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INVESTIGATION OF BIODEGRADABILITY OF COCONUT FIBER REINFORCED WITH POLYMER FOR POTENTIAL SUTURE APPLICATION

BY

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DECLARATION

I, EFRIM AARON AMANKWAH hereby declare that this dissertation which is submitted in partial fulfillment of the requirement for the degree in Master of Philosophy in Biomedical Engineering is the result of my own independent research project or investigation and that, except where otherwise other sources are acknowledged with explicit references and are included in the reference list, this work has not previously been accepted in substance for any degree and neither is it being concurrently submitted in candidature for any degree. I thus grant the Department of Biomedical Engineering permission to distribute and/or publish the dissertation in any suitable format, with my project supervisors serving as the first author or authors and me serving as the second or subsequent author.

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DEDICATION

Great is Thy faithfulness. This study is being conscientiously devoted to God, whose compassion never failed. To Miss Eunice Frimpong, who brought joy and motivation to every step of the journey. Thank you for being my rock. I gratefully dedicate this thesis to my family, whose guidance and love inspired me to pursue my academic dreams. And to The Biomedical Engineering graduating class of 2024, my sincere gratitude for your immense support throughout the study goes out to you.

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ABSTRACT

This study investigates the biodegradability of coconut fiber coated with Polylactic acid (PLA) and Polyglycolic acid (PGA) for potential suture applications. This research aims to address the restraints of coconut fibers, which have exhibited poor degradability properties. The mechanical properties and biodegradability rate of the coconut fibers coated with PLA, PGA, and PLA/PGA blends were determined by conducting tensile testing. It is observed that after the eight weeks of biodegradability of the uncoated coconut fiber and coated coconut fibers, Coconut fiber coated with PLA (CPLA) has the highest tensile properties, recording yield tensile strength of 38.9 MPa, ultimate tensile strength of 350.2 MPa, Young's modulus of 6.0 GPa and elongation of 11.6%. The outcome signifies that CPLA displays the highest tensile strength and elongation, and its biodegradation property is controlled. The results of this work add to the increasing amount of research in biomedical engineering intended to create eco-friendly and efficient medical devices.

CHAPTER ONE

1.0 Introduction

This chapter introduces the problem statement, provides an overview of the research, and provides an outline of the thesis's organization.

1.1 Background/Overview

In surgical procedures, incisions require appropriate closure and optical care to influence adequate wound healing and surgical success (Giray et. al., 1995). Surgical sutures have been used in medicine to regulate blood arteries, heal damaged tissues, and close the margins of wounds and incisions (Kadimalla et. al., 2016). Suture biomaterials are essential for wound healing because they facilitate the healing of various tissues, such as those involved in vascular surgery, hemostasis, and plastic surgery (Azevedo et. al., 2020). A suture material is considered absorbable if used in tissues where its transitory presence is necessary and within 60 days of tissue implantation (Ercin & Karahan, 2018). The surgical materials used for implantation in the human body have significantly transformed due to recent advancements in synthetic fibers.

Suture materials fall into two categories: multifilament and monofilament (Byrne et. Al., 2019). Sutures can also be categorized as natural or synthetic, absorbable or non-absorbable (Jamshaid et. al., 2022). Natural suture materials have a more pronounced inflammatory response and uneven strength distribution along the suture's length than synthetic ones. Proteolysis causes a natural absorbable suture to break down (Erçin & Karahan, 2018). The biological process called proteolysis breaks down proteins into smaller peptides or amino acids. Most frequently, sutures are used to treat cuts and wounds and to keep the body safe from dangerous environmental infections (Masood et. al, 2017). Suture materials must be responsible for wound infection since the bulk of wound infections develop along and at the suture lines and because they are the most

frequently employed foreign materials in surgery. Suture material acts as an adhering foreign body, raising the risk of wound infection (Howell-Jones et. al., 2005). Suture placement necessitates the passage of an outside substance through tissue, which causes the highest level of tissue response (Phani, et al., 2018). It is always felt that an alternative to sutures is necessary to address these challenges (Shah et al., 2023). Therefore, it would be ideal to have a suture that not only fulfills its traditional function of wound closure but could also prevent wound infection both at the infected sites and close by (Chu Cet. al.,1987). An ideal suture material is generally agreed to have exceptional tensile strength, excellent handling qualities, outstanding knot security, low tissue reactivity, lack of allergic qualities, infection resistance, and eventual absorption after tissue regeneration has reached a satisfactory level (Herrmann et. al., 1970). No suture material currently on the market combines all these qualities. As a result, researchers are still interested in finding the perfect suture material for biomedical purposes (Kandimalla et. al., 2016). Research in previous years focused on the development and affordability of natural fibers (Sun et al., 2023). Guambo et al., 2020 conducted research using two natural vegetable fibers, sisal, and coconut fiber and compared them with a commercially available silk suture in terms of their properties. The result indicates that coconut fibers are unsuitable for suture applications due to their poor biodegradability properties.

