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Signal Processing Method to Investigate Damage Detection in Natural Fibber Composites: A Proposal

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ABSTRACT

In recent years, natural fiber reinforced composites have received much attention as replacement for man-made fibbers in composite materials. This is because natural fibbers offer many benefits such as high strength, light weight, water resistance, electric resistance and the most important is more environmental friendly materials. A lot of research work has been performed all over the world on the use of natural fibbers as a reinforcing material for the preparation of various types of composites. However, there were none investigation made on damage detection in natural fiber composite (NFC). Therefore, this paper proposes the methodology to investigate damage detection in NFC based on signal processing method. The sugar palm fibber which is also known as Ijuk by the local reinforced epoxy have been chosen as the NFC.

Keywords: *Damage detection, Natural fibber, Signal processing*

1. INTRODUCTION

Polymer composites containing natural fibbers have obtained considerable attention. The interest in the natural fibber reinforced polymer composite arises rapidly due to the high performance in mechanical properties, significant processing advantages, low cost and low density [1,2]. Natural fibbers are renewable, cheaper, biodegradable and finally provide a solution to environmental pollution by finding new uses for waste materials. Furthermore, natural fibber reinforced polymer composite form a new class of materials which seem to have good potential in the future as a replacement for man-made fibbers in composite materials. Many plant fibbers have found applications as a resource for industrial materials [3,4]. In addition to cellulose, plant fibbers contain different natural substances. The most important of these is lignin. The different cells of hard plant fibbers are bonded together by lignin, acting as cementing materials. The lignin content of the plant fibbers influences its structure, properties and morphology. The composites mainly consist of cellulose fibrils embedded in lignin matrix. The properties of natural fibber composites were influenced by fibber loading, dispersion and fibber to matrix adhesion [5-8].

Various works in the application of natural fillers and fibbers in composites like pineapple, sisal, coconut coir, jute, cotton, rice husk, bamboo, wood and palm as the reinforcements in composites have been reported in the literature [9]. In this research, Arenga Pinnata fibber is used as a material to reinforce polymer matrix in epoxy composite. Arenga Pinnata also known as Ijuk is a potential source of natural fibber from the sugar palm plant, a member of palmea this fiber traditionally used in the wide range of application like roof, water filter, carpet, sofa cushion and for fish nest to hatch its eggs. There are many experiments conducted on Arenga Pinnata fibber composites that have achieved satisfying results. A summary of the existing results of the studies into Arenga Pinnata fibber composites is presented in Table 1. As shown in the table, regardless the form of Arenga Pinnata fibbers such as chopped random, woven roving and long random, resin, fibber fraction and chemical treatments, the tensile strength are within the range of approximately 13 – 52 MPa, which means that the tensile strength is comparable to other natural fibre composites. Similar conditions can be observed for flexural properties.

