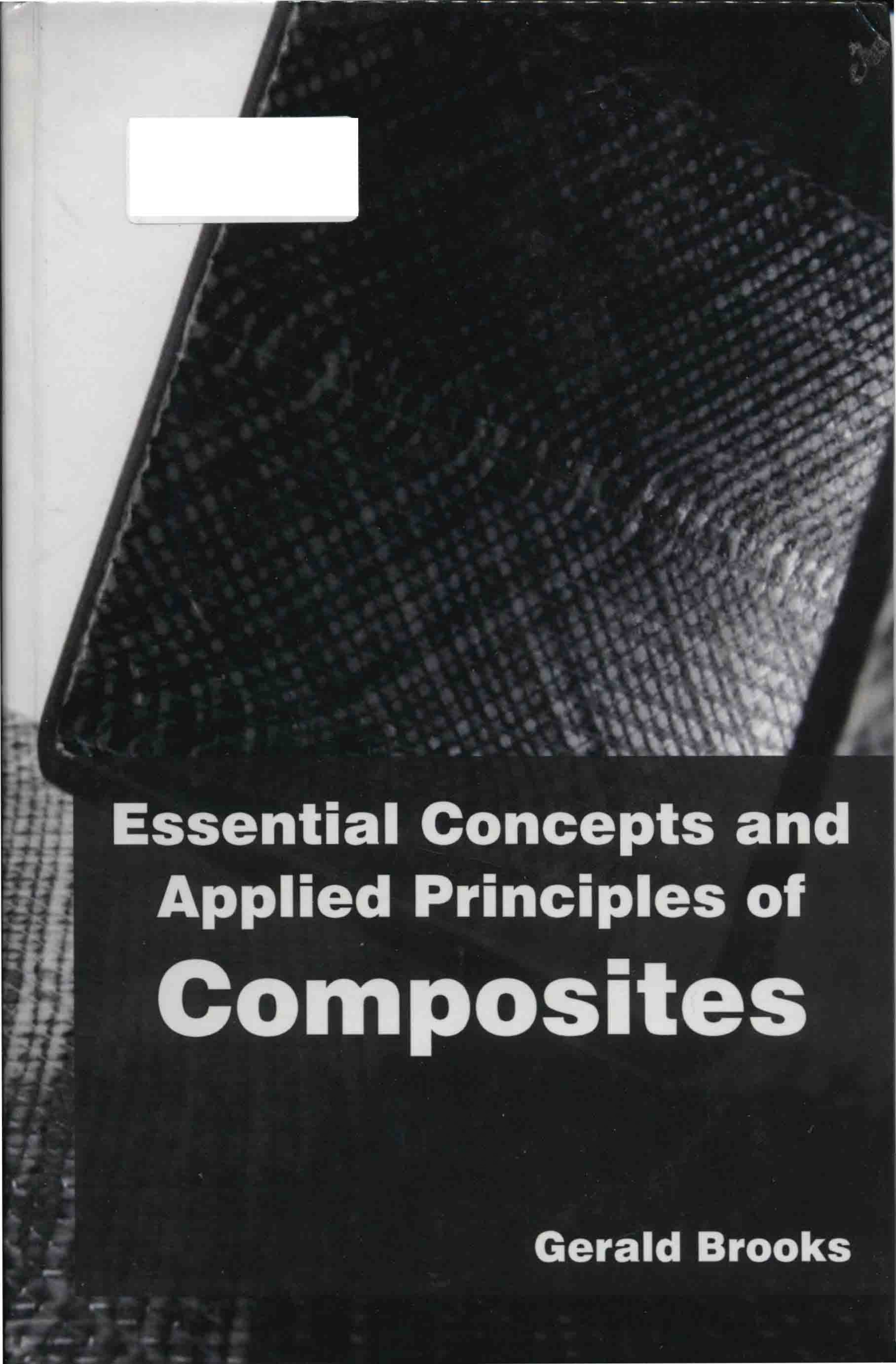

Essential Concepts and Applied Principles of Composites

Gerald Brooks

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Edited by **Gerald Brooks**

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Preface

This all-inclusive book discusses the essential concepts and applied principles of composites. Composites are a class of materials which possess some unique and extraordinary properties. They have received a lot of attention recently due to their role in the field of material research and also because of the advent of new forms of composites such as nanocomposites and bio-medical composites. Composite materials can be utilized in various industries such as aerospace and construction industries. This book discusses the properties of various composites and their potential applications. It will be useful as a reference for students and researchers studying this field.

