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# **ADVANCED STRESS ANALYSIS AND FEA (M6X00420)**

## **NDT TECHNIQUES**

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## EXECUTIVE SUMMARY

This report is intended to provide information on the different techniques used for non-destructive testing and their role within industry today. The report includes an overview of both non-destructive and traditional destructive testing, which enabled a comparison of the generalised techniques. To maintain continuity to the module subject, the report moves focus to detailing three applicable examples of non-destructive testing methods, which are used to determine stress (strain) within a component or structure. As only a small number of non-destructive techniques have relevance to experimental stress analysis. The report highlights the linear relationship which exists for stress and strain for many materials within their elastic limit, and determines that stress cannot be directly measured. The three non-destructive techniques described within the report are photoelastic coating, the bonded resistance strain gauge and brittle coating; all methods operate on the same principal of measuring the surface strain on a subject. Each method has been described detailing the associated scientific principles, advantages and disadvantages, possible sources of error and any necessary assumptions. Based on the understanding gained from researching current academic literature relevant to this study topic, it has become evident that through the comparison of destructive and non-destructive testing, both methods have strengths for different applications. However, the fundamental difference between the two methods is that non-destructive testing can satisfy the necessity to have a reliable method for monitoring the growth rate of defects during the service life of an assembly, material or component. Where traditional destructive testing ultimately involves the destruction of the part preventing such analysis.

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## 1.0 INTRODUCTION

Non-Destructive Evaluation (NDE), Non-Destructive testing (NDT), Non-Destructive Inspection (NDI), or Non-Destructive Examination (NDEx), are all terms used to describe the methods which determine if a material, component or system is flawed or defective without compromising, damaging or destroying the serviceability of the subject. Whilst throughout literature these terms appear synonyms, Meola, et al. (2017), highlights that with deeper analysis, there are fundamental differences; NDI can be attributed to some form of visual inspection, which may lead to further testing if nonconformities are found; NDT comprises of a physical action on a subject to further understand a characteristic, and NDE can be described as the final judgement on the basis of test results. However, ASM Handbook (2018), describes Non-Destructive Evaluation as the field of study in which many terms inclusive of NDT, NDI and NDEx reside. Therefore, for the purpose of semantics and to align with the assignment title (NDT Technologies), non-destructive testing will be favoured to describe all testing, inspection or examination techniques, which do not damage the subject in any way. As all methods are used to detect, locate, size, or determine something about an object or flaw, and allow an investigator to evaluate whether the object or flaw is acceptable.

## 2.0 NON-DESTRUCTIVE AND DESTRUCTIVE TESTING

### 2.1 DESTRUCTIVE TESTING

There are many standard tests which when conducted will provide information on the tensile, compressive, shear or impact properties of a component. However, these tests are of a destructive nature and have limitations when considering complex shapes and large engineering assemblies (Aire & Chimezie, 2016). These types of tests are often termed as destructive testing, or destructive physical analysis (DPA), and are often required when the quality of a component or structure must be ensured. Hence, destructive testing is often utilised to verify material selection, determine the allowable material discontinuity limits, acceptable environments and acceptable stresses during the manufacturing stage. When considering mass-production, this type of testing can be economical as only a small number of samples will be destroyed. When dealing with smaller production numbers, however, this method can be expensive. Since the point of failure during these tests often happens suddenly, tests are often recorded with high speed cameras to capture every detail. Tests also incorporate a number of measurement devices that give the exact conditions at the point of failure. Temperature, pressure and other data are often recorded for later evaluation along with the visual log of the destructive test. A typical example of destructive testing is when car manufacturers use crash tests to see what actually happens to a car when in a collision. These tests allow the car's safety

features to be tested in real-time that would be impossible if the car had to be kept intact (Corrosionpedia.com, 2017; Aire & Chimezie, 2016).

