UNIVERSITI PUTRA MALAYSIA

KENAF PATCH REPAIR FOR COMPOSITE PARTS AND DAMAGE IDENTIFICATION STRATEGY

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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DEDICATION

To Allah SWT, my beloved Wife, Parents, Family and Friends.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the Degree of Master of Science

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Chairman : Associate Professor Faizal Mustapha, PhD, PEng
Faculty : Engineering

Occasionally, fatigue cracks and damages are found to have developed along rivet holes and other highly stresses regions of aircrafts. In order to extend the life of these aircrafts, repairs should be made to arrest these cracks. Patch repair promotes an innovative repair technique, which can enhance the way in which aircrafts are being maintained. Such repairs generally have one of three objectives which are crack enhancement, crack patching or corrosion repair. Repair of cracked structure may be performed by bonding an external patch to the structure, to either halt or slow the crack growth proposition. Materials that used to repair the structure must be able to withstand the expected conditions in the damaged area. Natural fiber is one of materials or composites that have the potential to be used in the composites approach for aircraft parts. Natural fibers offer both cost saving and a reduction in density when compared to other fibers. Though the strength of natural fiber is not as great as glass, the specific properties are comparable and can be the patching component. The research has been done to find the suitability of natural fiber Kenaf, Hibiscus Cannabinus to be the part of potential material for patching repair. The acquired result was analyzed accordance with real application and the final properties were determined whether it satisfies the requirement such as high strength and stiffness, fatigue and environmental durability and formability, and also long-term durability of the patch. From experimental results, the compressive strength for kenaf patch repair panel is almost the same with undamaged panel and putty patch repair panel which are 230.08GPa, 230.41GPa and 230.47GPa. Meanwhile, the tensile strength for kenaf patch repair panel is slightly less than undamaged panel but higher than putty patch repair panel which are 725.94GPa, 874.07GPa and 672.68GPa. Hence, Kenaf fibre materials have great potential to be used as patch repair for composite parts. For damage detection strategy for the repair, the use of PZT sensors for Structural Health Monitoring (SHM) systems provided a continuous active monitoring on the panels. The specimens with bonded PZT sensors were subjected to mechanical testing. An online and active SHM monitoring was carried out during the compression and tensile testing. During this active sensing, the specimens showed different wave pattern from the elastic region to the specimen failure. A repaired specimen showed same signal behaviour with undamaged specimen. This is important since a new baseline of detecting new damage need to be established for the new monitoring to take place.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia Sebagai memenuhi keperluan untuk Ijazah Master Sains

PEMBAIKAN PERLEKATAN KENAF PADA BAHAGIAN KOMPOSIT DAN STRATEGI PENGENALAN KEROSAKAN

Oleh

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Kadangkala, keretakan dan kerosakan boleh berlaku di sepanjang lubang rivet dan bahagian lain pesawat yang mengalami tekanan tinggi. Dalam usaha untuk memanjangkan hayat pesawat ini, pembaikan perlu dibuat untuk menghentikan keretakan. Pembaikan perlekatan menggalakkan teknik pembaikan yang inovatif, yang boleh menambahbaik cara pesawat dikekalkan. Pembaikan tersebut umumnya mempunyai salah satu daripada tiga objektif iaitu penambahbaikan retakan, perlekatan retakan atau membaiki kakisan. Pembaikan struktur retak boleh dilaksanakan dengan menampalkan perlekatan luar kepada struktur, sama ada untuk menghentikan atau melambatkan keretakan. Bahan yang digunakan untuk membaiki struktur harus mampu menghadapi keadaan yang dijangka di kawasan yang rosak. Gentian semulajadi adalah salah satu bahan atau komposit yang mempunyai potensi untuk digunakan dalam pendekatan komposit untuk bahagian pesawat. Gentian semulajadi menawarkan kedua-dua penjimatan kos dan pengurangan ketumpatan berbanding gentian lain. Walaupun kekuatan gentian semulajadi tidak sekuat kaca, sifat-sifat tertentu boleh dibandingkan dan boleh menjadi komponen perlekatan. Kajian ini telah dilakukan untuk mencari kesesuaian gentian semulajadi Kenaf, Hibiscus cannabinus untuk menjadi sebahagian daripada bahan yang berpotensi untuk menampal pembaikan. Hasil yang diperolehi telah dianalisis berdasarkan aplikasi sebenar dan sifat akhir ditentukan sama ada ia memenuhi keperluan seperti kekuatan yang tinggi dan kekenyalan, kelesuan dan ketahanan alam sekitar dan kebolehbentukan, dan juga ketahanan jangka panjang prlekatan. Daripada keputusan ujikaji, kekuatan mampatan bagi panel pembaikan perlekatan kenaf adalah hampir sama dengan panel yang tidak rosak dan panel pembaikan perlekatan dempul iaitu 230.08GPa, 230.41GPa dan 230.47GPa. Sementara itu, kekuatan tegangan bagi panel pembaikan perlekatan kenaf adalah sedikit kurang berbanding panel yang tidak rosak tetapi lebih tinggi berbanding panel pembaikan perlekatan dempul iaitu 725.94GPa, 874.07GPa dan 672.68GPa. Oleh itu, gentian semulajadi Kenaf mempunyai potensi yang besar untuk digunakan sebagai pembaikan perlekatan untuk bahagian komposit. Bagi kerosakan strategi pengesanan untuk pembaikan, penggunaan sensor PZT untk sistem Pemantauan Kesihatan Struktur (SHM) menyediakan pemantauan aktif berterusan pada panel. Spesimen dengan sensor PZT tertakluk kepada ujian mekanikal. Sistem dalam talian dan pemantauan SHM aktif telah dijalankan semasa ujian mampatan dan tegangan. Dalam pengesanan yang aktif

