NDT) thermal infrared imaging (TIRI) as a way of reference to the heritage conservation. The assessment of thermography testing was done in order to evaluate the correspondence concerning the physical and chemical characterization and compatibility among original and restored plastered mortars and stuccos, considering the correlation between thermal emissivity values and other well-known materials characterization methods such as Fourier Transform Infrared (FTIR), X-ray diffraction (XRD).

Bo Hu et al [74] propose a non-destructive testing method for thin-plate aluminium alloys based on the geomagnetic field. A high-precision magnetic sensor was used to measure slight changes in the magnetic field strength. The relative permeability of aluminium alloys was proven to be greater than that of aluminium through the magnetization of aluminium alloy materials. Therefore, aluminium and its alloys are paramagnetic materials. The aims of the current study are to analyze the effect of magnetic field on defects and to determine the test mechanism based on the differences in relative permeability.

The inspection of voids in external PT tendons is important and necessary in order to protect strands before corrosion occurs. Based on literature review [75], several Non Destructive Testing (NDT) methods are compared for effectiveness of identifying voids in external PT tendons, and the Impact Echo (IE), ultrasonic, and sounding inspection methods are then selected and assessed using small-scale and mock-up specimens.

A variety of NDT tests were targeted at different parts of the bridge elements, and have been conducted as part of a major investigation into the bridges [76]. The NDT tests performed included; Magnetic Flux Leakage Tests and Radiographic Tests at hanger sockets and Dye Penetrant Testing / Magnetic Particle Testing of the welding, non destructive testing on the concrete parts in anchorage rooms comprised of Schmidt Hammer Tests and Carbonation Depth Tests of concrete.

I. Afara et al [76] evaluates the viability of near infrared (NIR) spectroscopy, an EM method for rapid non-destructive evaluation of articular cartilage. Intact, visually normal cartilage-on-bone plugs from 2-3yr old bovine patellae were exposed to NIR light from a diffuse reflectance fibre-optic probe and tested mechanically to obtain their thickness, stress, and stiffness.

A recently developed frequency-modulated thermal wave imaging (FMTWI) has been applied for subsurface defect detection of jute fibre-reinforced polypropylene (PP) matrix composite [77]. Composites are subject to manufacturing and in-service defects like voids, delamination, cracks and so on. Active thermography like lock-in thermography (LT) and pulsed thermography (PT) has been widely used for non-destructive testing of composites and laminates.

5. Summary of literature survey

The summery researches done by experts in the area of NDT have been presented in Table1 which Carries the Author name, year and investigated problem types.

Table 1: Summary of the developments in NDT on literature survey.

Sr. no.	Author Name (Year)	Investigated Problem Type
1	Bates, D. and Smith, G et al (2000)	Rapid thermal non-destructive testing of aircraft components
2	D.J. Titman et al. (2001)	Applications of thermography in non-destructive testing of structures
3	P Cawley (2001)	NDT current capabilities and future directions.
4	Jacek Jarmulak et al (2001)	Case-based reasoning for interpretation of data from NDT.
5	Li Zhijun (2001)	Non-Destructive Testing of Advanced Composites.
6	G. S. Park et al. (2001)	Optimum Design of a NDT System to Maximize Magnetic Flux Leakage.
7	P. Tschelisnig (2001)	Acoustic emission testing (AET) – an integral NDT method.
8	H. A. Crostack, W. Reimers (2001)	Evaluation of component integrity by non-destructive testing
9	Zahran, 0. S., Shihab, S. et al (2002)	Recent Developments in Ultrasonic Techniques for Rail-track Inspection.
10	K Mori, A Spagnoli et al (2002)	A non contacting NDT method for defect detection in concrete
11	Carosena Meola et al (2002)	Comparison between thermographic techniques
12	M.R Clark, D.M McCann, et al (2003)	Application of infrared thermography to the NDT of concrete and masonry bridges
13	M.D. Beard, M.J.S. Lowe et al. (2003)	NDT of rock bolts using guided ultrasonic waves
14	Young S. Cho, (2003)	NDT of high strength concrete using spectral analysis of surface waves
15	I. Tomasˇ (2004)	Non-destructive magnetic adaptive testing of ferromagnetic materials
16	Rainer Pohl , A Erhard et al. (2004)	NDT techniques for railroad wheel and gauge corner inspection
17	N.P. Avdelidis. et al. (2004)	Aircraft composites assessment by means of transient thermal NDT
18	Gui Yun Tian et al. (2005)	Reduction of lift-off effects for pulsed eddy current NDT
19	C. Hakan Gur et al. (2005)	Non destructive investigation of the effect of quenching and tempering on medium carbon low alloy steels