Globally, the rise in environmental awareness has significantly impacted engineering material design. The use of natural materials tackles current ecological problems regarding recycling and environmental safety. Natural fiber composites are important due to their sustainability; they are affordable, biodegradable, and harmless when compared to other man-made fibers. Governments, researchers, and scientists in developing countries are incredibly interested in the conversion of waste into wealth (Adeniyi et al., 2022). A significant number of agricultural residues or waste is

produced in Ghana by cultivating and consuming coconut. The results of the study conducted on coconut fibers for suture application have shown rapid biodegradation; hence, this research aims to investigate the biodegradability of coconut fibers coated with polylactic acid (PLA) and polyglycolic acid (PGA) for suture application. Coconut fiber is a desirable material for the use of surgical sutures because it has mechanical properties like those of silk.

1.2 Research Problem

The biodegradability test results on coconut fibers have shown poor degradability properties, making them unsuitable for suture application. As a result, this study attempts to investigate the biodegradability of coconut fibers for potential suture application by coating them with PLA, PGA and PLA/PGA blend.

1.3 Research Aim

The research aims to investigate the biodegradability of coconut fibers reinforced with polymer for potential suture application.

1.3.1 Research objectives

The objectives are to investigate the degradable property of fibers reinforced with:

1. PGA.
2. PLA.
3. PGA/PLA copolymer.

1.4 Research question

1. Which of the polymers will have a significant effect on the fiber's degradability?

2. Can the polymers control the degradability property of the coconut fibres?

1.5 Research Hypothesis

H0: The mean biodegradation of CPGA, CPLA, and CPGAPLA does not differ significantly from each other in potential suture application

H1: The average biodegradation of CPGA, CPLA, and CPGAPLA in potential suture application varies significantly

1.6 Innovation and Significance of study

1.6.1 Innovation

Controlling degradable properties of coconut fibers with polymer.

1.6.2 Significance

Potential to propose new natural plant fibers with improved properties for suture application.

The Ninth Sustainable Development Goal (SDG 9) objective is on developing resilient infrastructure, promoting sustainable industrial growth, and encouraging innovation. It emphasizes the significance of robust systems that promote economic growth and raise standards of living, particularly in developing countries. The work will have a social impact in accordance with the SDG 9, which focuses on industry, innovation, and infrastructure, suggesting that investment be made towards promoting sustainable industries and in scientific research and innovation. The work and result of this research align with this goal as it promises to reveal the potential of coconut fibers that can be used for low-cost sutures.

1.6.3 Organization of Thesis

The thesis write-up is presented in five chapters. It begins with the introductory chapter, where the following will be discussed: a background of the study problem statement, which identifies a problem that requires a solution, aims and the objectives of the study, which gives vivid information one needs to know about the project paradigm, research questions, research hypothesis and finally the innovation and significance of the study. The second part of the thesis is where the available literature and other related findings are discussed. The next chapter will deal with the methodology used and the required materials. The fourth part involves the presentation of data, analysis of data presented in tables and figures, calculation of measures of central tendency, evaluation and interpretation, and results discussion. Finally, the thesis concludes with a summary and recommendations that focus on the all-encompassing, concise objective of the study.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

Consumer awareness of new products derived from renewable resources has steadily increased in recent decades. Green marketing modifies consumers' cognitive values and provides new guidelines for recycling and social effects, which encourages them to purchase eco-friendly goods. Numerous researchers are looking for alternative fibers to reinforce construction materials because of growing environmental consciousness and a desire to guarantee the sustainability of those materials. Fibers that are neither synthetic nor manufactured are referred to as natural fibers. Plant fibers like sisal, bamboo, pineapple, banana, and so on can be used to make natural fibers (Namvar et al., n.d.). Plants that contain cellulose and lignin are the source of natural fibers. In addition to being renewable and biodegradable, natural fibers have several advantages over conventional fibers, including a more environmentally friendly production process, better modulus, increased strength, cheap cost, and lightweight (Adeniyi et al., 2020). The lignocellulosic structures that make up natural fibers are often elementary fibers, or individual plant cells, bundled together and formed in the stem of the plant or as part of the leaves, but they can also be found in fruit, seeds, roots, grass, and wood (Thomason C Rudeiros-Fernández, 2021). Plant-based natural fibers are gaining a lot of attention in this area due to their affordability, low density, high specific strength, and repeatability. Plants that generate cellulose fibers fall into several categories, including grass and reed fibers (rice, corn, and wheat), core fibers (hemp, kenaf, and jute), bast fibers (jute, flax, ramie, hemp, and kenaf), seed fibers (cotton, coir, and kapok), and leaf fibers (sisal, pineapple, and abaca)(Sadeq et al., 2022). Figure 1 below shows the classification of plant fibers.