Flexural properties of Arenga Pinnata reinforced epoxy have been studied by Sastra et al. [10], who proved that sugar palm fibbers can be successfully developed as a reinforcement agent for the epoxy matrix for a beneficial composite, particularly in term of strength and rigidity. It was found that 10% by weight woven Arenga Pinnata fibbers/epoxy composites have the highest flexural strength (108.15 MPa) and Young’s modulus (4421.8 MPa). In another study, Sastra et al.[11] reported that tensile strength of 10% woven Arenga Pinnata fibbers/epoxy composites was 51.725 MPa, hence the highest value of all the specimens. On the other hand, Suriani et al. [12] studied the interfacial adhesion of tensile Arenga Pinnata reinforced epoxy composite specimens. The results revealed that the woven roving fibber composites have good interface adhesion between the fibber and the matrix compared to that of long random and chopped random fibber reinforced epoxy composites. It also found that increasing the weight fraction of fibber from 10% to 15% and 20%, decreases the tensile strength. While, Leman et al. [13] attempted the freshwater and seawater treatments on the chopped Arenga Pinnata fibbers. Results showed that both freshwater and seawater treatment significantly improve the tensile strength of the specimens up to more than 50%. These chopped fibres were soaked for 30 days and the composites were made with the amount of fibbers 15% by weight. Another researcher Sapuan et al. [14] examined the effect of NaOH concentration (0.25 M and 0.5 M) solution for 1 hour, 4 hour and 8 hours soaking time for Arenga Pinnata fibber reinforced epoxy composites and concluded that the maximum flexural strength occurred at 0.25 M NaOH solution with 1 hour soaking time. The effect of accelerated age is well explained by Ali et al. [15]. It was found that the average tensile strength of the aged specimens was 32.28 MPa compared to 21.46 MPa of the original specimens. The specimens for accelerated aged Arenga pinnata fibbers/epoxy composites were prepared according to standard material age acceleration ASTM F1980, hence were put into an oven for 74 hours and 10 minutes to attain the desired equivalent aging time of 70 days in natural environment. In an experimental study on the moisture absorption behavior [16], the effect of alkaline treatment on the tensile properties of Arenga Pinnata fibbers reinforced epoxy composites [17] and the effect of aging Arenga pinnata fibber have already been studied, but none of the earlier studies have focused on characterizing the impact damage in natural fiber composites. Damage due to low velocity impact from accidents may be undetected by visual inspection but has a little potential to alter the local composite stiffness and strength considerably. It results in four major damage which is contact damage, delamination, matrix failure and fiber failure [18]. Therefore, the objective of this study is to develop a reliable damage detection procedure in Natural fiber composite (NFC) specifically for Arenga Pinnata. However, this method also can be implementing to other NFC upon successful development.

Table 1: Summary of Arenga Pinnata fibber composites properties from the literatures

Form of fibbers	Resin	Tensile stress (MPa)	Young Modulus (MPa)	Flexural stress (MPa)	Flexural Modulus (MPa)	Reference
Chopped random 20% wt.	Epoxy	30.49	1200	64.71	3145.8	Sastra et al. [11]
Woven Roving 10% wt.	Epoxy	51.73	1255.83	108.15	4421.8	Sastra et al. [11]
Long Random 15% wt.	Epoxy	49.61	1196	92.65	3997.3	Sastra et al. [11]
Woven roving 10%	Epoxy	51.717	1010.322	-	-	Suriani et al. [12]
Chopped 15% wt. untreated	Epoxy	13.78		-	-	Leman et al. [13]
Chopped 15% wt. 30d freshwater	Epoxy	21.27	-	-	-	Leman et al. [13]
Chopped 15% wt. 30d seawater	Epoxy	23.04	-	-	-	Leman et al. [13]
10% Vol. treated with 025 M NaOH (1 hour)	Epoxy	49.88	3750	-	-	Bachtiar et al. [14]
10% Vol. treated with 025 M NaOH (4 hour)	Epoxy	37.56	3900	-	-	Bachtiar et al. [14]
10% Vol. treated with 025 M NaOH (8 hour)	Epoxy	41.88	3700	-	-	Bachtiar et al. [14]
10% Vol. treated with 05 M NaOH (1 hour)	Epoxy	30.00	3620	-	-	Bachtiar et al. [14]
10% Vol. treated with 05 M NaOH (4 hour)	Epoxy	37.56	3860	-	-	Bachtiar et al. [14]
10% Vol. treated with 0.5 M NaOH (8 hour)	Epoxy	41.88	3750	-	-	Bachtiar et al. [14]
Long random 10%	Epoxy	21.46	4310	-	-	Ali et al. [15]
Long random 10% (aging)	epoxy	32.27	3920	-	-	Ali et al. [15]
10% wt. fibber treated with 0.25 M NaOH (1hour)	Epoxy	-	-	96.69	3510.54	Sapuan et al. [17]
10% wt. fibber treated with 0.25 M NaOH (4hour)	Epoxy	-	-	64.42	2213.25	Sapuan et al. [17]
10% wt. fibber treated with 0.25 M NaOH (8hour)	Epoxy	-	-	72.63	2548.92	Sapuan et al. [17]
10% wt. fibber treated with 0.5 M NaOH (1hour)	Epoxy	-	-	85.30	5028.92	Sapuan et al. [17]
10% wt. fibber treated with 0.5 M NaOH (4hour)	Epoxy	-	-	58.17	6947.88	Sapuan et al. [17]
10% wt. fibber treated with 0.5 M NaOH (8hour)	Epoxy	-	-	90.68	4672.49	Sapuan et al. [17]