20	Ch. Maierhofer et al. (2005)	Impulse thermography as NDT method in civil engineering
21	Yi-mei Mao et al. (2005)	Application of Hilbert Huang signal processing to ultrasonic NDT of oil pipelines
22	Gary S. Schajer et al. (2005)	Microwave NDT of Wood and Similar Orthotropic Materials
23	Allen G. Davis et al. (2005)	Rapid and economical evaluation of concrete tunnel linings with impulse response and impulse radar NDT
24	K. Kosmas et al. (2005)	Non destructive evaluation of magnetic metallic materials using Hall sensors
25	Bruce W et al (2006)	Ultrasonic arrays for non-destructive evaluation
26	Ch. Maierhofer, R. Arndt et al (2006)	NDT Application of impulse thermography for non-destructive assessment of concrete structures
27	Carosena Meola et al (2006)	Non-destructive evaluation of aerospace materials with lock-in thermography
28	Christoph Kohl et al. (2006)	Results of reconstructed and fused NDT data measured in the laboratory and on site at bridges
29	Francesca Cau et al. (2006)	A signal processing tool for NDT of inaccessible pipes
30	Gerd Dobmann (2006)	NDE for material characterisation of ageing due to thermal embrittlement, fatigue and neutron degradation
31	V. Sukhorukov (2006)	Steel cord conveyor belt NDT
32	D. Bracun et al (2006)	Indentation shape parameters as indicators of spot weld quality
33	Janez Marko Slabe et al (2006)	Measurement of acoustic emission and deformations in laser cutting of deep drawn sheet parts
34	Vaclav Matz et al (2006)	Classification of ultrasonic signals
35	Ralf B. Bergmann et al (2007)	Non-Destructive Testing in the Automotive Supply Industry
36	B. L. Luk et al (2007)	Human Factors and Ergonomics in Dye Penetrant and Magnetic Particles
37	Sayed H. El-Nekhaly (2007)	Electrochemical NDT for deducing physical and mechanical properties of steels.
38	Brian Hobbs et al (2007)	NDT for the forensic engineering investigation of reinforced concrete buildings
39	J. Rebelo Kornmeie et al (2007)	NDT of satellite nozzles made of carbon fibre ceramic matrix composite
40	E. Bayraktar et al. (2008)	New developments in non-destructive controls of the composite materials and applications in manufacturing engineering
41	Rodrigo Benenson et al (2008)	Towards urban driverless vehicles
42	Tran Dai Nghiep et al (2008)	Analysis of gamma ray incoherent scattering for NDT
43	Gerd Dobmann et al (2008)	Materials characterization a challenge in NDT for quality management
44	Peter Bieder et al (2008)	Current NDT Research & Development for NPP Inspections
45	U.C. Hasar (2009)	NDT of hardened cement specimens at microwave frequencies using a simple free-space method
46	M. Genest et al. (2009)	Pulsed thermography for non-destructive evaluation and damage growth monitoring of bonded repairs
47	Zoltán Orbán et al. (2009)	Assessment of masonry arch railway bridges using NDT
48	S. Chaki et al. (2009)	Guided ultrasonic waves for non-destructive monitoring of the stress levels in prestressed steel strands
49	A.A. Shah et al. (2009)	Non destructive evaluation of concrete in damaged and undamaged states.
50	Ahmed Haddad et al (2010)	Monitoring of metal powder by eddy current
51	G. Sposito et al (2010)	A review of NDT for the detection of creep damage in power plant steels
52	Yunze He et al (2010)	Defect classification based on rectangular pulsed eddy current sensor in different directions
53	Maryam Sargolzahi et al (2010)	Effectiveness of NDT for the evaluation of alkali–silica reaction in concrete
54	H. Ilker Yelbay et al. (2010)	Non-destructive determination of residual stress state in steel weldments by Magnetic Barkhausen Noise technique
55	J. HOŁA et al. (2010)	State-of-the-art non-destructive methods for diagnostic testing of building structures anticipated development trends.
56	(2011)	NDT Based Process Monitoring and Control
57	Yong-Kai Zhu et al (2011)	A Review of Optical NDT Technologies
58	B. Dutton et al. (2011)	Non-contact ultrasonic detection of angled surface defects
59	Javier Garcia Martin et al (2011)	NDT Based on Eddy Current Testing
60	Bretislav Skrbek et al. (2011)	Quantitative NDT structuroscopy of cast iron castings for vehicles
61	Vijay R. Rathod et al. (2011)	Analysis of radiographical weld flaws using image processing approach
62	Liudas Mazeika et al. (2011)	Ultrasonic guided wave tomography for the inspection of the fuel tanks floor.
63	Antonio J. Salazar et al. (2011)	Studies of the effect of surface roughness in the behaviour of ultrasonic signals in steel: spectral and wavelets analysis
64	Sharad Shrivastava et al. (2011)	Future research directions with Acoustic Emission and Acousto Ultrasonic technique.
65	Christian Garnier et al. (2011)	The detection of aeronautical defects in situ on composite structures using NDT.
66	I. Amenabar et al. (2011)	Comparison and analysis of NDT suitable for delamination inspection in wind turbine blades.
67	F. Van den Abeele et al (2011)	Non destructive testing techniques for risk based inspection
68	T.H. Loutas et al. (2011)	On the application of NDT techniques on rotating machinery
69	Bo Li, Yifu Shen, et al (2011)	The study on defects in aluminium thick butt friction stir welds with the application

