A STUDY ON TENSILE BEHAVIOR OF MODIFIED BANANA PSEUDO-STEM (BPS) FIBER/EPOXY COMPOSITE WITH SELECTED ALKALINE TREATMENT USING RESPONSE SURFACE METHODOLOGY (RSM)

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ABSTRACT

Natural fiber (NF) including banana pseudo-stem (BPS) was utilized as a reinforcing material and alternative substitution for synthetic fiber attributable to its abundance, inexpensive, lightweight and environmentally friendly. In this regard, the green material based on NF offers an excellent opportunity for composite development in sustaining renewable materials in many industries. Therefore, this current work aimed to evaluate the banana fiber reinforced epoxy composite influenced by novel alkaline treatment. Subsequently, the composite banana fiber (CBF) specimens were subjected to tensile load and corresponded stress-strain results according to ASTM D638 standard. Morphology analysis of these fibers was observed using a scanning electron microscope (SEM) and compared with untreated fiber. The finding showed that the treated banana fiber at moderate-level conditions (6% NaOH, 15 hours and 27ºC) was found to be provided higher mechanical properties and significantly offered optimum performance. From Analysis of Variance (ANOVA), only immersion time by immersion temperature interaction was less than 0.05 (p-value) and it significantly affected the tensile properties of CBFs. The range of R^2, predicted R^2 and adjusted R^2 was 70.88 to 94.69% (tensile strength), 52.30 to 90.79% (Young's modulus) and 79.90 to 95.66% (failure strain), respectively. In conclusion, the results confirmed that the optimum treatment setting was found to be at 6.5% NaOH, 17 hours and 27ºC of level conditions. This optimum result was predicted using response surface methodology (RSM) with 0.88 desirability. The average percentage error was found to be at 2.59% for tensile strength, 7.11% for Young's modulus and 6.07% for failure strain, respectively. A lower percentage of error showed a more significant effect of each factor on the corresponding response, which was acceptable. These have made them more competitive than unmodified fiber applications, especially for the automotive industry as a cover for door panels, seat backs and armrest consoles.

ABSTRAK

Gentian asli (GA) termasuk batang pisang pseudo (BPP) telah digunakan sebagai bahan penguat dan penggantian alternatif untuk gentian sintetik yang disebabkan oleh banyaknya, murah, ringan dan mesra alam. Dalam hal ini, bahan hijau berasaskan GA menawarkan peluang yang sangat baik untuk pembangunan komposit dalam mengekalkan bahan boleh diperbaharui dalam banyak industri. Oleh itu, kerja semasa ini bertujuan untuk menilai komposit epoksi bertetulang gentian pisang yang dipengaruhi oleh rawatan alkali baru. Selepas itu, spesimen gentian pisang komposit (GPK) tertakluk kepada beban tegangan dan keputusan terikan tegasan yang sepadan mengikut piawaian ASTM D638. Analisis morfologi gentian ini diperhatikan menggunakan mikroskop elektron pengimbasan (MEP) dan dibandingkan dengan gentian yang tidak dirawat. Dapatan kajian menunjukkan gentian pisang yang dirawat pada keadaan tahap sederhana (6% NaOH, 15 jam dan 27ºC) didapati mempunyai sifat mekanikal yang lebih tinggi dan menawarkan prestasi optimum yang ketara. Daripada Analisis Variasi (ANOVA), hanya masa rendaman dengan interaksi suhu rendaman adalah kurang daripada 0.05 (nilai p) dan ia memberi kesan ketara kepada sifat tegangan GPK. Julat R^2, ramalan R^2 dan R^2 terlaras ialah 70.88 hingga 94.69% kekuatan tegangan, 52.30 hingga 90.79% modulus tegangan dan 79.90 hingga 95.66% ketegangan kegagalan, masing-masing. Kesimpulannya, keputusan mengesahkan bahawa tetapan rawatan optimum didapati pada 6.5% NaOH, 17 jam dan 27ºC keadaan aras. Keputusan optimum ini telah diramalkan menggunakan metodologi permukaan tindak balas (MPK) dengan 0.88 keinginan. Purata peratusan ralat didapati pada 2.59% untuk kekuatan tegangan, 7.11% untuk modulus tegangan dan 6.07% untuk ketegangan kegagalan, masing-masing. Peratusan ralat yang lebih rendah menunjukkan kesan yang lebih ketara bagi setiap faktor terhadap tindak balas yang sepadan, iaitu boleh diterima. Ini telah menjadikan mereka lebih kompetitif daripada aplikasi gentian yang tidak diubah suai, terutamanya untuk industri automotif sebagai penutup untuk panel pintu, tempat duduk belakang dan konsol tempat letak tangan.