ini, spesimen menunjukkan corak gelombang yang berbeza dari rantau elastik sehingga ke kegagalan spesimen. Satu sampel yang dibaiki menunjukkan isyarat yang sama dengan spesimen yang tidak rosak. Ini adalah penting kerana satu asas baru untuk mengesan kerosakan perlu ditubuhkan untuk pemantauan baru berlaku.

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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LIST OF ABBRIVIATIONS

ASTM	American Society of Testing Material
CBM	Condition Based Monitoring
CFRP	Carbon Fibre Reinforced Plastic
CM	Condition Monitoring
CO_2	Carbon Dioxide
DP	Damage Prognosis
E	Modulus of Elasticity
EPDM	Ethylene-Propylene-Diene-Monomer
FAA	Federal Aviation Administrator
FAR	Federal Aviation Regulation
FRP	Fibre Reinforced Polymer
GFR	Glass Fibre Reinforcement
KF	Kenaf Fiber
MAPP	Maleic Anhydride Polypropylene
MRO	Maintenance, Repair and Overhaul
NDE	Non-Destructive Evaluation
NDI	Non-Destructive Inspection
NFR	Natural Fibre Reinforcement
PLA	Polylactide
PP	Polypropylene
PZT	Lead Zincornate Titanate
SHM	Structural Health Monitoring
SRM	Structural Repair Manual
TPNR	Thermoplastic Natural Rubber
UD	Uni-Directional
V_{PP}	Voltage Peak to Peak

CHAPTER 1

INTRODUCTION

This first chapter of thesis presents the research background and the current challenges face by the various industries, particularly in engineering industry. The objectives, scopes of research as well as the problem statement are included in this chapter.

1.1 Research Background

Despite the advanced technologies and techniques in improving the material used in many industrial applications such as aircraft, civil, mechanical, and piping industry, defects and damages still occurs at the part of components or the area of which repair application and services are needed. The probability of the whole structure to be damaged is high if the repair work could not be carried out and this may lead to higher cost for a new replacement.

In the area of repair application, development of new methods is required to prepare surfaces for adhesive bonding. Even though existing methods are tremendously effective, additional improvements would provide further reductions in repair time and cost. In fact, it enables repairs to be applied with reduced levels of quality assurance. It is demonstrated that the application of adhesive bonding technology, especially bonded composite repairs is successful in extending the lives of components and structural materials by bridging cracks in structure, repairing thinned areas by corrosion and reducing the strain levels.

Bonded composite reinforcements as depicted in Figure 1.2 are highly efficient when compared to conventional mechanically fastened repairs as showed in Figure 1.1 which are more uniform and efficient load transfer into the repaired, reduced stress concentrations, thinner repaired, easier application to double curative surfaces and reduced risk of corrosion (Gdoutos et al., 2006).