		of multiple non-destructive testing methods
70	A. Lopes Ribeiro et al (2012)	A simple forward direct problem solver for eddy current NDI of aluminium plates using uniform field probes
71	Umesh Singh et al. (2012)	Analysis study on surface and sub surface imperfections through magnetic particle crack detection for nonlinear dynamic model of some mining components
72	Rodrigo Velázquez Castillo et al. (2012)	Thermal Imaging as a NDT Implemented in Heritage Conservation.
73	Bo Hu et al (2012)	Magnetic NDT method for thin-plate aluminium alloys
74	Seok Been Im et al. (2012)	NDT Methods to Identify Voids in External Post Tensioned Tendons
75	Y. Dost et al. (2013)	NDT of Bosphorus Bridges
76	I. Afara et al. (2013)	Near Infrared for NDT of Articular Cartilage
77	D. Banerjee et al. (2013)	NDT of jute–polypropylene composite using frequency-modulated thermal wave imaging

6. Discussion

- The ultrasonic inspection can be considered an effective method of checking the common defects and damages in composites.
- AET as a NDT tool will make an important contribution to increased security for pressure vessels and better protection against environmental pollution.
- Pulse thermography is easy and fast to use for information about the state of the art treasures, but data may be affected by non-uniform heating and local variation of thermal emission.
- NDT is essential in the inspection of alteration, repair and new construction in construction industry and Spectral analysis of surface waves (SASW) in concrete structures is widely used.
- In the composite repairs cases thermal modelling and pulsed-phase thermography were also used, whilst in the case of through skin imaging thermal modelling was also used in order to demonstrate the importance of thermal contact resistance between two surfaces (skin and strut).
- Lock in Thermography is a more powerful technique to detect impact damage and that transient thermography is more suitable for detecting inclusions.
- A detection technique for locating and determining the extent of defects and cracks in oil pipelines based on Hilbert-Huang time-frequency analysis is proposed.
- The use of NDT to examine the efficiency of tunnel lining grouting programmes, with particular emphasis obtained by the impulse response and impulse radar methods.
- A new idea of NDT was applied for low and medium carbon steel, and high manganese steel known as Electrochemical Non destructive Testing (ECNDT).
- Gamma ray incoherent scattering on free and binding electrons method is based on computational simulation and back scattering gamma ray measurements for thickness carbon steel walls by the theory of the energy transfer model.
- An eddy current based monitoring system developed to measure metal powder density is expanded for monitoring metal powder diameter in metal compounds.
- Pulsed eddy current (PEC) testing is a new emerging and effective electromagnetic NDT technique, used to identify surface defects and sub-surface defects using features based rectangular pulsed eddy current sensor.