2. DAMAGE DETECTION

Sohn et al. [19], defined damage as ‘changes introduced into a system that adversely affects its current or future performance. Implicit in this definition is the concept that damage is not meaningful without a comparison between two different states of the system, one of which assumed to represent the initial, undamaged state. As an example, a crack that forms in a mechanical part produces a change in geometry that alters the stiffness characteristics of that part. Depending on the size and location of the crack and the loads applied to the system, the adverse effects of this damage can be either immediate or may take some time before they alter the system’s performance. In terms of length scales, all damage begins at the material level and then under appropriate loading scenario progresses to component and system level damage at various rates. In terms of time scales, damage can accumulate incrementally over long periods of time such as that associated with fatigue or corrosion damage accumulation.

Rytter [20] mentioned that damage state is described by answering the following questions:

a. Is there damage in the system? (Existence)
b. Where is the damage in the structure? (Location)
c. What kind of damage is present? (Type)
d. How severe is the damage? (Extent)
e. How much useful life remains? (Prognosis)

Generally, identification of the damage type and extent require prior knowledge of the structural behaviour in the presence of each of the possible expected failure modes for future correlation with experimental data, which is normally achieved by resorting to analytical models. Early damage detection can benefit most industries in relation to maintenance cost reduction, structural design improvements, safety and reliability [21]. Conventional structural integrity inspections require downtime and use non-destructive methods such as ultrasonic imaging or X-radiography, are very labour intensive and prone to human error. Therefore, Structural Health Monitoring (SHM) is a new and alternative way of Non-Destructive-Inspection (NDI) in order to ensure the structural integrity. SHM is the continuous, autonomous in-service monitoring of the physical condition of a structure by means of embedded or attached sensors with a minimum manual intervention, to monitor the structural integrity.

Structural health monitoring (SHM) has been conceived to provide an early warning of the damage extent through the development of embedded sensors. Several techniques for monitoring the impact event in composite structure with sensors were proposed by many researchers. Sung et al. [22] investigated the characteristics of impact damage of quasi-isotropic laminates using the wavelet analysis. While Park et al. [23] showed the possibility for the monitoring of low-velocity impact damage initiation of Gr/Ep panel using a piezoelectric thin film sensor. In other research, Shih and Mal [24] proved that the acoustic emission (AE) signals carry important information regarding the nature of the impact process using spectral analysis The piezoelectric sensors can be used to detect not only vibration behavior but also stress wave signals due to impact damage. In this article, the sensors were used for monitoring impact damage to illustrate this potential benefit in natural fibber composites. A series of impact tests at various impact energies by changing the impact height was performed on the instrumented drop weight impact tester. The wavelet transform (WT) and short time fourier transform (STFT) were used to decompose the piezoelectric sensor signals in this study. Another research approach done by Aymerich and Staszewski [25], demonstrated the application of nonlinear acoustics for detecting impact damage in composite structures and monitoring its progression under multiple impacts. The method was based on frequency modulation of the ultrasonic wave propagating in the plate by a low-frequency modal excitation signal. While Kessler et al. [26], explored the optimization of lamb wave methods for damage detection in composite materials, covering the problems of choosing the appropriate actuating frequency, pulse shape and sensor geometry for lamb wave application. There results were compared by performing a wavelet decomposition using the Morlet wavelet and plotting the magnitude of the coefficients at the driving frequency. Soutis [27], on the other hand, monitor the interaction of Lamb waves with defects. The feasibility of using an array of piezoelectric transmitters to generate Lamb waves in composite plates is investigated both experimentally and numerically. Krawczuk et al. [28], presented the results of the application of a genetic algorithm and a neural network to detect and locate multi-layered GFRP beam. Two different procedures were followed to identify the damage location and size. The first one is based on finite element (FE) model updating and error localization, while the second considers a set of possible damage scenarios. Hatem et al. [29], also applied genetic algorithms and neural networks for damage detection in CFRP composites. Four types of damage were considered in the model of a cantilevered beam which is circular holes, delamination, linear surface cracks and linear through cracks. Damage type is identified by the generalized regression network. The results showed that generalized regression network successfully classified damage type with a success rate ranging from 85% to 98%.