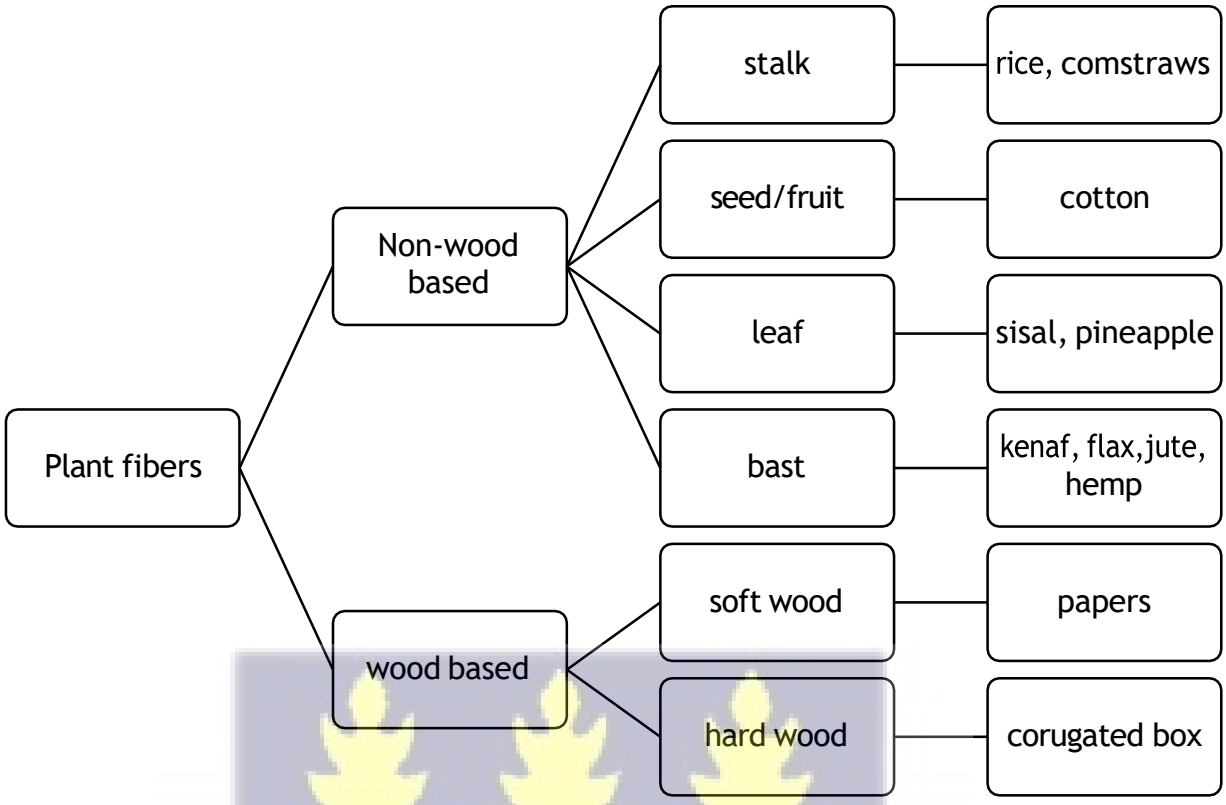

Figure 1. Classification of plant fibers (Sadeq et al., 2022).

The global production per unit time of natural fibers is displayed in Table 1.

Table 1. demonstrates the world's natural fibers and their production per unit time *(Faruk et al., 2012)*

Fiber	Source World production (10^3ton)
Sugar cane	75000
Bamboo	30000
Kenaf	2300
Flax	970
Grass	830
Sisal	700
Hemp	375
Coir	214
Ramie	100
Abaca	70

The primary constituents of plant fibers are pectin, lignin, cellulose, and hemicellulose, which are joined by moisture and trace amounts of wax or other contaminants. The main determinant of fiber qualities is often the plant's origin and the section or source from which it is extracted. Compared to fibers derived from other plant components, those derived from plant stems had comparatively favorable properties (Divya et al., 2022). Table 2 below shows natural plant fibers sources.