- Eddy current testing is one of the most extensively used non-destructive techniques for inspecting electrically conductive materials at very high speeds that does not require any contact between the test piece and the sensor.
- A novel ultrasonic NDT based on application of a transmission tomography of guided ultrasonic waves is proposed for floor inspection of large storage tanks and detection of non-uniformities like corrosion.
- The diagnosis of artificial defects in a single stage gearbox using two non-destructive techniques (vibration and acoustic emission) and advanced signal processing techniques to discriminate between different load and defect states.
- Magnetic particle crack detection (MPCD) is now a widely acceptable technique in the world and has simplified inspection processes, leading to significant cost reductions and quality control enhancement and confidence.

7. Conclusions

Based on the literature review, it is concluded that the various non destructive techniques have many advantages, but also some disadvantages. Many NDT techniques have the ability to detect and characterize defects in structures made entirely of composite materials. Based on the literature review, it was found that most of the NDT techniques are primarily being used in the aerospace industry, manufacturing industries and have the potential to be used for evaluating civil infrastructures. More research needs to be performed on these techniques to make them applicable for field use for civil infrastructure.

8. References

[1]. D. Bates, G Smith, D Lu, J Hewitt; Rapid thermal non-destructive testing of aircraft components; Composites Part B: Engineering; Volume 31, Issue 3, 1 April 2000, Pages 175–185

[2]. D.J. Titman; Applications of thermography in non-destructive testing of structures; NDT & E International; Volume 34, Issue 2, March 2001, Pages 149–154

[3]. P Cawley; Non-destructive testing—current capabilities and future directions; Journal of Materials: Design and Applications; October 1, 2001 vol. 215 (213-223).

[4]. Jacek Jarmulak, Eugene J.H. Kerckhoffs, Peter Paul van't Veen; Case-based reasoning for interpretation of data from non destructive testing; Engineering Applications of Artificial Intelligence; Volume 14, Issue 4, August 2001, Pages 401–417.

[5]. Li Zhijun; Non-Destructive Testing of Advanced Composites; Aerospace Materials & Technology, 2001.

[6]. G. S. Park, P. W. Jang, Y. W. Rho; Optimum Design of a Non Destructive Testing System to Maximize Magnetic Flux Leakage; Journal of Magnetics Vol.6 No.1, 2001, (31-35)

[7]. P. Tschelisnig; Acoustic emission testing (AET) an integral non-destructive testing method; International Journal of Materials and Product Technology 2001 - Vol. 3, No.3/4 pp. 267 - 275

[8]. H. A. Crostack, W. Reimers; Evaluation of component integrity by non-destructive testing; International Journal of Materials and Product Technology 2001 - Vol. 3, No.2 pp. 147 - 162

[9]. Zahran, 0. S., Shihab, S. and AI-Nuaimy, W. (2002). Recent Developments in Ultrasonic Techniques for Rail track Inspection. NDT 2002, Southport, The British Institute of NDT.

