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NON-DESTRUCTIVE TESTING FOR QUALITY CONTROL IN AUTOMOTIVE INDUSTRY

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Abstract— **Due to the technological revolution, in order to withstand competition, giant production companies are obliged to provide customers with the most reliable and safe products in the shortest possible time while keeping the price of the product affordable to customers as well. To achieve this goal, the companies must undertake several complicated tasks, such as making complex dimensional measurements, detecting the defects, and repairing them before bringing the product to market. At that point the non-destructive testing (NDT) comes into play which is a very broad concept containing myriad of conventional and also state-of-the-art methodologies. In this paper, several techniques for NDT, such as X-ray imaging, acoustic emission, ultrasonic testing, infrared thermography, digital image correlation, terahertz testing, shearography will be investigated. Moreover, the principles, advantages and disadvantages and application areas of these techniques will be introduced, and specific examples will be described for some of the methods.**

Keywords— **Non-Destructive Testing, Automotive Industry, Defect Inspection.**

I. INTRODUCTION

Today the manufacturers are endeavoring to produce 100% efficient product while keeping the safety considerations, production, and maintenance costs in mind as well. Furthermore, a small defect or dimensional inaccuracy in any part of the device can lead the customer company to loss of millions, such as shut-down of an oil-producing company, or result in disasters, such as airplane crash. As an example, the graph illustrated in Figure 1 shows the trend of breaks happened in freight cars:

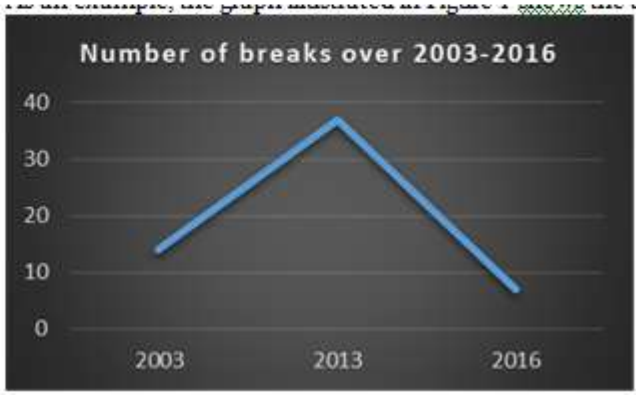

Fig. 1. Statistics of breaks

Between 2003 and 2013 more than 14 breaks happened in running parts of a car with 19 wrecks of rollick stock, while this number increased to 37 breaks of parts with 6 wrecks. The remaining part of the graph shows satisfying result with up to 7 breaks, which means within 3 years it decreased more than 5 times.

To make the manufacturing process reliable, safe, economical, and prevent the graphically described disasters, the non-destructive testing (NDT) takes an important part in almost all sectors, such as automotive, aerospace, petrochemical, medical, and power generation industries. The definition for the NDT given by the American Society for Non-destructive Testing (ASNT) is described 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)." To express this official definition in other words, the NDT creates the possibility to check the technical objects without making any change to the microstructure of the products and additionally, with its help, geometrical properties and defects (if any exists) can be determined. Non-destructive testing can be utilized for in-line testing as well, which is the preventable measure for waste production. As testing is such a necessity in manufacture, several techniques have been developed over the years, such as visual and optical inspection, electromagnetic, radiographic, liquid penetrant testing, acoustic emission, ultrasonic testing,

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infrared thermography, terahertz testing, shearography, digital image correlation, X-ray and neutron imaging, etc.
To achieve the goals of the NDT, several factors must be considered in order to make the testing process most efficient, such as used equipment, personnel understanding of process, exact technical documentations for all parts, control conditions, etc.
In this research paper, first some of the mentioned testing techniques will be described, then the methods for improving the testing process will be analyzed, some examples of NDT applications will be demonstrated and as final thoughts the comparison of the techniques and possible ways to improve the process will be discussed.

