ULTRASONIC NON-DESTRUCTIVE TESTING OF ADHESIVE BONDED ALUMINUM PLATES

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A thesis submitted in fulfillment of
the requirement for the award of the degree of
Master of Science (Physics)

Faculty of Science
Universiti Teknologi Malaysia

JULY 2017

to my father,

Hj. Mhd Subre Bin Ishak and family

Kerana Allah, untuk manusia

ACKNOWLEDGEMENT

In the name of ALLAH The Most Gracious and Most Merciful, I am very grateful unto Him for allowing me to complete my MSc research. I would like to take this opportunity to express my thanks and gratitude to all for their contributions to my thesis which made it better in many ways.

I have been very fortunate to work under the supervision of Associate Prof. Dr. Md Supar Rohani, whose provided thoughtful advice and captivating spirit contribute to the quality of this thesis. I greatly appreciate the time he spent on helping me and giving me sound advices and ample assistances, and I extend my most sincere thanks to him. His contribution in the completion of my project means a lot to me and I am indebted to him. My acknowledgement also goes to my colleagues, for their friendship during my study at UTM.

I am also grateful to all my family members who have been supporting me in every possible way. Last but not least, million thanks to those who involve directly and indirectly for helping me to achieve the success of this project.

Thank you very much.

AZIM FIKRI BIN MHD SUBRE

ABSTRACT

Ultrasonic wave technique has been proven to be an effective method for adhesive bond integrity evaluation of isotropic materials. Short ultrasonic pulsed waves with center frequencies ranging from 5-7 MHz are launched into adhesive bonded aluminum plates to detect internal flaws. Shear wave is generated by using normal compressional probe attached to a perspex wedge which allows the sample to be scanned easily without requiring of immersion liquid. The ultrasonic wave is generated through the adhesive bonded aluminum to measure non-destructively the adhesive layer of aluminum wafer (aluminum-epoxy-aluminum) and the aluminum plates for detection of simulated defect. The resulted wave patterns of adhesively joint metal plates are studied and analysed. The measurement was carried out to evaluate the quality of bond, in the existence of gas porosity and the existence of foreign material between adhesive plates. The results of this experiment show that the ultrasonic wave generated for different conditions of bonds gives distinctive type which enables to distinguish the traveled wave in different media.

ABSTRAK

Teknik gelombang ultrasonik telah terbukti menjadi kaedah efektif untuk menilai keutuhan ikatan pelekat bahan isotropik. Denyut pendek gelombang ultrasonik dengan frekuensi pusat dalam julat 5-7 MHz telah ditujukan ke dalam plat-plat aluminum yang terikat dengan pelekat untuk mengesan kecacatan dalaman. Gelombang ricih dijana dengan menggunakan penduga mampatan normal digabung dengan baji perspeks yang memungkinkan sampel diimbas dengan mudah tanpa memerlukan cecair rendaman. Gelombang ultrasonik dijanakan menerusi aluminum pelekat terikat untuk mengukur secara tanpa musnah lapisan pelekat wafer aluminum (aluminum-epoksi-aluminum) dan plat-plat aluminum bagi mengesan kecacatan simulasi. Corak-corak gelombang yang terhasil bagi plat-plat logam yang dilekat dengan pelekat dikaji dan dianalisis. Pengukuran dilakukan untuk menilai kualiti ikatan, dengan kewujudan liang gas dan bahan asing di antara plat pelekat. Keputusan dari eksperimen ini menunjukkan bahawa gelombang ultrasonik yang dijana bagi keadaan ikatan yang berlainan memberikan jenis tersendiri yang membolehkan untuk membezakan gelombang yang menempuh media yang berlainan.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREAVIATIONS

ASNT	-	American Society for Non-Destructive Testing
CRT	-	Cathode Ray Tube
JIS	-	Japanese Industrial Standard
LPI	-	Liquid Penetrant Testing
NDI	-	Non-destructive Inspection
NDT	-	Non-destructive Testing
NDT&E	-	Non-destructive Testing and Evaluation
NTSB	-	National Transportation Safety Board
PTFE	-	Polytetraflouroethlyne
TOFD	-	Time Of Flight Distance
UI	-	Ultrasonic Inspection
UT	-	Ultrasonic Testing