Yan et al. [30], proposed a damage detection method for SHM under varying operational and environmental conditions based on Principal Component Analysis (PCA). This method relies on the principle that the measured features changes due to environmental causes are different from those arising from structural damage. Novelty analysis on the residual errors provides a statistical indication of damage. The environmental conditions are assumed to have a linear effect on the vibration features. The example from wooden bridge shows that different levels of damage can be correctly assessed independently from the environment effects.

Another research approach done by Nichols et al. [31], demonstrated damage detection in the fields of sensing and signal processing. A nine fibre Bragg grating strain sensor network was used to measure the vibration responses of a thin steel plate subjected to successive growing saw cut damage levels. The relationship between a reference (undamaged) state and the actual (damaged) state can be mathematically established when the structure is interrogated with a deterministic chaotic signal. This method relies on the principle that this function loses differentiability when damage exists.

In the present study, advanced signal processing method will be applied to investigate impact damage localisation in NFC structures. Impact events on NFC structures will produce impact strain data. These strain signals are usually affected by undesirable noise effects, although data pre-processing can be used to remove these effects. Several features related to impact data will be obtained using data feature extraction and selection. These features will be employed for damage identification by using ANNs, to map strain data into impact locations. The results from this mapping will be used to indicate impact locations in NFC structures.

3. PROPOSED METHODOLOGY

The study will be carried out in the following main two phases: Experimental Study and Artificial Neural Network Study. The following paragraphs will explain in detail each phases accordingly.

Phases 1: Experimental Study

a. Prepare composite sampel using lay up method (sugar palm fiber and epoxy, based on weight %)
b. Fabricate sample according ASTM D3763-02, ASTM D790-99, ASTM D638
c. Mechanical testing
    Tensile test
    Flexure test
    Impact test
d. Physical test
    SEM test
    Density test

Determine the material properties of sugar palm

e. Impact test for low velocity impact series of impacts will be applied to the composite plate using an impact hammer at the approximately spaced locations as shown in Figure 1. The oscilloscope will be used to capture and display all strain data from the impact events.
f. Identify the damage location

Phases 2: Artificial Neural Network Study

a. Result of the experimental study will be compared with previous researcher's work
b. If confirmed they show a reasonable agreement with each other, proceed with the neural network
c. The Multi Layer Perceptron (MLP) network was trained and simulated using MATLAB Neural Network Toolbox.
d. The inputs are signal features obtained from impact strain data (Signal features will be used such as maximum, minimum, peak to peak and variance values calculate in the time domain and the arithmetic mean values for the absolute, real and imaginary spectra calculated in the frequency domain)
e. The location (outputs) are estimated x and y coordinates

Figure 2 shows the MLP network procedure for impact location in a NFC.

4. EXPECTED RESULT

Potential contributions of this study are as follow;

a. It is expected that signal processing is a new fresh way to implement damage detection in NFC since no work yet has been reported in the literature.
b. The performance impact energy absorption and damage localization of NFC was achieved.
c. New research can be explore about damage detection for NFC in the future due to the high interest on natural fibber composite

5. CONCLUSION

Currently, an immense number of techniques exist for the identification and location of damage. Because of all the technique have their own advantages and disadvantages, there is no general algorithm that allows the resolution of all kinds of problems in all kinds of structures. However, a reliable damage detection procedure has not yet been fully addressed and implemented in NFC. Hence this paper is an attempt to

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propose damage detection in NFC using signal processing method.