II. NON-DESTRUCTIVE TESTING AND EVALUATION METHODS

As it is mentioned before non-destructive testing methods is getting more crucial in different engineering areas as well as automotive industry. Due to high strength and low weight, vast usage of composite materials can be observed in automotive industry. Two different types of NDT methods are broadly used for composite materials: contact and non-contact methods. Contact methods are ultrasonic testing, magnetic testing, eddy current testing, electromagnetic testing, and penetrant testing whereas non-contact methods are through transmission ultrasonic, radiography testing, thermography, shearography, and visual inspection. NDT methods according to their type is provided in the following Table 1. [17]

Table -1 Contact and Non-contact NDT methods

Contact methods	Non-contact methods
Traditional ultrasonic testing	Through transmission ultrasonic
Eddy current testing	X-ray radiography testing
Magnetic testing	Thermography
Electromagnetic	Infrared Testing
Liquid penetrant testing	Holography
Liquid Penetrant	Shearography
	Visual Inspection

The very first NDT methods are traditional ultrasonic, X-ray radiography, liquid penetrant testing (LPT), magnetic particle testing and eddy-current testing and they were used for steel industry before which makes them possible to use for composite materials.

III. LIQUID PENETRANT TESTING

The main application of using liquid penetrant testing (LPI) is to check nonporous materials such as aluminum, copper, steel, titanium etc. of the automotive surfaces by capillary action. It is worthwhile to mention that although it is possible to apply liquid penetrant testing over all non-ferrous and ferrous materials, magnetic-particle inspection is mostly used for due to containing capability to check subsurface. 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 and after waiting for a better interpretation, it is required to render the crack visible. [6]

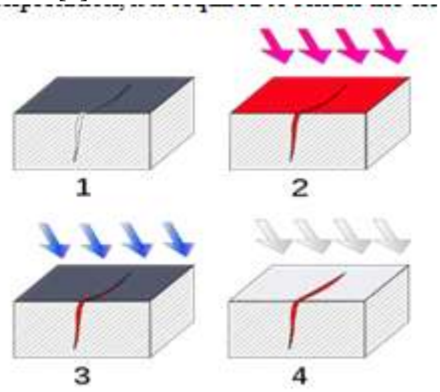

Fig. 2. Each step of Liquid Penetration Testing

LPI handles to determine discontinuities such as tiredness fractures, shrinkage fractures, porosity, laps, and seams. Overall, LPI is capable of identifying cracks with a width of around 5 μm can be determined using visible dye penetrant while cracks with width varying from 1 to 2 μm can be spotted utilizing fluorescent penetrant.
To complement liquid penetrant testing, more non-contact and sensitive NDT techniques (such as ultrasonic testing) are needed. Liquid penetrant screening's suitability for additively manufactured parts Liquid penetrant testing for fault detection on additively generated metal parts is incompatible without additional post-processing processes such as machining and polishing. [8]

IV. X-RAY COMPUTER TOMOGRAPHY TESTING (X-RAY CT)

This method relies on the ability of high-energy, short-wavelength electromagnetic radiation sources like X-rays to penetrate the material. The correspondence could be stated as follows: The higher the penetrating power, the shorter the wavelength of electromagnetic radiation. [8]
To understand the differences of NDT methods, the classification of each method in various conditions is very crucial. That is why, it is required to be aware of parameters of the system such as detectable defect location and spatial resolution.
X-ray computer tomography is one of the main NDT methods that could be used for automotive industry whereas it is obvious that not all of the NDT methods can be applied to automotive components. In the following illustration, the classification of X-ray CT, ultrasonic testing, eddy-current

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measurement and optical inspection techniques based on the abovementioned parameters was provided.

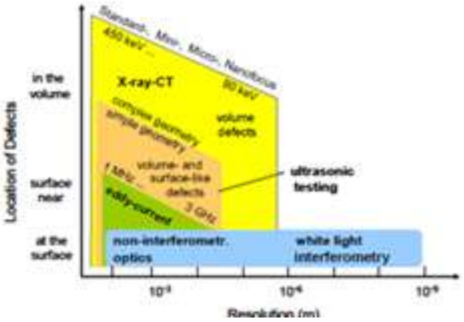

Fig. 3. Graphical representation of difference among X-ray CT, eddy current, ultrasonic testing

X-ray CT is formed by the components of an X-ray source, a flat panel detector and both hardware and software for the image acquisition. This is illustrated in Figure 4. In this paper, only X-ray sources will be elaborated according to parameters.