[10]. K Mori, A Spagnoli, Y Murakami, G Kondo, I Torigoe; A new non-contacting non-destructive testing method for defect

detection in concrete, NDT & E International; Volume 35, Issue 6, September 2002, Pages 399–406
[11]. Giovanni M. Carlomagno, Carosena Meola Comparison between thermographic techniques for frescoes NDT, NDT & E International, Volume 35, Issue 8, December 2002, Pages 559–565
[12]. M.R Clark, D.M McCann, M.C Forde. Application of infrared thermography to the non-destructive testing of concrete and masonry bridges, NDT & E International, Volume 36, Issue 4, June 2003, Pages 265–275
[13]. M.D. Beard, M.J.S. Lowe. Non-destructive testing of rock bolts using guided ultrasonic waves International Journal of Rock Mechanics and Mining Sciences, Volume 40, Issue 4, June 2003, Pages 527–536
[14]. Young S. Cho, Non-destructive testing of high strength concrete using spectral analysis of surface waves; NDT & E International,Volume 36, Issue 4, June 2003, Pages 229–235
[15]. I. Tomáš, Non-destructive magnetic adaptive testing of ferromagnetic materials, Journal of Magnetism and Magnetic Materials, Volume 268, Issues 1–2, January 2004, Pages 178–185
[16]. Rainer Pohl , A Erhard, H.J Montag , H.-M Thomas, H Wüstenberg; NDT techniques for railroad wheel and gauge corner inspection; NDT & E International, Volume 37, Issue 2, March 2004, Pages 89–94
[17]. N.P. Avdelidis. D.P. Almond, C. Hawtin, Ibarra-Castanedo, X. Maldague; Aircraft composites assessment by means of transient thermal NDT, Progress in Aerospace Sciences, Volume 40, April 2004, Pages 143–162
[18]. Gui Yun Tian, Ali Sophian, Reduction of lift-off effects for pulsed eddy current NDT, NDT & E International, Volume 38, Issue 4, June 2005, Pages 319–324
[19]. C. Hakan Gur, B. Orkun Tuncer; Nondestructive investigation of the effect of quenching and tempering on medium-carbon low alloy steels; International Journal of Microstructure and Materials Properties 2005 - Vol. 1, No.1 pp. 51 - 60
[20]. Ch. Maierhofer, A. Brink, M. Röllig, H. Wiggenhauser; Quantitative impulse-thermography as non-destructive testing method in civil engineering – Experimental results and numerical simulations; Construction and Building Materials; Volume 19, Issue 10, December 2005, Pages 731–737
[21]. Yi-mei Mao, Pei-wen Que; Application of Hilbert-Huang signal processing to ultrasonic non-destructive testing of oil pipelines; Journal of Zhejiang University SCIENCE A Volume 7, Issue 2 , pp 130-134, 2006
[22]. Gary S. Schajer, F. Bahar. Orhan; Microwave Non-Destructive Testing of Wood and Similar Orthotropic Materials; Subsurface Sensing Technologies and Applications , Volume 6, Issue 4 , pp 293-313, 2005
[23]. Allen G. Davis, Malcolm K. Lim, Claus Germann Petersen; Rapid and economical evaluation of concrete tunnel linings with impulse response and impulse radar non-destructive methods; NDT & E International, Volume 38, Issue 3, April 2005, Pages 181–186
[24]. K. Kosmas, Ch. Sargentis, D.Tsamakis, E. Hristoforou; Non-destructive evaluation of magnetic metallic materials using Hall sensors; Journal of Materials Processing Technology; Volume 161, Issues 1–2, 10 April 2005, Pages 359–362
[25]. Bruce W. Drinkwater, Paul D. Wilcox, Ultrasonic arrays for non-destructive evaluation: A review, NDT & E International, Volume 39, Issue 7, October 2006, Pages 525–541
[26]. Ch. Maierhofer, R. Arndt, M. Röllig, C. Rieck, A. Walther, H. Scheel, B. Hillemeier; Non Destructive Testing Application of impulse-thermography for non-destructive assessment of concrete structures, Cement and Concrete Composites, Volume 28, Issue 4, April 2006, Pages 393–401