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LIST OF SYMBOLS AND ABBREVIATIONS

ANOVA	-	Analysis of variance
ASTM	-	American Society for Testing and Materials
BPS	-	Banana pseudo-stem
CBFs	-	Composite banana fibers
D	-	Distance between grips
DOE	-	Design of experiment
EP	-	Epoxy
FCCD	-	Face Centered Center Composite Design
FS	-	Failure strain (%)
g	-	Gram
g/cm^3	-	Gram per cubic centimeter
G	-	Gauge length
GA	-	Genetic algorithm
GPa	-	Gigapascal
h	-	Hours
kg	-	Kilogram
kg/m^3	-	Kilogram per cubic meter
kN	-	Kilonewton
l	-	Length
l/d	-	Aspect ratio
L	-	Length of narrow section
LO	-	Length overall
mL	-	Milliliter
mm	-	Millimeter
mm/min	-	Millimeter per minute
mm^2	-	Square millimeter

MAPP	-	Maleic anhydride polypropylene
MPa	-	Megapascal
N	-	Newton
NaOH	-	Sodium hydroxide
NF	-	Natural fiber
NFCs	-	Natural fiber composites
OVAT	-	One variable at a time
ρ	-	Density
ρ_c	-	Density composite
ρ_f	-	Density fiber
ρ_m	-	Density matrix
pH	-	Scale of acidity or basicity
PE	-	Polyethylene
PLA	-	Polylactic acid
PP	-	Polypropylene
PVC	-	Polyvinyl chloride
R	-	Radius of fillet
ROM	-	Rule of mixture
RSM	-	Response surface methodology
RT	-	Room temperature (±27°C)
SEM	-	Scanning electron microscope
STD	-	Standard deviation
T	-	Thickness
TS	-	Tensile strength (MPa)
TM	-	Taguchi methodology
UTM	-	Universal Testing Machine
v_f	-	Volume fractions of fiber
v_m	-	Volume fractions of matrix
V	-	Volume
V_c	-	Volume composite
V_f	-	Volume fiber
V_m	-	Volume matrix

w	-	Weight
wt.%	-	Chemical composition
w/v%	-	Weight per volume percentage
W	-	Width of narrow section
WO	-	Width overall
W_c	-	Weight fractions of fiber
W_f	-	Weight fractions of composite
W_m	-	Weight fractions of matrix
X_1/x_1	-	Alkaline concentration (%)
X_2/x_2	-	Immersion time (hours)
X_3/x_3	-	Immersion temperature (°C)
YM	-	Young's modulus (GPa)
°	-	Degree
°C	-	Degree Celsius
%	-	Percentage or percent