This book is a comprehensive compilation of works of different researchers from varied parts of the world. It includes valuable experiences of the researchers with the sole objective of providing the readers (learners) with a proper knowledge of the concerned field. This book will be beneficial in evoking inspiration and enhancing the knowledge of the interested readers.

In the end, I would like to extend my heartiest thanks to the authors who worked with great determination on their chapters. I also appreciate the publisher's support in the course of the book. I would also like to deeply acknowledge my family who stood by me as a source of inspiration during the project.

Editor

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Chapter 1

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K.D. Mohd Aris, F. Mustapha, S.M. Sapuan and D.L. Majid

Additional information is available at the end of the chapter

1. Introduction

At present, the advanced composite materials have gained it acceptance in the aerospace industries. The content of these materials has increased dramatically from less than 5% in the late eighties to more than 50% at the beginning at this decade. [1] The materials offer high strength to weight ratio, high strength to weight ratio, corrosion resistance, high fatigue resistance etc. These benefits have transformed the aviation world traveling to better fuel consumption, endurance and more passengers. However, the use of these materials has posed new challenges such as impact, delamination, barely visible internal damage (BVID) etc. Before a part or component being used on the actual structure, they are being tested from small scale to the actual scale in a controlled environment either at lab or test cell. However the attributes imposed during the operation sometimes shows different behavior when the actual operations are performed due to environment factors, human factors and support availability. To ensure the safety is at the optimum level, the continuous conditional monitoring need to be carried out in order to ensure the component operate within the safety margin being placed by the aircraft manufacturers. [2] One of the areas under investigation is the structural integrity assessment through the use of non-destructive inspections (NDI). The NDI allows aircraft operator to seek information on the aircraft structure reliability by inspecting the structure without having to remove it. There are many types of inspection methods which are limited to materials, locations and accuracy depends on methodology applied. [3] Few of popular techniques are eddy current, ultrasonic, radiography, dye penetrant which have been existence in quite a time. However due to composite material applications new methods have emerged in order to improve detection to attain converging results such as tap test, laser shearography, phase array etc.. So far, these methods prove its effectiveness and consistency in finding the anomalies.

However these techniques require total grounding of the aircraft and the inspection are manually intensified. The only clue where to inspect the area from the occurrence report, maintenance schedule or mandatory compliance by the authority. New inspection paradigm need to be developed as defects will arise in the non-conventional ways as the composite materials being used in the pressurized area such as in Boeing 787 and Airbus A350 aircrafts. Therefore, the available methods need to be systematically chosen depends on thin laminate, thick laminate or sandwich structure.[4] The active monitoring offers continuous monitoring either by interrogating or listen to the structure behavior. Embedded sensor and on surface sensors offers the advantages and disadvantages that yet not being explored fully and can accommodate the NDI techniques. The structure integrity will behave differently as the structure being modified and repair to ensure continuation of the aircraft operation and prolong its service life. The aircraft structural health monitoring (SHM) is one of the conditioning monitoring that has gained its usefulness. Such health monitoring of a component has been successfully being used in the aircraft avionics systems, engine management systems, rotary blade systems etc. Since the SHM is still at its infant stage, several methodology and detection methods are been explored to suite the monitoring purposes. Acoustic emission, fiber bragg grating, compact vacuum monitoring etc. are being investigated for their potential. [5] Therefore the paper is focusing on issues on the implementation of the SHM at post repair through the use of PZT sensor by using guided waves as a method of monitoring for active and passive structural surface conditions.

2. Theoretical background

The use of advanced composite materials has shifted the paradigm in aircraft structure design, operation and maintenance philosophy. A simple stop drills procedure is used to prevent further propagation of crack or by removing the damage area and replacing the damage area. This procedure are well written in typical aircraft structural repair manual (SRM) under Chapter 50-xx-xx found in the ATA 100 (Air Transport Associations) [6]. The procedure above can only be applied to metallic structure since the behavior is isotropic in which properties such as damage tolerance, fracture mechanics and fatigue can be predicted although the repair has been done on the damaged structure. The composite structures are made up from various constituents that are laid up and bonded together with the assistance of pressure and temperature at predetermine times. During operations, the aircraft structures are subjected to damages due to impact, environmental, residual imperfections, delaminations that reduces the structural integrity of the aircraft [7]. Typically, there are four types of repair applied to the composite structures. There are external bonded patches, flush or scarf bonded repair, bolted patch and bonded patches [8]. This operation requires the strength to be returned back to the original strength [9]. Due to the orientation, number of plies and materials used the level of recovery of the operating strain is much dependent on the stiffness of the laminates. The governing equation for the actual load to be transmitted to the new repaired laminates are given by the equation below [10] & [11]