## 2.2 NON-DESTRUCTIVE TESTING

At its beginning non-destructive testing was an unsophisticated technology and can be traced back hundreds of years. Metalworkers would test for strength and integrity by evaluating the tone produced from tapping their work. This methodology was still in use on locomotive wheels to check for fatigue cracks as recently as the early 20<sup>th</sup> century. The test is still performed today, although now with more advanced equipment and is referred to as the acoustic impact test (Aubele & Keown, 2008). Non-destructive Testing can be categorised into nine distinct areas because of the type of defect, or parameter under evaluation:

- Flaw detection and evaluation
- Leak detection and evaluation
- Metrology (measurement of dimension) and evaluation
- Location determination and evaluation
- Structure or microstructure characterization
- Estimation of mechanical and physical properties
- Stress (strain) and dynamic response determination
- Signature analysis
- Chemical composition determination

(ASM Handbook, 2018).

The appellation of different NDT techniques used to evaluate the nine different area categories generally make reference to a particular scientific principle, or to the equipment used to undertake the evaluation. Hence, ultrasonic testing is centred on the propagation of ultrasonic sound waves in a material, and magnetic particle testing, through the use of small particles which are affected by the application of a magnetic field. Hse.gov.uk (2019) generalises that NDT techniques fall into two categories:

- Techniques which only detect and size defects/damage present on the surface of a component.
- Techniques which can detect and size defects/damage embodied within a component.

A surface NDT technique at its simplest form, is visual inspection, which can be realised as a method every manufacturer uses naturally to verify a parts correctness. Through visual inspection; part dimensions, shape and surface finish can all be determined, and further enhanced with the use of

mechanical templates, gauges, or optical magnifying equipment. Often, visual inspection is self-consistent, however, dependant on the industry and outcome, it can often lead to further evaluation through more advanced NDT methods (Dwivedi et al., 2018; Hull & John, 1988).

Fundamentally, volumetric non-destructive tests involve launching an energy input into a material, or sample and recording the response for analysis. The energy input or signal (which may be an electric current, heat flux, ultrasound waves, X-rays or something else), is sent to a material's surface and the reaction to the stimulus, or the modification to the signal, is observed and compared to a known standard. The signal propagation within the test sample is dependent on the optical, mechanical, thermal, chemical and acoustical properties of the material. These properties change when in the presence of inhomogeneities, or if the material has been subject to alteration. Therefore, NDT often evaluates a material based on the measurement of one type of property, to determine the variation of another property. The importance of selecting the correct, or most appropriate NDT technique is vital for the effectiveness of the test. As no technique is capable of detecting every type of defect and the most effective type for a specific application must be selected. The two main factors which ultimately influence volumetric NDT technology selection are the ability of the subject's material to allow the signal to travel through it, and the extent of the deviation of the signal that a defect would cause, therefore, the readable quantity related to the perturbation must be large enough to not be mistaken with background noise (Aire & Chimezie, 2016; AMC Handbook, 2018).

Non-destructive testing can be applied throughout a product, part or structures full life cycle and is used to determine:

- If a part, product or structure is acceptable after each manufacturing step, which is often referred to as in-process inspections.
- If a part, product or structure is acceptable for final use; this is often called final inspection.
- If an existing part, product or structure is acceptable for continued use; this is frequently referred to in-service inspection.

(AMC Handbook, 2018).

The industry is promoted through many national and international trade associations, where knowledge, standard methods and training is developed about non-destructive testing. These trade associations include the American Society for Non-destructive Testing, the Non-Destructive Testing Management Association, the International Committee for Non-Destructive Testing, the European Federation for Non-Destructive Testing and the British Institute of Non-Destructive Testing (AMC Handbook, 2018; Dwivedi et al., 2018).