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CHAPTER 1

INTRODUCTION

1.1 Background of study

The increasing demand for green composite based on natural fiber as reinforcement has promised a sustainable and renewable materials [1]. The use of these materials from agricultural and waste products have gained the attention of numerous research areas in the context of sustainable development. In order to minimize waste disposal problems, natural fibers have become a central issue as a potential to replace synthetic fibers in composite materials that recently attracting higher priority in various engineering applications [2]. In contrast to synthetic fibers, natural fibers demonstrate their main advantages in terms of cost, renewable and minimum health hazard. This scenario induces the utilization of natural fiber in automotive industry namely Proton company (Malaysian national carmaker) and the market is growing rapidly [3]. For example, an improvement in car door panels behind the eco-friendly composites is able to produce a high potential for weight reduction from that materials by 20% [4]. Certainly, this eco-car trend aids in improving the protection for passengers in case of an accident or collusion. Following the safety technology, this sustainable aspect offers excellent durability with low density component and deformation behavior of parts during the service lifetime. However, natural fiber base composite possesses several drawbacks (due to material defects) as the compatibility between the fiber and matrix is considerably poor. Owing to this issue, a proper compatibility in composite material is necessary in order to improve their mechanical properties. Several methods have been employed to improve the fiber modification with higher reinforcement material that can be achieved by performing chemical treatment (alkalinization) on one of the composite components.

Hence, this study generated a major contribution to the related research area through a newly developed modification by utilizing natural fibers that considerably meet the requirements of environmentally friendly and sustainable materials. In this study, the banana fibers was selected due to the plant fibers based on stems that tended to improve the mechanical behavior [5] and alkaline treatment in terms of optimum conditions for extending the area of knowledge in conducting combinational parameters for more definitive conclusions. An improvement from the alkaline treatment of fiber properties modification was experimentally investigated regarding the physical characteristics and mechanical performance for the potential of the newly developed composite with enhanced properties. Comprehensively, the properties treated composite were compared with the untreated fiber (as a control variable) to provide important insights in ensuring the effective fiber compatibility.

1.2 Problem statement

There are still several negative factors related to public awareness regarding environmental issues including non-recyclable and non-degradable materials which has significantly driven towards the end-of-life vehicle. The challenges that has commonly been faced in a relation to the use of composite materials in automotive industry is to develop lightweight and low cost components, especially in the automobile interior parts [2]. Due to substantial weight reduction, natural fiber composites are preferable as compared to synthetic fiber-based composites for fuel efficient and eco-friendly. However, the relatively poor bonding between natural fiber (hydrophilic) and matrix (hydrophobic) is the primary concerns related to the widespread adoption in developing banana fiber reinforced composites remains as a difficulty [6]. These features result in a tendency to high moisture absorption and poor composite behavior that may affect the long-term performance due to low water resistance (microcracks). Moreover, these issues encompass the variability of physical and mechanical properties of the natural fiber that highly dependent on the climate changes or processing methods that may reduce the fiber quality due to unstable and unpredictable outcomes [7, 8]. Subsequently, it is essential to consider the aforesaid problems on their physical and mechanical properties corresponding to study on surface fiber modification using alkaline treatment (alkaline concentration, immersion time and temperature). Therefore, continuing the studies on the utilization of natural banana pseudo-stem (BPS) fiber can ensure valuable sustainable development.

1.3 Objectives

This study aimed to analyze the significant effect of alkaline treatment conditions on composite banana fibers (CBFs) reinforced epoxy resin. The objectives of this study were detailed as follows:

a) To evaluate the tensile properties of CBFs with selected alkaline treatment conditions.
b) To optimize the setting of alkaline treatment conditions in enhancing CBFs properties.

1.4 Scope of study

This study contributed to new modification of composite product development by the alkaline treatment process. The scopes of this study were limited as follows:

a) Natural fiber preparation
    i. Natural fiber based originated from BPS (trunks) were selected and underwent water retting process.
b) Experimental design (DOE) setup
    i. Response surface methodology (RSM) was conducted to evaluate CBFs performance for optimizing alkaline treatment at specific conditions.
c) Alkaline treatment (NaOH) preparation
    i. Fiber treatment process was conducted at alkaline concentration (4, 6 and 8%), immersion time (6, 12 and 24 hours) and immersion temperature (27, 60 and 100^{o}C).
    ii. Untreated banana fiber was used as a control variable.

d) Composite fabrication process

i. Fiber volume fraction was calculated according to Rule of Mixture (ROM) with 25% of banana fibers and 75% of polymer matrices.

ii. The fabrication technique was conducted by hand lay-up method using polymer matrix of epoxy resin and hardener.

iii. Banana fibers orientation layer was performed in discontinuous fiber reinforced at random orientation.

e) Composite properties evaluation

i. Tensile properties of CBFs reinforced epoxy were conducted for evaluating the tensile strength, Young’s modulus and failure strain according to ASTM D638 Type 1 standard.