$$P=e_aE_xt \tag{1}$$

Where, P, e_a, E_x, and t are actual load, ultimate design strain, modulus in the primary loading direction and the laminate thickness respectively. A simple calculation of the strength of materials can be applied to scrutinized the scarf join for the maximum allowable stress [10] & [11]. The equation is given by

$$P_{\max} = \sigma_u t \leq \frac{\tau_p t}{\sin\theta\cos\theta} \tag{2}$$

Where P_{max}, σ_u, t, θ and τ_p is the maximum load, ultimate stress, thickness, shear stress and scarf angle respectively. By solving the value of θ, the scarf angle is found to be at 2^0 or at 1:30 ratio in order to attained minimum ultimate stress for the repair structure strength to be similar with the parent structure.

Studies have shown the use of PZT sensors on experimental aircraft component such as flaps and wings are promising [12] and [13]. For this experiment, an aircraft spoiler was used as the experimental subject by mounting the sensor arbitrarily on the spoiler's surface. The sensor can also be used to detect the surface condition of normal, damaged and repaired structures.

Most of the structural damage diagnoses were predicted by using analytical or finite element modeling [14], [15] and [16]. Although the results were accepted but it requires a powerful computing hardware, labor intensive interaction and modeling errors before a solution can be converged. Another method is to utilize the statistic to evaluate the captured data. However large amount of data are required to achieve higher reliability and probability to converge to the intended solution. The statistical approach utilizes supervised and unsupervised learning in order to process the data. [17] and [18] The supervised learning uses data as its references and the unsupervised learning uses to cluster the data and group them for selective conditions. The approach can be achieved by using the Statistical Pattern Recognition [19]. The principles in SPR are:-

1. Operational Evaluation,
2. Data Acquisition & Cleansing,
3. Feature Extraction & Data Reduction and
4. Statistical Model Development or Prognosis

Only no 1 and 2 were concerned in this paper.

Outlier Analysis is one of the method applied in SPR. The OA is used as the detection of cluster, which deviates from other normal trend cluster. One of the most common discordance tests is based on the deviation statistic [19] given by

$$z_i = \frac{d_i - \bar{d}}{\sigma} \tag{3}$$

where z_i is the outlier index for univariate data, d_i is the potential outlier and $\bar{d}$ and σ are the mean sample and standard deviation. The multivariate discordance test was known as Mahalanobis square distance given by

$$Z_i = (\{x_i\} - \{\bar{x}\})^T [S]^{-1} (\{x_i\} - \{\bar{x}\}) \tag{4}$$

where Z_i is the outlier index for multivariate data, x_i is the potential outlier vector and $\bar{x}$ is the sample mean vector and e is the sample co-variance matrix [20] and [21]. The result of the above equation is congregated when the distance of a data vector is higher than a preset threshold level.

3. Experimental setup

There were two experimental procedures were taken place. The first was the study of the wavelet through an aircraft part at normal, damaged and repaired conditions. The second is to observed the guided Lamb wave behavior when subjected to tensile loading for the three conditions stated above.

The APC 850 PZT sensor from APC International Inc. was used for both experiments. The properties of the sensors are shown in Table 1 below. Two sensors were used as an actuator and receiver with a diameter of 10mm and thickness of 0.5mm. The pitch catch active sensing was used to obtain the data at the receiving sensors. The sensors were placed at 100mm apart due to the optimum wave attenuation from the actuator to the receiver. The actuator was connected to a function generator where a selected input variable were set and the receiver were connected to the oscilloscope for data mining and further processing.

Description	Value
Voltage limit AC/DC	8/ 15 V
Output Power	20 watts/ inch
Relative dielectric constant	1750
Dielectric loss	1.4%
Curie Temperature	360^{0}C
Density	7.7 X 10^3 kg/m^3
Young's Modulus	6.3 X 10^{10} N/m^2

Table 1. APC-850 properties [22]

3.1. Aircraft component analysis

An aircraft spoiler was used for this research. The use of the structure is only arbitrary at this stage. It is use to seek the workability of the sensor upon trial on several flat panels. Three conditions were introduced to the panel which is the undamaged/ parent, damaged and repaired area. The undamaged/ parent was the area free from any defects. The undamaged area is the original conditions or controlled area. The damaged area was damage caused by impact that removes the top laminate. It was made by impacting the faced planes with a blunt object and creating damage less than 40mm diameter fracture. The level of impact is not an interest in this particular testing due to the studied conditions is only applicable to small surface damage due to impact. The repaired area was where the