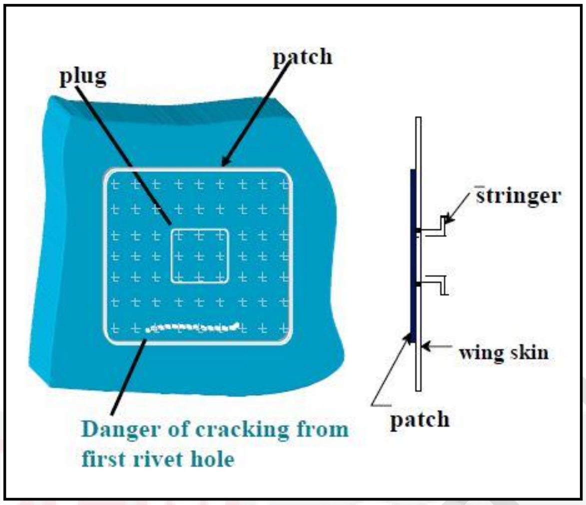

Figure 1.1: Typical SRM wing skin repair (Boeing Inc., 2001)

Repairs can be categorized into non-patch procedures for minor damage and reinforcement or patch procedures to restore structural capability. The specialized technique for repairing cracked structures using high strength advanced composite materials is well-known as "Crack Patching". For a damaged or weaken structures, the composite reinforcement or patch procedures can be applied via mechanical fastener or adhesive bonding. There are numerous advantages of using adhesively bonded composite patches as a method of repair compared to mechanically fastened repair methods, including the reduction of installation cost, increasing strength and fatigue life, which leads to effective crack retardation.

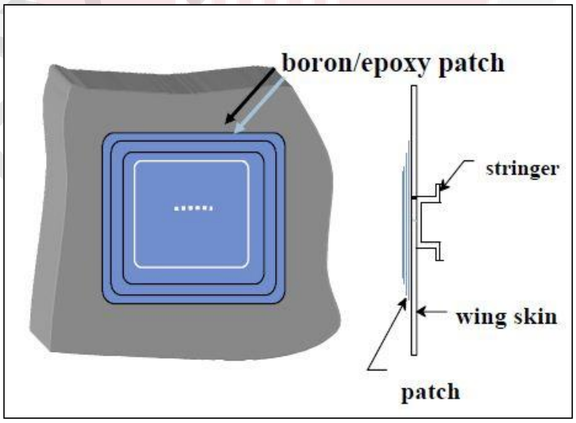

Figure 1.2: Crack patching (Boeing Inc., 2001)

The most vital characteristics of a patch repair are less repair time, corrosion resistance, lightweight, high stiffness and elimination of unnecessary fastener holes in an already weakened structure and stress concentrations at fasteners. There are three critical steps in implementing the repair which includes design, choice of materials and application. Generally, metal, polymers, ceramic or composite are the material selected for the patch and within these classes are many different materials with various advantages and disadvantages associated with their use.

Metals are strong materials, but it is heavy and susceptible to corrosion; both ceramics and glasses are light but brittle in nature, whereas polymers are malleable and vulnerable to extreme weather (Hoque, 2014). Hence, composites are more preferred to be used in patch repair application due to its advantages compare to metal and others. A composite material made by combining two or more materials to give a unique combination of properties (Rowell, 1995). They come in two typical configurations which are monolithic and sandwich structures. These composite materials are high strength, high stiffness, resistance to corrosion and durability.

However, composite material also has disadvantages such as high cost and non-environmental friendly. In order to overcome this problem, bio-composite or natural fibre composite has been chosen to be used as patch repair material. Nowadays, natural fibres played a major role as potential replacement of composites, polymers and metals. One of the advantages of natural fibre composites is that the decomposition of the natural fibre composite does not add any new net of carbon dioxide (CO2) to the global environment, since the components came from plant material (Sahari et al., 2014). Currently, the utilization of bio-composites in industry is greatly ascending, due to the increasing environmental awareness among people. Considerable attention has been paid to bio-composites as an alternative reinforcement for fibre reinforced polymer (FRP) composites by researchers, engineers and scientists. Bio-composite become attractive due to its low cost, high specific strength, fairly good mechanical properties, eco-friendly, non-abrasive and bio-degradability characteristics. It is exploited as a replacement for the conventional fibre, for instance carbon, glass, aramid and others.

1.2 Problem Statements

As of today, the research had been carried out to develop effective patch repair which are less processing time, environmental friendly, lightweight and cost effective. Cost effective includes the types of material that used for patch repair and also the patching techniques. Due to this, it is encouraged to have a structure patch repair which low cost, environmental friendly and lightweight. Knowing the challenges, this research focus on fabricate the patch for repair the structure by using bio-composite material.