LIST OF SYMBOLS

C	-	Elastic constant
G	-	Shear moduli
t	-	Time
K	-	Rigidity
R	-	Reflected fraction of the incident wave intensity
T	-	Transmitted fraction of the incident wave intensity
U	-	Displacement
V	-	Velocity
V_L	-	Longitudinal wave velocity
V_S	-	Shear wave velocity
°C	-	Degree Celsius
x	-	Position
∂x	-	Change in position
∂t	-	Change in time
ρ	-	Material density
ω	-	Ultrasonic frequency
θ_1	-	Incident angle
θ_n	-	Refracted angle
Z	-	Acoustic impedance

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Foreword

Non-destructive testing (NDT) is a testing technique without destroying the products or structures of the material undertreat. It will deliver evidence on the material quality but does not alter or damage the material under test. Materials and manufactured products are often tested prior to provide the end-user for quality ensuring and expectations required by the customers. It is essentials that any test made on a product intended for future use does not in any way jeopardies its properties and performance. Gradually, NDT is used as an economic tool in predictive maintenance approach of plant operators. Based on scheduled replacement or restoration of deteriorated devices the lifetime of the device could be extended. Instead of common spot inspection, this tendency requires full surface coverage of plant components. This challenge is met by the present time developments in cutting-edge NDT. Any technique used to test under these conditions is called a non-destructive method [1]. In this chapter, an overview about the NDT, background of the study, the objectives of research, and the scopes of research would be discussed briefly.

Instruments working in factories such as automobiles, rail line, aircrafts, structures, power plants, petroleum and gas tanks will require inspection to check whether there were defects at or in the structure of the substance. For any defect detected, estimation on the propagation rate of the defects to the durability of the material in term of their shape, dimension and working stress will be studied. Thus, it is not overrated to state that NDT contributes very much in estimating the life span of industrial products. Prior to this, regular inspection is very important for confirming the safety of the workers or human who use the product. Through regular inspection, NDT inspectors are able to form the situations of defect propagation whether the defects are tolerable to loads that will be applied on it or further nature environment which will affect the quality of the item. This will avoid such accident as the Aloha Airlines Flight 243 which suffers extensive damage caused by the decompression explosion in mid-air. The cause of this accident has been determined by the NTSB in their findings. It was reported that the maintenance program standard is not up to satisfaction which led to failure in detecting the presence of disbanding and fatigue damage, which at last led to the failure of lap joint at the stringer [2].

1.2 Non-Destructive Testing And Inspections

A routine inspection is required to monitor the defect growth and action will be taken prior to defect impact due to time on the material. For a safer environment of industrial operation, there is also a scheduled inspection to check for the containers of fluid such as oil, gasoline and gas for hazardous leakage in order to prevent the whole plant from ceasing its operation. Thus, this scheduled inspection is necessary in order to avoid any further loss if there is any unexpected factory accident. The focus on an inspection is to detect a flaw or a defect. According to Japanese Industrial Standard (JIS), a flaw is defined as discontinuity judging from the results obtained by NDT [3].

However, a defect is defined as a flaw rejected because of exceeding the judging standard prescribed in the inspection or the standard.

NDT should not be confused with non-destructive inspection (NDI). NDT means to examine whether there is a flaw in objects which the smaller ones are like on the ICs and the larger ones as the examples the oil tanks, aircraft body, flapperons, or oil tankers, of which their sizes and inner defect structures cannot be seen through. NDT can be applied to all types of material. The test includes visual testing, radiographic testing, ultrasonic testing, magnetic particle testing, liquid penetrant testing and eddy current testing. However, NDI includes the judgment whether it is safe when we continue to use the objects for certain time, or it is necessary to undergo treatment (repairing or refurbishing) which all depends on the results obtained by using NDT. In conclusion, the inspectors will decide and recommends whether the items are in good condition in certain period of time or need to be replaced immediately through NDI.

NDT method chosen depends on the factors of the material and its dimensions, the surrounding environment, the position of interest which is within the structure or surface of component under examination. The first and foremost of examination often is via optical inspection. Unfortunately inspection by naked eye will not reveal much other than relatively large defects which cannot detect the break through under the surface. The efficiency of visual examination can be improved by using visual aids such as microscope or optical scope [4].