## 2.3 DESTRUCTIVE AND NON-DESTRUCTIVE TESTING COMPARISON

Table 1: Destructive and Non-destructive Testing Comparison.

| COMPARISON TABLE    |                                                                                                                                                                                                                                                                                                                                                                                                                                            |                         |                                                                                                                                                                                                                                                                          |
|---------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| DESTRUCTIVE TESTING |                                                                                                                                                                                                                                                                                                                                                                                                                                            | NON-DESTRUCTIVE TESTING |                                                                                                                                                                                                                                                                          |
| 1                   | Tests often copy service conditions and measure directly and reliably.                                                                                                                                                                                                                                                                                                                                                                     | 1                       | Tests generally involve indirect measurements of properties of no direct service significance. The correlation between measurements and serviceability must be proven by other means.                                                                                    |
| 2                   | Tests are usually quantitative measurements of load for failure, significant distortion or damage, or life to failure under given loading and environmental conditions. Consequently, they may yield numerical data useful for design purposes or for establishing standards or specifications.                                                                                                                                            | 2                       | Tests are usually qualitative and rarely quantitative. They do not usually measure load for failure or life of failure even indirectly. They may however reveal damage of the mechanisms of failure.                                                                     |
| 3                   | The correlation between most destructive test measurements and the material properties being measured (particularly under simulated service loading) in most observers may agree upon the results of the test and their significance with respect to the serviceability of the material or part.                                                                                                                                           | 3                       | Skilled judgement and test or service experience are usually required to interpret test indications. Where the essential correlation has not been proven, or where experience is limited, observers may disagree in evaluating the significance of the test indications. |
| 4                   | Destructive tests are not usually convenient to apply to parts in service. Generally, service must be interrupted and part permanently removed and replaced.                                                                                                                                                                                                                                                                               | 4                       | Non-destructive tests may often be applied to parts in service assemblies without interruption or service beyond normal maintenance or idle periods. They involve no loss of serviceable parts.                                                                          |
| 5                   | Cumulative change over a period of time cannot readily be measured on a single unit. If several units from the same lot or service are tested in succession over a period of time, it must be proven that the units were initially the same. If the units are used in service and removed after various periods of time, it must be proven that each unit was subject to similar conditions of service, before valid data can be obtained. | 5                       | Non-destructive tests permit repeated checks of a given unit over a period of time. In this way, the rate of service damage, if detectable, and its correlation with service failure may be established clearly.                                                         |

(Aire & Chimezie, 2016).

Table 2: Destructive and Non-destructive Testing Comparison Continued.

| COMPARISON TABLE    |                                                                                                                                                                                                                                      |                         |                                                                                                                                                                                                                                                               |
|---------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| DESTRUCTIVE TESTING |                                                                                                                                                                                                                                      | NON-DESTRUCTIVE TESTING |                                                                                                                                                                                                                                                               |
| 6                   | With parts of high value, It may not be economically viable to perform a variety of destructive tests.                                                                                                                               | 6                       | High valued parts are not lost in non-destructive testing. Repeated testing during production or service is feasible when economically and practically justified.                                                                                             |
| 7                   | Tests are not made on the objects actually used in service. Consequently, the correlation or similarity between the objects tested and those used in service must be proven by other means.                                          | 7                       | Tests are made directly upon the objects to be use in service. Consequently, there is no doubt that the tests were made on representative test objects.                                                                                                       |
| 8                   | Tests can be made on only a fraction of the production lot to be used in service. They may have little value when the properties vary unpredictably from unit to unit.                                                               | 8                       | Tests can be made on every unit to be used in service if economically justified. Consequently, they may be used even when great differences from unit to unit occur in production campaigns.                                                                  |
| 9                   | Tests often cannot be made on complete production parts. The tests are often limited to part models of production parts or from special material specimens processed to stimulate the properties of the parts to be used in service. | 9                       | Tests may be made on the entire production part, or in all critical regions of it. Consequently, the evaluation applies to the part as a whole. Many critical sections of the part may be examined simultaneously or sequentially.                            |
| 10                  | A single destructive test may only determine one or a few of the properties that may be critical under service conditions.                                                                                                           | 10                      | Many non-destructive tests, each sensitive to different properties of the material or part, may be applied simultaneously or in sequence. In this way, it is feasible to measure as many different properties correlated with service performance as desired. |

(Aire &amp; Chimezie, 2016).