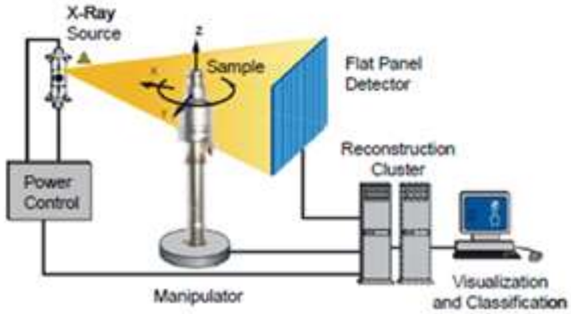

Fig. 4. The formulation of X-ray CT system with parts for industrial testing

An X-ray source with the maximum feasible intensity should be used to obtain measurement process in a short time. However, the highest feasible heat dissipation of the X-ray target is fundamentally limited the X-ray intensity. When a critical material-dependent power density is exceeded, the target is vaporized. As a result, higher intensity necessitates a bigger target area, limiting the measurement's resolution. As a result, in order to achieve high speed and spatial resolution, the X-ray tube's brilliance must be increased, which is defined as

$$B = \frac{P_{x-ray}}{A}$$

while P_{x-ray} is the power of the X-ray radiation and A is the target area. [1]

V. EDDY CURRENT TESTING METHOD

A. Theoretical Background –

Eddy current testing method is one of the most widely used as non-destructive techniques for analyzing electrically conductive materials. This method does not require any contact between the sensor and the testing substance. It is one of the electromagnetic methods which is based on Faraday's Law which describes the magnitude of the electromotive force (emf), or voltage, induced (generated) in a conductor due to electromagnetic induction (changing magnetic fields). It states that the induced emf in a conducting circuit is proportional to the rate of change of magnetic flux linkage Φ within the circuit. According to Faraday's law of induction, eddy currents (also known as Foucault's currents) are loops of electrical current induced within conductors by a changing magnetic field in the conductor. It defines the following equation when the magnetic flux changes over time:

$$\varepsilon = -\frac{d\phi}{dt}$$

where ε is the electromotive force (emf), Φ is magnetic induction flux. [18]

To generate Eddy current, we need to obtained continuously changing magnetic field which can be provided by the coils. There are two coils inside Eddy current sensors: first for generating the field (Excitation coil) and second one (Pick up coil) is used to measure magnitude of Eddy currents. If the sensor show 0 V means that there is not any Eddy currents around it, or it does not close to the testing piece enough (see Figure 5). [8]

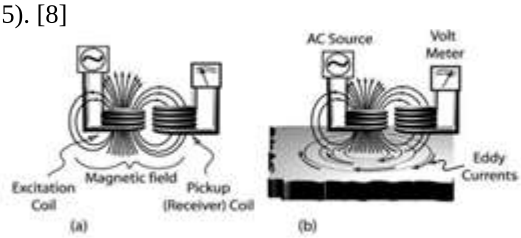

Fig. 5. Probe response (a) in the absence of conductive material (b) in the presence of conductive material

Within conductors, eddy currents flow in closed loops in planes perpendicular to the magnetic field. A time-varying magnetic field formed by an AC electromagnet or transformer, for example, or relative motion between a magnet and a neighboring conductor might induce them within nearby stationary conductors. The size of the current in a given loop is related to the magnetic field intensity, loop area, and flux rate of change, and inversely proportional to the material's resistivity.