Several inspections which do not depend on naked eye examination methods have been made using well-established physical principles. The Low And High Energy RTR (Real Time Radiography) for instance used to detect corrosion under insulation. The unit of density variance between two areas on a radiograph referred as radiographic contrast. In order to differentiate region of interest in the X-ray, such as defects or cracks from the surrounding or background area, contrast became very helpful. A low energy which below 70kV X-ray beam tangentially illuminates the “horizon” of the material under test such as pipe [5]. Radiation is detected by an image intensifier, upon which metal loss particularly the corrosion product causes a “shadow”. The RTR system can be safely man-operate and used in a continuous mode moving on a ‘skate-board’ similar to robot. Such a system needs a robot for remote manipulation due to the high radiation levels. Some of these systems are developed for use on the North Slope of Alaska with extremely long lengths of thermally insulated gasoline pipe work.

Quite similar to visual inspection is usual inspection done using liquid which commonly called Liquid Penetrant Inspection (LPI). It is one of key industrial practice which can be used to point out the existence of defects in such fatigue, quench and grinding cracks. LPI also able to give optical of overload and impact fractures, porosity at laps and fusion lacking or simmering along the edge of the joint line. Penetrants come in two basic types whereas type 1 is fluorescent penetrants and type 2 is visible penetrant which each type has their own specific type of chemicals. However same technique will be applied for both type which cleaning, penetrant, penetrant dwell, excess penetrant removal, developer application and indication development.

Unfortunately for the LPI, those flaws must be open to the surface as become one of the main limitations of a penetrant inspection. Thus only surface crack defects can be spotted and just materials with a relatively nonporous surface can be inspected. For the technique to be done the inspector must have direct access to the surface being inspected besides the surface finish and roughness can affect inspection sensitivity. Most important for LPI, is the post cleaning of standard parts and chemical handling with proper disposal is required. Liquid penetrant has been used in some industrial inspections for the reason that the method has great sensitivity to minor surface breaks. Besides that, the method has few material limitations. It can be applied to most all types of materials for example the magnetic or nonmagnetic, metallic or nonmetallic, and the conductivity of the materials is not an issue as they are able to be inspected. Moreover, vast areas and volumes of parts or substances can be inspected in short of time at low cost, which the penetrant materials and associated equipment are relatively economical. The indications are generated right away on the surface of the part and establish a visual representation of the flaw.

Recent work has developed state to the art eddy current usage in NDT which the access to insulated pipes is no longer a concern. RTD INCOTEST technology has made eddy current inspection became more reliable. In mission of surveying ferrous pipes and vessels through their thermal insulation RTD INCOTEST is a fast, accurate and reliable method. It does not interrupt insulation or coatings besides provides precise results through aluminum, galvanized or stainless steel claddings. This method has the survey capability up to 1,000 points per day. Through its outstanding repeatability, RTD INCOTEST is ideally suited for baseline and periodic monitoring services and provides a reliable solution for a variety of applications depending on accessibility to material surface. The operation is tolerance in temperatures from -100° C to 498° C which the system transducer may be located up to 100 meter from the base unit. INCOTEST also provides computed thickness readings within 2 to 24 seconds depending on wall thickness and has high levels of reproducibility +/- 2%. It will also capable of measuring through any non-conductive and non-magnetic material such as fire retarder, insulation concrete, pipe or vessel wall thickness. Along the lines, the INCOTEST is able in detection of CUI (Corrosion Under Insulation) and FAC (Flow Accelerated Corrosion). Besides that, on-contact "dry" wall thickness measurements can be carried out with coated, dirty, rough and high temperature objects.

The process also is possible across a wide range of climatic conditions with consistently high levels of reproducibility. RTD INCOTEST also detects and calculates average general levels of corrosion or erosion and able to provides an instant on site report. RTD INCOTEST Subsea is innovative tool for the ROV deep water inspection of non-piggable pipelines, its proven to be a more faster, safer way and importantly cost-effective in order to detect corrosion [6].