### 3.0 EXAMPLES OF NDT TECHNIQUES

To maintain continuity to the module subject (Advanced Stress Analysis and FEA), this report will move its focus to detailing three applicable examples of NDT techniques which are used to determine stress (strain) and dynamic response determination, which was listed earlier from the aforementioned nine NDT categories. As only a small number of NDT techniques have relevance to experimental stress analysis, some of which are listed below.

- X-ray diffraction; Barkhausen noise measurement.
- SPATE (Stress Pattern Analysis Thermal Emission).
- Neutron diffraction and scattering.
- Strain gauging, photoelasticity and brittle coating.
- Electronic Speckle Pattern Shearing Interferometry (ESPSI).
- Alternating Current Stress Measurement.

(bindt.org, 2019).

Methods of non-destructive testing in relation to experimental stress analysis can be used throughout all life stages of load-bearing parts, members or structures. These techniques can be used for product design engineering, preliminary design evaluation, productive design testing, failure analysis, material selection and structural research. The fundamental principles of experimental stress analysis are based on the relationship which exists between stress and strain. The relationship is one of the most basic concepts from the study of mechanics of materials and is vital when determining stress. Stress itself cannot be directly measured, however, strain can, and for many materials within their elastic limit, there is a linear relationship between stress and strain. When considering unilateral loading conditions, stress divided by strain gives a constant known as Young's Modulus of Elasticity for a material. Strain is defined as the linear deformation of a material, which is a result of applied forces or a temperature change. Therefore, if strain can be measured, and from a knowledge of the mechanical properties of the material from which the structure is manufactured, stresses can be calculated. From this knowledge, the maximum stresses which are likely to occur under normal service conditions can be calculated to ensure, that the allowable working stress for the material in either tension or compression are not exceeded. The allowable working stress is often taken to be the yield stress of the material divided by a convenient safety factor, to allow for any unexpected increase in the level of service loading. If the maximum stress in the component is likely to exceed the allowable working stress, the component is considered unsafe (AMC Handbook, 2018; bindt.org, 2019; Hearn, 1997).

Stress analysis through non-destructive testing is generally used to measure and locate the most significant strains in a part or structure. The purpose is not only to identify those areas at high-level stress, but also to locate stress concentrations where failure is most likely to occur. However, the low stress areas are also important, as these are the areas where material can be safely removed to save on cost and performance. Locating significant strains within designs will normally require a full-field measurement technique such as brittle coating. Once a full-field test has highlighted any areas of concern, further measurements may then be taken to accurately determine the magnitude and direction of the principal strains. Once established, depending on the type of load, material and failure mode, it may be necessary to measure the maximum shear strain. To undertake this type of point measurement of strain, resistance strain gauges and photoelastic coatings are widely used. Many factors such as location, types of loading, anticipated strain range, required resolution, operating environment and the duration of the test must all be considered; along with the type of strains to be measured when considering practical criteria for selecting the appropriate strain measurement technique (AMC Handbook, 2018; Hearn, 1997).

### 3.1 BONDED RESISTANCE STRAIN GAUGE

#### 3.1.1 BONDED RESISTANCE STRAIN GAUGE OVERVIEW

A common and frequently used strain measurement technique used in the field of NDT and experimental stress analysis is the bonded resistance strain gauge. Basically, the strain gauge is an extremely thin, small strain sensitive electrical resistor which is bonded to a flexible backing material. The gauge is adhesively bonded to a part or structure to convert mechanical displacement (strain), into electrical resistance. The change in resistance is very small and direct measurement is not possible, the resistance must be read from an appropriate measurement system, normally consisting of a Wheatstone bridge, amplifier and an indication instrument. This change in resistance can then be read directly as load, pressure, torsion and so on. Fundamentally, all types of strain gauges convert mechanical motion into an electronic signal. The change in capacitance, inductance, or resistance is proportional to the strain experienced by the sensor. This can be likened to the effect of a wire held under tension, the longer the wire is stretched, the more its cross section is reduced. This change in cross-section is proportional to the wire's resistance. However, there is also a change in the value of the resistivity in the conductor material when subjected to strain, a property called the piezo-resistive effect. To mitigate this eventuality, strain gauges are manufactured from alloys which exhibit a near-linear ratio between their resistance and mechanical strain. This ratio is known as the gauge factor and typical strain gauge alloys range from a gauge factor of two to four (Learnmech.com, 2019; Nde-ed.org, 2019; Omega.co.uk, 2019).