1.5 Significant of study

The finding of study using modified fibers indicated that these natural fibers might offer certain potential value to replace the synthetic fibers in automotive structural components. This phenomenon may be due to the physical and mechanical improvement that significantly reduce the vehicle overall weight thus resulting in energy saving and lower emission. Generally, this significance of study contributed several benefits to the following research in terms of comprehension on the combination parameter of alkaline treatment configuration between alkaline concentrations, immersion time and immersion temperature in order to produce banana fiber composite with improved properties. Broadly, the alkaline treatment is commonly regarded as a surface treatment method based on existing literature, which has been widely used to achieve the necessary compatibility in applications of developing natural fiber reinforced composite. There is a growing form of previous literature that recognizes the importance of chemical treatment, particularly alkalinization or mercerization that emerged as powerful platforms for surface fiber modification. Specifically, this study aided researchers to understand further about the procedure in conducting the optimization in alkaline treatment process with significant interaction effects on tensile stress response of banana fiber reinforced composite. Following the experimental design setup, this analysis assisted to reduce the processing time and costs as well as minimizing the number of experimental runs, thereby the potential improvements can be easily achieved from alkaline treatment for the optimum condition of banana fiber reinforced polymer composites. Consequently, a proper alkaline treatment in a combination of studied parameters in enhancing the modification of composite properties might put up economic implications. Therefore, this study offered the opportunity for future researchers in continuing the study on utilizing natural fiber and serves as a reference for effective significant fiber treatment on the banana fiber as it becomes increasingly prevalent with a key instrument in particular environmental benefit.

1.6 Outline of study

The overall structure of the study takes the form of five chapters, including this first introductory chapter. The second chapter explained the theoretical and review of the studies, the third chapter describe the methodology of this current work, the fourth chapter presented the results and discussion of this study and the fifth chapter summarized the finding including recommendation for future study.

The main study in Chapter 1 was the implementation of a study on CBFs reinforced epoxy, followed by a primary explanation of the background of this study. In addition, problem statements, objectives, scope of study, significance of study and outline of study were also highlighted in this chapter.

In Chapter 2, a comprehensive review of the current research was specifically reviewed. The main topic of the discussion covered the related of current trend in natural fiber, banana fiber, fiber treatment, polymer matrix composite, composite properties and DOE analysis.

Chapter 3 described the DOE setup for the variability parameter of alkaline treatment conditions. The optimization technique emphasized the RSM and ROM. Furthermore, the procedure for the testing was initiated by the preparation of material for raw banana fiber, NaOH, polymer matrix and mold. Subsequently, the preparation of alkaline treatment process, fabrication process and composite specimen for evaluated on composite fiber tensile analysis.

Chapter 4 presented the analysis of results and discussions by conducting experimental design based on the methodologies and procedures. This section discussed the analysis of composite tensile properties (tensile strength, Young's modulus and failure strain) and composite material morphologies. The remaining part of the section was continued by the optimization conditions of the alkaline treatment process with supported of mathematical and statistical analysis.