Magnetic particle inspection is one of NDT methods of specimen magnetization which relies on the existence of leakage field. It will set up around defects whereas the test specimen is magnetized internally by a very large direct current. This method bring along with disadvantages as it needs a very high current in order to magnetize the material and the qualitative nature of the results do not allow the method to be used as an effective in- line control tool. It comes to trouble when large component need to be gone under test, extremely large current are essential and safety cares must be prioritized to avoid localized heating and surface burning at the points of electrical contact. The indications observed in magnetic particle testing may be visibly instantly but, frequently, considerable reliance must be place on the skill and experience of the operator for accurate interpretation of the significance indications. Magnetograph is essentially an extension of magnetic particle testing. In the nature of the magnetic particle inspection, a large direct current is required to set up the leakage fields around surface defects, which then recorded on magnetic tape [7]. The advantage of magnetographic is that corner defects on billets are detectable because the physical properties of magnetic tape allow it to be formed to the surface of the billet. One disadvantage of magnetographic is that due to the intimate contact must be maintaining between the magnetic tape and the test specimen, it requires excessive or too much tape wear.

Several methods have realistic potential for non-destructive inspection of adhesive joints, as example, ultrasonic waves, electromechanical impedance, and acoustic emission. Ultrasonic wave pitch-catch techniques have proven to be an effective method for inspection of adhesive bonds integrity of isotropic materials. Corrosion detection at locations with limited access gives rise to many inspection problems in daily practice. Hidden corrosion at inaccessible locations such as pipes on sleepers or supports, insulated pipe work, tank floor, clamping and complex joints made the inspection difficult to be done. For the solution, a new ultrasonic pulse echo method, the Long Range Ultrasonic System (LORUS) has been optimized for inspection over considerable distance (typically one meter) which can overcome most of the access problem. The technique utilizes optimized bulk wave transducers with a dedicated data recording system [7].

Among variations of NDT methods, a very useful and versatile one is Ultrasonic Inspection, as it is sensitive to both surface and subsurface discontinuities. The Ultrasonic Inspection has the depth of penetration for flaw detection and measurement superiority compared to other NDT methods due to its advantages. Besides that, when the pulse-echo technique is used, only a single-sided access is required. For reflector position determination and size or shape estimation, it is highly accurate. Least part of preparation is required when using the ultrasonic technique and the results will appear instantaneously. With usage of automated systems, detailed images can be produced. Moreover Ultrasonic Inspection (UI) has other usages, for instance as thickness measurement, also as flaw detection procedure.

Some limitations also exist when using Ultrasonic to inspect materials, where the surface must be easily reached and accessible in order to transmit ultrasound. Moreover, the skills is required and the training is more extensive than part of other methods. In transmitting the sound energy into the test specimen, it is normally requires a coupling medium which assist to promote the transfer of the sound energy. When material’s surface are rough, irregular in shape, very small, extremely thin or not homogeneous which they are difficult to inspect and these became the major problem when using UI. Due to low sound transmission and high signal noise some material such as cast iron and other coarse grained materials are difficult to inspect. Besides that, linear defects oriented parallel to the sound beam may go undetected. In other hand, reference standards are required for both equipment calibration and the characterization of flaws.

All these NDT methods co-exist and depending on the application, may either be used one at a time or in conjunction with one another. There are some overlaps between the various test methods but they are complementary to one another. The fact that, for example, ultrasonic testing able to reveal both internal and surface flaws does not necessarily mean that it will be the best method for all inspection applications. Usually, a combination of two or even more methods may be required for the complete inspection of an object. The methods most commonly used in industry are ultrasonic testing, X-ray radiography, eddy current testing, magnetic particle inspection and dye-penetrant application. These methods are the most common and practical method which has given prodigious attention from international standard organizations. Regular training courses in practical applications and certificates of proficiency provided by recognized organizations such ASNT to generate skilled operators. Each of NDT method has its advantages and disadvantages. Hence, it is necessary to consider appropriate NDT method, to be applied to the part which will be undergoing test or inspection.

1.3 Problem Statement

The problem is to inspect non-destructively the adhesive bonded metals of aluminum alloy (aluminum-epoxy-aluminum) and the aluminum plates using ultrasonic nondestructive testing.