B. Applications –

Eddy-current testing has a high level of sensitivity for material identification and microstructure condition characterization. Absolute coil probes use impedance to assess physical properties such as electrical conductivity and magnetic permeability of test components. Eddy current testing can detect heat damage and control heat treatment because of the relationship between hardness and these variables. Lift-off variation is also used in eddy current techniques to measure the coating thickness of non-conductive materials and the oxide thickness of conductive materials [18]. Eddy current screening can discover conductive specimens with defects such as cracks and inclusions that produce a change in output impedance. The changes in conductivity between the conductive specimen and the finishing can be used to investigate variations in coating thickness. For inspection, this procedure does not necessitate the removal of surface coverings such as paint and anodized film. With enough sensitivity, eddy current testing can be used to check conductive parts with a thickness of up to 6 mm [8]. Water-cooled probes can be used to inspect various sorts of bars and profiles at temperatures up to 1,200 °C in the field of hot eddy current testing. Testing a hot-wire line has several challenges, including a low fill factor due to water cooling between the hot wire and the encircling coil, as well as the need for high-speed data processing due to the line's rapid speed. Eddy current testing is the only automated non-destructive test method that can produce accurate findings at speeds of up to 150 m/s [18].

C. Advantages and disadvantages –

Eddy current screening has a number of advantages over other methods, including the fact that it is a non-contact technique that allows for automated high-speed evaluation. It has a high sensitivity to surface defects, and under ideal conditions, it can identify defects of millimeters in length [8]. It's possible to automate it. Wheels, boiler tubes, and aero-engine disks are examples of relatively consistent parts that may be inspected rapidly and reliably using automated or semi-automatic equipment. Eddy current testing is one of the few assessment methods that can be used in high-temperature environments. This method can be used in the airplane industry to assess the hardness and tensile strength of aluminum elements by measuring their conductivity of heat. In a wide range of materials, eddy current testing allows for crack identification and measurements that are beyond the capabilities of other techniques such as non-conductive coating thickness, alloy composition, and hardness. The only requirement is that the materials being evaluated be electrical conductors with the ability to conduct eddy currents.

Eddy current sensors are unaffected by dirt, dust, humidity, oil, or dielectric material in the measurement gap, and have been proved to work reliably across a wide temperature range. Standard coils can be utilized in a wide range of applications, and coil probes are the most extensively used type of sensor [18].

Despite its benefits, Eddy current testing has a few drawbacks. The fundamental limitation of eddy current testing is that it can only test electrically conducting materials. Another disadvantage is that it is highly susceptible to variations in magnetic permeability. Small changes in permeability, especially in ferromagnetic materials, have a big impact on eddy currents. This approach is unable to detect defects that run parallel to the surface. Eddy currents flow in a straight line parallel to the surface. A planar flaw will not be identified if it does not cross or interfere with the current. This approach can only detect discontinuities that are perpendicular to the surface area being scanned [8].

VI. ULTRASONIC TESTING METHOD

A. Theoretical Background –

Ultrasonic testing (UT) is a non-destructive test method for detecting cracks and defects in components and materials using sound waves. Internal and surface defects in sound conducting materials are detected using this methodology. In some ways, the idea is comparable to echo sounding. An electric charge is supplied to a piezoelectric crystal, which vibrates for a very short time at a frequency linked to the crystal thickness, resulting in a short pulse of ultrasound [6]. The transformation of a voltage pulse into an ultrasonic pulse by a transducer is the foundation of ultrasonic testing. The transducer is placed on the item, and the transmitted pulses (ultrasonic waves) go through it. In most cases, ultrasonic waves with frequencies ranging from 1 to 10 MHz are employed. Because in homogeneities reflect ultrasonic waves, the transmitted and reflected energy can be utilized to determine the product's stability. The typical occurrence pulse-echo, angle beam pulse-echo, and through-transmission methods are all common ultrasonic inspection methods. In all situations, the captured signals are converted to electrical pulses and shown on a cathode ray tube (CRT) [8].