[27]. Carosena Meola, Giovanni Maria Carlomagno, Antonino Squillace, Antonio Vitiello; Non-destructive evaluation of aerospace materials with lock-in thermography, Papers presented at the First International Conference on Engineering Failure Analysis Part III; Engineering Failure Analysis, Volume 13, Issue 3, April 2006, Pages 380–388;
[28]. Christoph Kohl, Doreen Streicher; Results of reconstructed and fused NDT-data measured in the laboratory and on-site at bridges; Cement and Concrete Composites, Volume 28, Issue 4, April 2006, Pages 402–413 Non-Destructive Testing
[29]. Francesca Cau, Alessandra Fanni, Augusto Montisci, Pietro Testoni, Mariangela Usai; A signal-processing tool for non-destructive testing of inaccessible pipes; Engineering Applications of Artificial Intelligence, Volume 19, Issue 7, October 2006, Pages 753–760
[30]. Gerd Dobmann; NDE for material characterisation of ageing due to thermal embrittlement, fatigue and neutron degradation; International Journal of Materials and Product Technology 2006 - Vol. 26, No.1/2 pp. 122 – 139
[31]. V. Sukhorukov; Steel-cord conveyor belt NDT; International Journal of Materials and Product Technology 2006 - Vol. 27, No.3/4 pp. 238 - 246
[32]. D. Bracun, I. Polajnar, J. Diaci; Indentation shape parameters as indicators of spot weld quality; International Journal of Materials and Product Technology 2006 - Vol. 27, No.3/4 pp. 247 – 257
[33]. Janez Marko Slabe, Tomaz Kek, Janez Grum; Measurement of acoustic emission and deformations in laser cutting of deep-drawn sheet parts; International Journal of Microstructure and Materials Properties 2006 - Vol. 1, No.3/4 pp. 383 - 396
[34]. Vaclav Matz, Marcel Kreidl, Radislav Smid; Classification of ultrasonic signals; International Journal of Materials and Product Technology 2006 - Vol. 27, No.3/4 pp. 145 - 155
[35]. Ralf B. Bergmann, Florian T. Bessler and Walter Bauer; Non-Destructive Testing in the Automotive Supply Industry, Research and Advance Engineering, 2007
[36]. B. L. Luk and Alan, H. S. Chan; Human Factors and Ergonomics in Dye Penetrant and Magnetic Particles Nondestructive Inspection Methods; 2007
[37]. Sayed H. El-Nekhaly ; Electrochemical nondestructive testing for deducing physical and mechanical properties of steels; International Journal of Microstructure and Materials Properties 2007 - Vol. 2, No.3/4 pp. 402 - 419
[38]. Brian Hobbs, Mohamed Tchoketch Kebir; Non-destructive testing techniques for the forensic engineering investigation of reinforced concrete buildings, Forensic Science International, Volume 167, Issues 2–3, 11 April 2007, Pages 167–172
[39]. J. Rebelo Kornmeier, M. Hofmann, S. Schmidt; Non-destructive testing of satellite nozzles made of carbon fibre ceramic matrix composite, C/SiC; Materials Characterization, Volume 58, Issue 10, October 2007, Pages 922–927
[40]. E. Bayraktar, S.D. Antolovich, C. Bathias, New developments in non-destructive controls of the composite materials and applications in manufacturing engineering; Journal of Materials Processing Technology, Volume 206, Issues 1–3, 12 September 2008, Pages 30–44
[41]. Rodrigo Benenson, Stephane Petti, Thierry Fraichard, Michel Parent; Towards urban driverless vehicles; International Journal of Vehicle Autonomous Systems 2008 - Vol. 6, No.1/2 pp. 4 - 23
[42]. Nguyen Thanh Cong; Analysis of gamma ray incoherent scattering for non-destructive testing; International Journal of