When considering strain gauge installations, the ultimate aim is to achieve changes in resistance only when surface deformations occur. The entire gauge installation cannot be calibrated and an assumption is made that the gauge is deformed in exactly the same way as the subject being tested. Unfortunately, in real applications, temperature, material properties, the adhesive that bonds the gauge to the surface, and the stability of the metal all affect the results. The most desirable strain gauge materials are also sensitive to temperature and tend to change resistance as they age. This may not be of concern if the required test is for a short period, but for a continuous monitoring system, temperature and drift must be compensated for (Hbm.com, 2019).

### 3.1.2 BONDED RESISTANCE STRAIN GAUGE - ADVANTAGES AND DISADVANTAGES

The advantages of selecting a bonded resistance strain gauge are:

- Relatively inexpensive
- Can achieve overall accuracy of  $\pm 0.1\%$ .
- Available in short gauge lengths
- Only moderately affected by temperature changes.
- Small physical size and low mass for small curvatures and designs.
- Both static and dynamic analysis can be conducted on the subject.

(Hearn, 1997; Hbm.com, 2019, Nde-ed.org, 2019).

The disadvantages of selecting a bonded resistance strain gauge are:

- Can be sensitive to creep as a result of the adhesive material degradation used to bond the gauge to the subject.
- Electrical noise and interference may alter your readings, cables often require shielding.
- Temperature influences.
- Hysteresis caused by thermoelastic strain, care must be taken to select the correct adhesive for each application and environment.
- Drift - gauges change resistance as they age.
- Accuracy during positioning of the strain gauges can be detrimental to the results and can also be time consuming. Brittle coating is often utilised to determine the optimum location and direction in which to place strain gauges to gain more accurate measurements.

(Hearn, 1997; Hbm.com, 2019, Nde-ed.org, 2019).

### 3.1.3 BONDED RESISTANCE STRAIN GAUGE APPLICATIONS

The bonded resistance strain gauge is widely used in a variety of different environments and applications. The gauge is used to measure surface strains on solid materials and is often used to determine component or structural stresses. The bonded resistance strain gauge is used to determine:

- Strain measurement
- Residual stress measurement
- Vibration measurement
- Torque measurement
- Bending and deflection measurement
- Compression and tension measurement

(Learnmech.com, 2019; Nde-ed.org, 2019; Omega.co.uk, 2019).

## 3.2 PHOTOELASTIC COATING

### 3.2.1 PHOTOELASTIC COATING OVERVIEW

Photoelasticity is a non-destructive, full-field stress analysis technique based on an optomechanical property called birefringence, which is a property displayed by many transparent materials, such as glass or plastic. When a load is applied to a photoelastic material, internal strains develop that can be observed in polarized light. Light normally vibrates in two planes, however, through polarization, one plane of light is removed. Polarization involves passing light through a substance called a polarizer; two polarizers that are crossed ordinarily do not transmit light, but if a stressed material is placed between them and if the principal axis of the stress is not parallel to this plane of polarization, some light will be transmitted in the form of coloured fringes. Stresses in mechanical structures can be analysed by modelling a prototype in an opaque plastic to study the fringe pattern displayed under polarized light. The fringe patterns are related to the difference between the principal stresses in a plane normal to the light propagation direction, which are often captured on a digital camera and saved onto a computer. This enables the full-field measurement over the whole area of the subject through a non-contact method, as opposed to conventional point-by-point methods. The technology is one of the oldest methods used for determining the stress distribution in a material, especially in areas where mathematical methods are inconvenient because of complex part geometries. As the term implies, photo refers to the use of light rays and optical techniques, while elasticity represents the study of stresses and deformations in elastic bodies (AMC Handbook, 2018; Britannica.com, 2019; Shinde et al., 2016).