The uses of kenaf fibres as a reinforcement material in the polymeric matrix have been widely investigated. Recently, the Malaysian government has been promoting the planting of kenaf for social-economic reasons. The research in kenaf plastic composite is growing tremendously. In addition, kenaf fibre offers the advantages of being biodegradable, of low density, non-abrasive during processing and environmentally safe. The attractive features of these fibres include low cost, light weight, high specific modulus, renewability and biodegradability (Ray et al., 2005).

As industry attempts to lessen the dependence on petroleum-based fuels and products, there is an increasing need to investigate more environmentally friendly, sustainable materials to replace the existing glass fibre and carbon fibre reinforced materials. Therefore, attention has recently shifted to fabrication and properties of natural fibre reinforced materials (Mohantry et al., 2003).

The worldwide automotive production rate increases and is estimated to reach 76 million car annually by 2020 (WBCSD, 2004). Limited petroleum resources will increase the price of petroleum-based products in the near future. It is estimated that 25% reduction in car weight would be equivalent to saving 250 million barrels of crude oil (Mair, 2000). Therefore it is possible that manufacturers will consider expanding the use of natural fibre for their new products. Moreover, the recycling concerns being driven by EU End of Life Vehicles (ELV) regulations has asked manufacturers to consider the environmental impacts of their production and possibly shift for petroleum-based to agro-based materials (Reihs et al., 2001; Davoodi et al., 2010).

Natural fibre reinforced (NFR) composites are likely to be environmentally superior to glass fibre reinforced (GFR) composites in most applications because natural fibre production gives lower environmental impacts compared to glass fibre. The production of natural fibre reinforced transport pallets use 45% less energy and results in lower emission of toxic gases such as CO2, methane, SO2 and CO than production of GFR transport pallets (Van de Velde, 2001).

1.3 Research Objectives

Recognizing these difficulties and challenges mentioned in the previous section, the aim for this research is to develop a patching method for damaged structures by using bio-composite material. Therefore, the objectives to achieve this include:

1) To undergo feasibility study in incorporating kenaf as bio-composite patch to repair the structure or crack patching.
2) To design and fabricate compression test jig which can eliminated the buckling effect.
3) To experimentally evaluate the use of bio-composite patch repair by comparing the strength of bio-composite patch against composite patch and undamaged structure.
4) To identify the crack and damage of the structure by attaching the structural health monitoring system to the materials.

1.4 Scope of the Research

The aim of this research is to fabricate the bio-composite patch repair. Parent specimens are fabricated by using carbon fibre pre-pregs and vacuum bagging technique. Structure of the specimens is simulated damaged so that they can be patched. The damaged panels are repaired by using kenaf fibre materials and putty compound. The undamaged and damaged specimens are tested by compressive and tensile test. Compression test fixture is designed and fabricated to prevent buckling effect during compression test. Structural health monitoring system is attached to the specimen during the testing process to monitor the crack and damage. The data from the tests are analysed and evaluated and the graph will be plotted. The natural fibre patching results will be compared with undamaged panel results.

This research attempts to evaluate the potential of natural fibre material which is kenaf to be used as patch repair materials as replacement of composite materials. For this research, the undamaged specimens, kenaf patched specimens and putty compound patched specimens have been fabricated. Four specimens for each type undergo compressive test and tensile test due to ASTM standards. The data from both tests will be recorded and analysed. For structural health monitoring, the smart PZT sensors are attached to the specimen during the test and connect to the wave generator and oscilloscope.

1.5 Thesis Organization

The overall thesis covers the development of one of the SHM tools in order to evaluate the repair integrity of a damaged part. This is due to the removal and replacement of the plies and/or core which can change the reliability of the component strength. The thesis is organized in the following way.

Chapter 2: Literature Review

This chapter represents the background of the research which is divided into several main sections. The first section depicts the application of structure patch repair in engineering industry. The second section represents the vacuum bagging technique for fabrication and patch process. The next sections discuss the composite materials and natural fibre materials. The last section describes the sensors technology for the SHM approach.

Chapter 3: Methodology

This chapter highlights the methodology used in implementing the experiment. More detailed information on the materials used, the apparatus and the technique is given in this section.

Chapter 4: Results and Discussions

Chapter 4 provides the results for mechanical testing subjected to the CFRP lab- scale specimens. Statistical pattern recognition by identifying the outlier was used to classify the studied conditions. A comparison between results is also depicted in this chapter to ensure consistency and good result repeatability. This chapter also examines damage detection technique by applying the PZT sensors on CFRP panels.

Chapter 5: Conclusions and Recommendations

The final overview of the thesis findings provides a comprehensive conclusion in which all the steps taken in preparing this thesis are aligned with the problem statement and objectives.

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