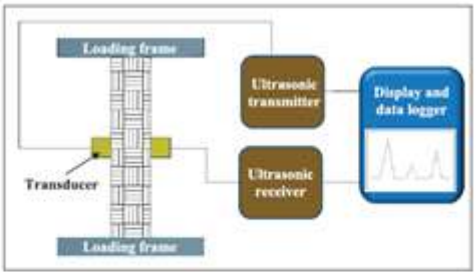

Fig. 6. Principle of ultrasonic testing a composite material in transmission mode.

Due to their anisotropic character, elastic waves, also known as 'Lamb waves,' propagate in chosen directions for NDT inspection of composite materials. UT systems come in a variety of shapes and sizes, with hundreds of guided wave modes and frequencies to choose from. Figure 6. shows a typical UT system, which includes a transmitter and receiver circuit, as well as a transducer tool and display devices. The transmitter can be placed at an angle to the sample or in a phased array configuration. Ultrasonic probe, laser, piezoelectric element, interdigital transducer, or optical fibre can all be used to generate guided Lamb waves [14].

B. Applications

For decades, ultrasonic testing has been widely used in a variety of areas. This method can be used to assess corrosion or erosion, as well as wall thinning in pipes and vessels, without requiring internal access. Moreover, in-service inspection for cracks and crack propagation, such as stress rupture cracks, thermal or mechanical fatigue cracks and creep cracks are other applications for ultrasonic condition monitoring. In power plants, high-energy steam pipework and components such as steam valves are crucial elements that must be inspected utilizing ultrasonic techniques on a regular basis [8]. Composite UT procedures have been standardized: ASTM E237392 specifies the requirements for developing a time-of-flight (TOF) UT examination; ASTM E258093 specifies the requirements for inspections on flat composite panels and sandwich structures in aerospace applications; and ASTM E298194 specifies the requirements for filament-wound pressure vessels in aerospace applications [14]. Microstructural variations in metals are also assessed using ultrasonic methods. For this, attenuation, velocity, and backscatter measurement can be employed [8].

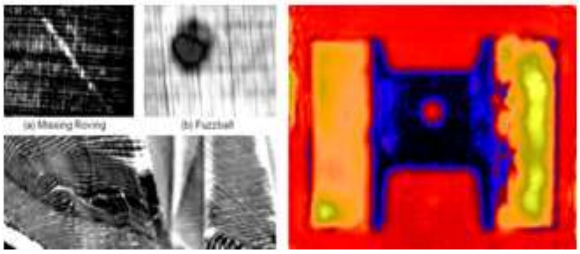

Fig. 7. [12] Scenario of automated thermography within production environment

C. **Advantages and disadvantages** –
The main benefit of the UT is that internal defects can be found and sized. It's a flexible and durable method that's been used extensively in industries for NDT. Only ultrasonic and X-ray techniques out of all NDT technologies are effective in detecting a large proportion of subsurface faults in goods. Ultrasonic testing, unlike X-ray procedures, does not pose any environmental or health dangers. Despite its benefits, it has some downsides, the most significant of which being the requirement for a high level of operator expertise and integrity. As a result, qualified and certified NDT workers are required. In addition, UT sensors are more costly than some other NTD devices [8].

VII. THERMOGRAPHY

Thermography method is used to achieve higher quality and reduce production costs. The disadvantage of this method is that it has industrial lack implementation. [12]
The science of Infrared thermography includes measuring and mapping surface temperatures. Usually, thermal imaging cameras are used in this method and the response of the object is characterized by thermal measurements. Flash thermography techniques are successful in imaging composite parts. [6] Due to the Thermography's ability to visualize defects in the composite part, it detects missing rovings, fuzzballs and fiber orientations. It also detects defects in cured parts such as delaminations, dry spots, porosity or disbondings. These situations are shown in Figure 7. [12]
An infrared thermographic scanning system can be used in day or night conditions and can measure temperature patterns based on small temperature differences. Every object emits electromagnetic radiation and depends on this temperature, these radiations are detected by radiometers. Imagers of this system convert the emitted radiation into electrical signals. It does this with an infrared detector. [6] Automatic thermography is shown in Figure 8.