Photoelastic coatings work on the same principal of birefringence, however, a photoelastic material coating can be applied to a solid body and used to analyse surface stresses in bodies of complex

geometry or irregular surfaces. The photoelastic coating material (which is usually a polymer), can be applied by either bonding a prefabricated sheet to the surface of a flat specimen, or by forming photoelastic material around a contour during polymerization for complex curves. The component is carrying the primary load and not the photoelastic coating, and the in-plane strains are assumed to be equal to the in-plane surface strains in the component. The analysis is based on the principal strain difference, which is related to the principal stress difference in the component through the elastic constants of the component material (AMC Handbook, 2018; Microscopyu.com, 2019; Shinde et al., 2016).

### 3.2.2 PHOTOELASTIC COATING - ADVANTAGES AND DISADVANTAGES

The photoelastic coating method has many advantages over other methods of non-destructive experimental stress analysis. The technique can be used to measure surface strain in parts and structures of virtually any shape, size, or material. The analysis can be conducted under actual service conditions at, or near room temperature. Further advantages of the photoelastic coating method include:

- Ease of use.
- The coated area displays the entire strain field which is visually displayed.
- Stress gradients can be accurately measured from the almost zero-gauge length.
- The strain pattern remains visible after the load is removed permitting easily detectable yielding.
- Provides full-field values of the principal stress directions (sometimes called stress trajectories).
- The combination of many different loading conditions can be observed and measured.
- Both static and dynamic analysis can be conducted on the subject.
- Residual stress can be determined.
- Only a small investment in equipment and materials is required to perform basic analysis.
- Provides the value of the nonvanishing principal normal stress along the perimeter(s) of the model, where stresses are generally the largest

(AMC Handbook, 2018; Shinde et al., 2016).

The disadvantages of the photoelastic coating method include:

- Requires expensive equipment for precise analysis of large components.
- Complicated calculations are required to separate the values of principal stresses at a general interior point.

- Surface preparation is required to obtain suitable adhesion and to prevent errors from the strain transfer from coating to specimen.

(AMC Handbook, 2018; Shinde et al., 2016).

### 3.2.3 PHOTOELASTIC COATING APPLICATIONS

The latest advances in photoelastic analysis present engineers the opportunity to conduct real-time stress monitoring of structure. The traditional time-consuming coating applications and manual reading of fringes has given way to quick cure coatings and automated polariscope systems, high speed cameras can monitor changing stress patterns in real time. The modern photoelastic technique offers a powerful and unique full-field dynamic stress analysis method, often used within the following applications:

- Infra-red photoelasticity
- Dynamic photoelasticity
- Image processing for fringe analysis
- Flaw detection and glass inspection
- Residual stress analysis
- FEA model verification
- Impact testing
- Polarimetric fibre optic sensors
- Stereolithography applications
- Research on fracture behaviour in materials

(AMC Handbook, 2018; Hearn, 1997; Shinde et al., 2016).

## 3.3 BRITTLE COATING

### 3.3.1 BRITTLE COATING OVERVIEW

Brittle coating is one of the most basic forms of experimental stress analysis and involves coating a part or structure with a strain sensitive coating or lacquer. The coating is brittle and will fracture with a clean break, that is always orientated normal to the direction of the largest principal stress. This technique distinguishes the magnitude and direction of stress in a part or structure, and is often used to determine stress concentrations. The brittle coating application gives a qualitative result, and is generally used to quickly locate and evaluate the high-stress points in a design, unfortunately, this method provides very little information about the stress sign or level. This technique is not used for detailed measurements and instead can show the location of where strain gauges need to be placed