Lastly, Chapter 5 summarized the findings of the study and suggested several recommendations for future research in further improvements.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The purpose of this chapter was to present the previous studies regarding towards activity of composite banana fiber with alkaline treatment on corresponding to mechanical properties. The overall structure of the study focused on eight main sections, including this introductory and summary chapter about detailed information for further investigation. Firstly, this section was focused on the recent history of natural fiber by describing the current trends, classification, configuration and application of natural fiber. The next section of this study explained about the natural banana fiber by mainly addressing their fiber chemical composition, physical characteristic, mechanical behavior and comparability performance. Fiber treatment was explained starting from the classification of chemical treatment and influence of alkaline treatment towards natural fiber behavior. Furthermore, the effect of alkaline treatment on mechanical fiber properties for tensile properties were also discussed. For composite material section, the review was described including polymer matrix, classification and variability control in composite materials. Section seven outlined the entire study to review on banana composite properties by laying out the theoretical dimensions of the tensile properties between tensile strength, Young's modulus and failure strain. This section also discovered clearly about tensile load response after applied surface modification. The last section identified with the study gaps that fulfilled the previous works, then followed by the chapter summary as a guideline at the end of the review.

2.2 Natural fiber

Due to the progressive growth of eco-friendly technology, natural fiber composite materials become a significant momentum for both industry and research groups [9]. In nature, composite materials based on natural sources are not a new component in the world as it might offer numerous promisingly favorable properties for various engineering applications. The gaining interest in incorporating the appropriate use of natural fibers as a composite reinforcement agent contributes to a sustainable development in a number of fields of engineering and technology [10]. These modifications of natural fiber have a broad variety in thermoset or thermoplastic composite paralleled to glass and carbon fibers mainly due to its low cost, lightweight, biodegradability. For instance, the fabrication of natural fiber composite mostly linked to cost-effectiveness with improved mechanical as compared to the element of steel and aluminum fiber that extends in the automotive, aerospace sector and building systems [11, 12].

Theoretically, natural fiber has a massive environmental impact in a primary fiber production as it releases oxygen and absorbs carbon dioxide (CO_2) [13]. Synthetic fibers demonstrate contrary nature towards the natural fibers as they emit a lot of carbon dioxide during the product manufacturing, thus deteriorating green globalization. Moreover, the petrochemical polymers can cause negative environmental impact due to non-renewable and low biodegradability as well as a raise to the waste landfills and ecosystem pollution statistically around 22 to 43% and 6 to 7%, respectively [14]. As an alternative, sustainable development of product reuse and recycling is one of the primary topics of waste products as shown in Figure 2.1. The life cycle of natural fiber reinforced composite initially from natural crops that extracted to the fiber material for further product manufacturing using matrix materials. The final product will be further used until meet life span and recycled, then disposed to the landfills after as it is no longer recyclable. Ultimately, the disposal material will be consumed by the green plant in order to sustain the ecological system.

Nowadays, conventional structural components are harmful to the environment due to opposite characteristics as non-degradable and non-renewable products. As a consequent, the use of synthetic fibers is highlighted to increase oil consumption from mineral sources [15]. The possibility of replacing polymer, steel or synthetic fibers with natural fibers becomes a tendency to realize the growth of eco-friendly, greener,

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LIST OF PUBLICATIONS

Journal papers (Scopus)

1. M. Y. Hashim, A. M. Amin, O. M. F. Marwah, M. H. Othman, N. H. Hanizan, and **M. K. E. Norman**, "Two Parameters Weibull Analysis on Mechanical Properties of Kenaf Fiber Under Various Conditions of Alkali Treatment," *Int. J. Integr. Eng.*, vol. 12, no. 3, pp. 245–252, 2020, doi: 10.30880/ijie.2020.12.03.028.

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1. **M. K. E. Norman** and M. Y. Hashim, "Tensile Strength of Single Banana Fibers (SBFs) Improved by Novel Alkaline Treatment," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1244, no. 1, p. 012001, Jun. 2022, doi: 10.1088/1757-899X/1244/1/012001.
2. **M. K. E. Norman**, M. Y. Hashim, M. Z. Ngali, and I. Masood, "Reviews on the Effects of Non-Acidic Treatment to Mechanical Properties of Natural Fiber Reinforced Composites (NFRCs)," *AIP Conf. Proc.*, vol. 2530, no. 1, p. 70001, May 2023, doi: 10.1063/5.0122525.