From the earlier conducted research on Ultrasonic NDT mainly about implementing the system to the flaw detection procedure which focusing on the adhesive joints which varies in materials such as metal, ceramics and polymers [8-19]. Cawley [8] working on two features to inspect adhesive bonds that are; reflection coefficient amplitude and the frequencies of the zeros of the reflection coefficient from the adhesive layer. Lowe and Cawley [9] concluded that Lamb wave is one of good technique to inspect adhesive joints because they are sensitive to the change of material properties. Titanium diffusion bonds then were studied by Rose et al. [10], who establish that the frequency shift and spectral peak amplitude ratio are good damage indicators. Charlier [11] and Adams [12] on their study had applied the Ultrasonic Non-destructive testing to measure the adhesion between metal, ceramics and high polymers which managed to present the inspection wave of the bonded and unbonded region of the metals epoxy. Biayang et.al on their study mainly specified on selecting ultrasonic guided wave modes in one waveguide that will convert a waveguide transition into a mode sensitive to damage in second waveguide in the adhesive area [13].

Several authors have studied the propagation of guided waves in adhesively bonded lap joints and the influence of bond conditions on wave parameters [14–17]. In some of these studies, laser ultrasonic techniques were used to obtain the degree of aging [14] or detection of large disbonds [15,16]. Kissing bonds, which are invisible to longitudinal waves when subjected to high compressive strength, can be detected by the proper Lamb wave mode selection [17].

Moreover, there was less study conducted on wave analysis of metal-epoxy laminates. Therefore, this research will aim on inspecting non-destructively using ultrasonic testing on the aluminum plates and the aluminum-epoxy-aluminum which diverse in types of bonding defects.

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1.4 Objectives

i: To generate the ultrasonic wave into the adhesive bonded aluminum.

ii: To measure non-destructively the adhesive layer of aluminum (aluminum-epoxy-aluminum) and the aluminum plates using ultrasonic nondestructive testing for detection of simulated defect

(a) Void or zero-bond.

(b) Inclusion of foreign material.

1.5 Significance and Scope of Study

The study will be generally focusing on the metal adhesive bonded structure which widely applied in the industries. Adhesive bonding has been used for some time with success in industrial fabrication processes, such as in automotive and aerospace industries. One of the advantages, when compared with other traditional techniques such as bolting, riveting, or spot welding, is the fact that unavoidable stress between the parts could be transmitted more uniformly. For addition, bonding also offers a smoother appearance. In efforts to create lighter and more fuel efficient aircraft, aviation manufacturing companies have tried to maximise the usage of adhesive instead of using metal components riveted or bolted. Virgin Atlantic Airlines for instance estimates that a one-kilogram reduction on every aircraft across their fleet would result in fuel savings of 116,068 litre of fuel usage per year [18].

The adherents that will be used in this experiment is aluminum plates which were bonded by an epoxy. Epoxy that will be used is the steel epoxy for daily industrial use which is commercially available (Araldite 2014,Vantico, Duxford, Cambridge, UK).The artificial defect will be used for some samples which are made from teflon.

The study of adhesive bonds between metals will benefit large area especially the manufacturing industries. These industries involved the sector of automotive, aircrafts, and also applied in developing of the hovercraft panels [19]. Moreover, the study of non-destructive testing for adhesive bond will helps in the structural health monitoring mainly on aircraft related field. This is because there is international standard that must be fitted for all aircrafts before they are allowed to be flown.

The study will be focused on the ultrasonic non-destructive testing waves formed and the sound wave properties that across diverse layer of medium (aluminum-epoxy aluminum). Commercial ultrasonic flaw detector ISONIC-NDT used to determine the pulse arrivals and hence the quality of bonding. Analysis from different conditions and surround of the epoxy laminates and plates will be done. This technique is called guided wave technique which applied on the study of Ultrasonic Non Destructive Testing. As comparison, the samples will also be inspected using ultrasonic pulser-receiver.

1.6 Thesis Outline

This thesis is divided into five chapters. Chapter 1 is about the introduction, background of the study of NDT, the problem statement, objectives scope and significance of the research, as well as the thesis outline. Chapter 2 will focus on the review of waves and background of the wave study. It will only focus on the mechanical wave instead of electromagnetic wave. Chapter 3 cover all experiment work on how the sample be prepared, method that been used and schematic diagram of instrument used for the experiment to be done. For chapter 4, the results of the experiment been discuss and the data obtained were projected. Finally the study will be summarized in chapter 5 and some recommendations were made for future study in UT.

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