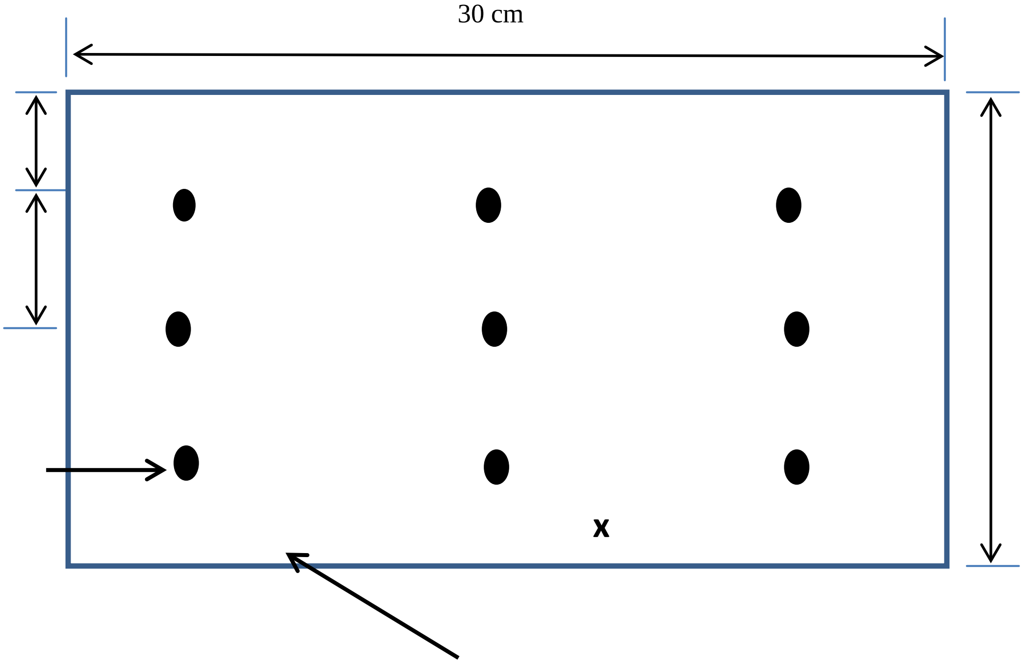

Fig 1: Composite plate with nine sensors

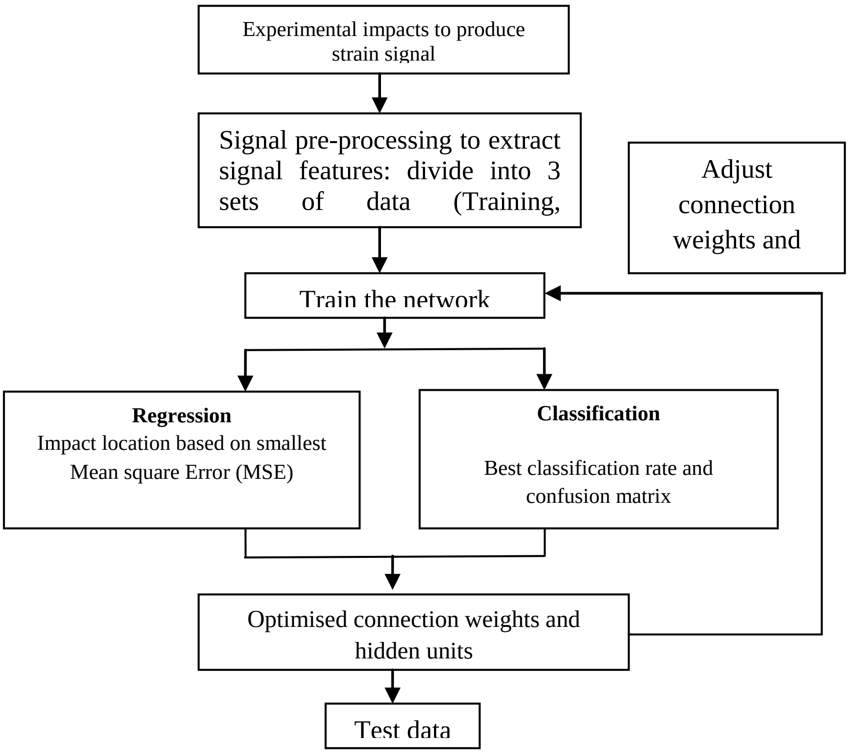

Fig 2: MLP network procedure for impact location in a NFC structure.

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