Nuclear Energy Science and Technology 2008 - Vol. 4, No.2 pp. 88 – 96

[43]. Gerd Dobmann, Iris Altpeter, Bernd Wolter; Materials characterization a challange in ndt for quality management; International Non-Destructive Testing Symposium and Exhibition, Istanbul Turkey, April 2008

[44]. Peter BIEDER, Gerd DOBMANN, Michael KRÖNING, Jinhong LIU, João G.RIBERO; Current NDT Research & Development for NPP Inspections; 17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China

[45]. U.C. Hasar, Non-destructive testing of hardened cement specimens at microwave frequencies using a simple free-space method, NDT & E International, Volume 42, Issue 6, September 2009, Pages 550–557

[46]. M. Genest, M. Martinez, N. Mrad, G. Renaud, A. Fahr; Pulsed thermography for non-destructive evaluation and damage growth monitoring of bonded repairs; Composite Structures; Volume 88, Issue 1, March 2009, Pages 112–120

[47]. Zoltán Orbán, Marc Gutermann; Assessment of masonry arch railway bridges using non-destructive in-situ testing methods; Engineering Structures; Volume 31, Issue 10, October 2009, Pages 2287–2298

[48]. S. Chaki, G. Bourse; Guided ultrasonic waves for non-destructive monitoring of the stress levels in prestressed steel strands; Ultrasonics; Volume 49, Issue 2, February 2009, Pages 162–171

[49]. A.A. Shah, Y. Ribakov; Non-destructive evaluation of concrete in damaged and undamaged states; Materials & Design, Volume 30, Issue 9, October 2009, Pages 3504–3511

[50]. Ahmed Haddad, Mourad Zergoug, Mohamed Azzaz, Abdelhamid Tafat, Said Bergheul; Monitoring of metal powder by eddy current; International Journal of Microstructure and Materials Properties 2010 - Vol. 5, No.1 pp. 3 - 14

[51]. G. Sposito, C. Ward, P. Cawley, P.B. Nagy, C. Scruby; A review of non-destructive techniques for the detection of creep damage in power plant steels; NDT & E International, Volume 43, Issue 7, October 2010, Pages 555–567

[52]. Yunze He,, Feilu Luo, Mengchun Pan, Xiangchao Hu, Junzhe Gao, Bo Liu; Defect classification based on rectangular pulsed eddy current sensor in different directions; Sensors and Actuators A: Physical; Volume 157, Issue 1, January 2010, Pages 26–31

[53]. Maryam Sargolzahi, Serge A. Kodjo, Patrice Rivard, Jamal Rhazi; Effectiveness of nondestructive testing for the evaluation of alkali–silica reaction in concrete; Construction and Building Materials, Volume 24, Issue 8, August 2010, Pages 1398–1403

[54]. H. Ilker Yelbay, Ibrahim Cam, C. Hakan Gür, Non-destructive determination of residual stress state in steel weldments by Magnetic Barkhausen Noise technique; NDT & E International, Volume 43, Issue 1, January 2010, Pages 29–33

[55]. J. HOŁA, K. SCHABOWICZ; State-of-the-art non-destructive methods for diagnostic testing of building structures – anticipated development trends; Archives of civil and mechanical engineering, Vol. X , 2010

[56]. Bernd Wolter* - Gerd Dobmann - Christian Boller; NDT Based Process Monitoring and Control; Journal of Mechanical Engineering 57(2011)3, 218-226

[57]. Yong-Kai Zhu, Gui-Yun Tian, Rong-Sheng Lu and Hong Zhang; A Review of Optical NDT Technologies; Sensors 2011, 11(8), 7773-7798

[58]. B. Dutton, A.R. Clough, M.H. Rosli, R.S. Edwards, Non-contact ultrasonic detection of angled surface defects, NDT & E International, Volume 44, Issue 4, July 2011, Pages 353–360

[59]. Javier García-Martín, Jaime Gómez-Gil and Ernesto Vázquez-Sánchez; Non-Destructive Techniques Based on Eddy Current Testing; Sensors 2011, 11(3), 2525-2565

[60]. Bretislav Skrbek, Ivan Tomas; Quantitative NDT structuroscopy of cast iron castings for vehicles; International Journal of Microstructure and Materials Properties 2011 - Vol. 6, No.3/4 pp. 293 - 306

[61]. Vijay R. Rathod, R.S. Anand, Alaknanda Ashok; Analysis of radiographical weld flaws using image-processing approach; International Journal of Signal and Imaging Systems Engineering 2011 - Vol. 4, No.4 pp. 228 - 237

[62]. Liudas Mazeika, Rymantas Kazys, Renaldas Raisutis, Reimondas Sliteris; Ultrasonic guided wave tomography for the inspection of the fuel tanks floor; International Journal of Materials and Product Technology 2011 - Vol. 41, No.1/2/3/4 pp. 128 - 139