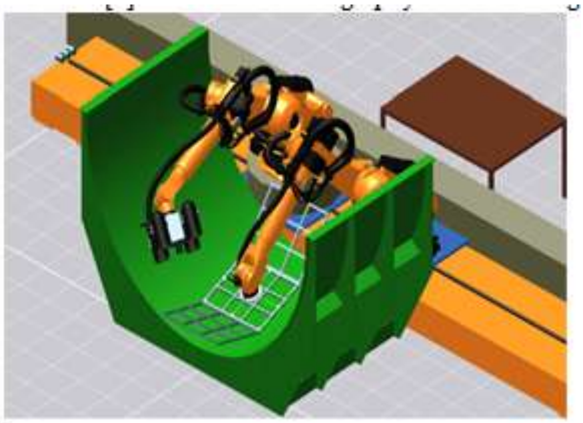

Fig. 8. [12] Approach - production integrated, automated Thermography

A. **Improvement of NDT**
In this paper we investigated the various methods of non-destructive testing and their pros and cons. It is apparent that testing process is quite necessary for the effectiveness of the production. However, the efficiency of the testing process is also important as inefficient testing results in the escape of defects. The predominant factors affecting the non-destructive testing are personnel, equipment, control conditions and technical documentation. We took the statistical analysis carried out by [7] as a reference to explore the reliability of the NDT.
The information about the personnel includes the educational and professional state and work experience. The control means are evaluated according to manufacture and calibration date and grade. Most part of the database came from the records of control tools and monitoring process. Additional factors considered are control and testing methods, tested parts, defect kinds, etc. The division of the database has been illustrated in the Figure 9.

Fig. 9. [7] Data sources for statistical analysis

The first and foremost requirement for the trusted NDT is proper appliance of the steps mentioned in the regulation documents for the testing units. Workers must participate in regular periodic qualification, certification and attestation. The type of defects also determine the factors required for the process to be proficient. For example, to determine the defects in the bolsters does not require specially skilled and experienced workers. However, magnetic particle tests require full attention of the operator and any fault originated by the operator will lead to the escape of defective production. To identify the relationship between the qualifications of the operator and the proportion of rejected parts, the graph shown in Figure 10 has been obtained which shows 0.93 correlation coefficient. This value means that the work experience and control process results are fully related to each other.

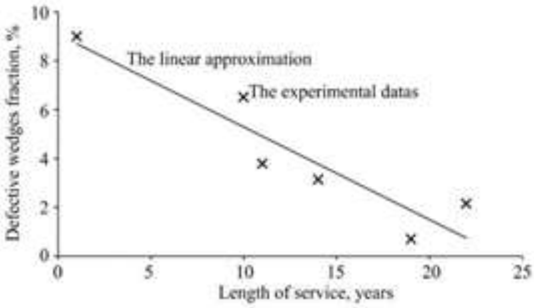

Fig. 10. [7] Relationship between operator knowledge and rejected parts

So, from the investigations of the magnetic particle inspection of side frames and bolsters, we come into conclusion that it is necessary to continuously monitor the proficiency of NDT process and apply corrective measurements, such as inspection, re-inspection, employee attestation, training, etc, when necessary, in order to prevent the undesirable accidents caused by faulty production.

VIII. CONCLUSION AND OUTLOOK

All things considered, according to literature review the importance of non-destructive testing methods is elaborated in this paper and categorized by their advantages and limitations. Most of the advanced NDT methods are able to accomplish the product without any defect and high quality. Non-destructive testing of composite materials has become more important as composite tools are increasingly employed in critical-safety applications. It is crucial to understand each method and their scale of ability to detect defects and choose suitable one for the application in the composite materials and automotive industry. Based on our research, the obtained conclusion refers that non-contact NDT methods are more useful due to the fact that they could be used for in-line inspection whilst it leads to less time for inspection as it decreases the preparation time. This research paper provides information about improving the efficiency of NDT methods and factors that have impacts on performance of testing methods. To sum up, the selected method should be attentively analyzed while it is used for automotive industry to minimize the costs of inspection and obtain higher efficiency and zero defects in the production line.

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