and orientated for strain gauge installations. For most applications the lacquer is sprayed onto the surface of the subject under evaluation. However, some lacquers are in the form of wax or powder and require pre-heating of the subject's surface. Prior to the application of the coating, the subject's surface is cleaned or prepared using standard solvents to remove grease or dirt. To ensure accuracy and to determine the strain sensitivity of the coating, calibration bars are often sprayed at the same time and in the same manner as the subject. The bars are normally simple square solid sections that are able to fit into a cantilevered calibration jig. Once the lacquer is fully cured, the calibration jig is used to load the bars and fracture the coating, enabling the strain to be measured at fracture point. This process enables quantitative measurements of strain to be made on the components under evaluation. Unfortunately, this type of quantitative measurement is generally only accurate to 10-20%, and for this reason the technique is often only used to locate the maximum stress in a component. This method of analysis is based on the assumption that the surface strain of the specimen is transmitted from the part to the coating without any magnification or reduction. (ASM Handbook, 2018; Hearn, 1997).

### 3.2.2 BRITTLE COATING - ADVANTAGES AND DISADVANTAGES

The advantages of the brittle coating technique include:

- It is nearly a whole field stress analysis technique.
- The technique can be directly applied to a machine component in operation and there is no necessity for any model or prototype.
- Analysis for converting the data into stress in the component is uncomplicated.
- Can identify the location and direction of maximum stress in a subject, allowing for accurate position of strain gauges.

(ASM Handbook, 2018; Hearn, 1997; Walker, 2001).

The disadvantages of the brittle coating technique include:

- The behaviour of the coating can be strongly affected by temperature and humidity during testing which will provide inaccurate results.
- A number of variables can affect the sensitivity of coating; therefore, the behaviour of the coating has to be fully understood.
- This technique is more qualitative in nature than quantitative.
- Surface preparation is required prior to the application of the coating.
- The quantitative measured accuracy is only accurate to 10-20%.
- A brittle coating does not respond to compressive loads and in order to overcome this problem a relaxation technique is required. Where, a load is applied to a coated specimen

before it has had the opportunity to dry. Under this condition the coating is stress free, while the specimen is highly compressed. When the load is released, the specimen will stretch and tensile stress will develop in the coating causing the coating to crack.

- This method is incapable of detecting pre-existing stresses from processing or assembly.

(ASM Handbook, 2018; Hearn, 1997; Walker, 2001).

### 3.2.3 BRITTLE COATING APPLICATIONS

This technique is particularly suitable for inaccessible areas; a typical example of an application of this method is when car manufacturers brittle coat an inaccessible part during vehicle testing. The part can be coated prior to assembly and after a road test, the part can be disassembled and evaluated. The knowledge from these tests can reduce the time taken in locating the correct placement for subsequent strain gauge studies. Therefore, the brittle coating method can be used to:

- Locate small areas of high stresses.
- Determining directions of principal stresses.
- Measure the approximate magnitudes of tension and compression stress concentrations under static loads.
- Measuring tension stress concentrations under dynamic and impact loads.
- Indicating localised plastic yielding.

(ASM Handbook, 2018; Hearn, 1997; Walker, 2001).

#### 4.0 CONCLUSION

Based on the understanding gained from researching current academic literature relevant to this study topic, it has become evident that through the comparison of destructive and non-destructive testing, both methods have strengths for different applications. The simplest and often most accurate form of testing materials and components is to test to destruction, where, real service conditions can be imitated to determine characteristics about the test subject. However, destructive testing is not always possible on large or complex structures, or may be undesirable on expensive parts when considering small production numbers. During such applications, non-destructive testing can provide an organisation with the ability to inspect, test and evaluate their products throughout their full life cycle without harming the subject in any way. Non-destructive testing can ascertain a part's conformity to a known quality standard and ensure the absence of defects throughout each manufacturing stage. There is also a necessity to have a reliable method for monitoring the growth rate of defects during the service life of an assembly, material or component; which would enable informed decisions to be made on remaining equipment life evaluations. This is where we move from destructive testing into the realm of non-destructive testing. Through the continued evolution of technology, new materials are being created and new types of defects require detection, with this evolution, more sophisticated detection methods are being developed, as well as enhancement to the existing ones.

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