[63]. Antonio J. Salazar, Edda C. Rodríguez; Studies of the effect of surface roughness in the behaviour of ultrasonic signals in AISI-SAE-4340 steel: spectral and wavelets analysis; International Journal of Microstructure and Materials Properties 2011 - Vol. 6, No.3/4 pp. 224 – 235

[64]. Sharad Shrivastava, Ravi Prakash; Future research directions with Acoustic Emission and Acousto–Ultrasonic technique; International Journal of Biomedical Engineering and Technology 2011 - Vol. 6, No.4 pp. 375 - 386

[65]. Christian Garnier, Marie-Laetitia Pastor, Florent Eyma, Bernard Lorrain; The detection of aeronautical defects in situ on composite structures using Non Destructive Testing; Composite Structures; Volume 93, Issue 5, April 2011, Pages 1328–1336

[66]. I. Amenabar, A. Mendikute, A. López-Arraiza, M. Lizaranzu, J. Aurrekoetxea; Comparison and analysis of non-destructive testing techniques suitable for delamination inspection in wind turbine blades; Composites Part B: Engineering, Volume 42, Issue 5, July 2011, Pages 1298–1305

[67]. F. Van den Abeele and P. Goes; Non destructive testing techniques for risk based inspection; Sustainable Construction and Design 2011

[68]. T.H. Loutas, J. Kalaitzoglou, G. Sotiriades, V. Kostopoulos; On the application of non-destructive testing techniques on rotating machinery; International Journal of Materials and Product Technology 2011 - Vol. 41, No.1/2/3/4 pp. 117 - 127

[69]. Bo Li, Yifu Shen,Weiye Hu; The study on defects in aluminum 2219-T6 thick butt friction stir welds with the application of multiple non-destructive testing methods; Materials & Design, Volume 32, Issue 4, April 2011, Pages 2073–2084

[70]. A. Lopes Ribeiro, H. Geirinhas Ramos, O. Postolache, A simple forward direct problem solver for eddy current non-destructive inspection of aluminum plates using uniform field probes; Measurement; Volume 45, Issue 2, February 2012, Pages 213–217

[71]. Umesh Singh, Mohan Singh and M. K. Singh; Analysis study on surface and sub surface imperfections through magnetic particle crack detection for nonlinear dynamic model of some mining components; Journal of Mechanical Engineering Research Vol. 4(5), pp. 185-191, May 2012

[72]. Rodrigo Velázquez Castillo, Miguel A. Pérez-Lara, Eric Rivera-Muñoz, José L. Arjona, Mario E; Thermal Imaging as a Non Destructive Testing Implemented in Heritage Conservation; Journal of Geography and Geology; Vol. 4, No. 4; 2012, ISSN 1916-9779; Canadian Center of Science and Education 102

[73]. Bo Hu, Runqiao Yu, Hengcai Zou; Magnetic non-destructive testing method for thin-plate aluminum alloys; NDT & E International, Volume 47, April 2012, Pages 66–69

[74]. Seok Been Im and Stefan Hurlebaus; Non-Destructive Testing Methods to Identify Voids in External Post Tensioned Tendons; KSCE Journal of Civil Engineering (2012) 16(3):388-397

[75]. Y. Dost, N. Apaydın, E. Dedeoğlu, D. K. MacKenzie, O. Z. Akkol; Non-Destructive Testing of Bosphorus Bridges; Nondestructive Testing of Materials and Structures; RILEM Bookseries Volume 6, 2013, pp 819-825

[76]. I. Afara, T. Sahama, A. Oloyede; Near Infrared for Non-Destructive Testing of Articular Cartilage; Nondestructive Testing of Materials and Structures; RILEM Bookseries Volume 6, 2013, pp 399-404

[77]. D. Banerjee, S.K. Chattopadhyay, K. Chatterjee, S. Tuli, N. Jain, I. Goyal, S. Mukhopadhyay; Non-destructive testing of jute–polypropylene composite using frequency-modulated thermal wave imaging; Journal of Thermoplastic Composite Materials, 2013