Table 2. Natural plant fiber sources*(Mwaikambo & Mwaikambo, 2006)*.

S.No	Fiber	Origin
1	Bamboo	Stems
2	Kenaf	Stems
3	Jute	Stems
4	Flax	Stems
5	Abaca	Leaves
6	Ramie	Stems
7	Hemp	Stems
8	Coir	Fruits
9	Pineapple	Leaves
10	White straw	Straws
11	Rice straw	Straw
12	Kapok	Seeds
13	Milk weed	Seeds
14	Nettle	Stems

2.1 Properties of natural plant fibers

Natural composite materials with a polyamine cell structure are plant fibers. Each cell wall is made up of varying amounts of cellulose, lignin, and hemicellulose(Bittner C Oettel, 2022) The foundation of the fibers is made up of chains of cellulose molecules, which also significantly influence the plant fibers' tensile characteristics (Mwaikambo et al., 2006). The characteristics of

natural fibers from plants vary greatly. The qualities may be impacted by the fiber type, moisture content, and fiber form (felt, yarn, weaved, twine, etc.). Furthermore, the location of the fibers' growth, the conditions of cultivation, the portion of the plant from which they are picked, the growing season, and any retting or extraction procedures all impact the fibers' qualities (Namvar et al., 2014).

2.1.1 Physical properties of natural plant fibers

Natural fibers from plants have a multicellular physical structure that gives them a superior feel and beauty (Gaba et al., 2021). The length, width, aspect ratio, texture, and appearance of plant fibers vary depending on the plant source. Table 3 below shows the geometric properties of known plant fibers.

Table 3. Summary of geometric parameters of some typical fibers found in natural plants (Djafari Petroudy, 2017).

Fiber types	Mean length (mm)	Mean width (µm)	Aspect ratio
Softwood	2-6	20-40	50-200
Hardwoods	1-2	10-50	28-86
Wheat straw	15	15	100
Rice straw	0.65-3.48	15-14	170
Flax	33	19	1737
Hemp	25	25	1000
Kenaf	5	21	238
Sisal	3	20	150
Jute	2	20	100
Cotton	25	20	1250
Ramie	12-15	20-75	2000-6000
Abaca	6	24	250
Bamboo	27	14	193
Esparto	1.9	13	146
Bagasse	0.68-1.7	2.2-20	29.8-85
Oil palm fiber	6	15-50	12-40
Coir	0.7	20	35
Cellulose	100-600	2-20	10-100
Whisker			
Cereal straw	1.5	23	63

2.1.2 Mechanical characteristics of natural plant fibers

The amount of cellulose in the plant fiber determines its strength and stability. Plant fiber's hemicellulose provides the fiber's distinctive strength and structure (Bakar et al., 2020). Many factors, including the chemical makeup, structure, age, growth environment, harvest, and retting process, affect the mechanical qualities of natural fibers (Bledzki et al.,1999). Within the same plant kind, mechanical characteristics can differ. As a realistic composite reinforcement in high throughput, high-performance applications, many writers believe that natural fibers have a bright future despite their great degree of variability, which can only be seen as a significant disadvantage in terms of their processability and performance (Thomason & Rudeiros-Fernández, 2021). The angle that microfibrils create regarding the fiber axis is known as the microfibrillar angle (MFA). MFA is the main factor affecting intrinsic fiber strength characteristics. According to research (Djafari Petroudy, 2017), a lower MFA and a higher cellulosic content are also necessary for high fiber strength.

Young's modulus of the cell wall will therefore be determined by the volume fraction of cellulose and the average MFA with respect to the loading direction. When the MFA is modest, the fiber can have greater stiffness and strength; nevertheless, a higher MFA causes the fiber to have more ductility. The ductility of the fiber is also impacted by the microfibril orientation. When the microfibrils are spirally oriented to the fiber axis, plant fibers are shown to have greater ductility. On the other hand, if the microfibrils are aligned parallel to the fiber axis, the fiber possesses high tensile strength and will be rigid and inflexible. Decreased MFA also results in less failure strain. Additionally, the MFA determines the nonlinear stress-strain behavior of plant fibers. The plastic range grows as MFA rises, but the elastic range decreases as MFA rises (Djafari Petroudy, 2017).

2.1.3 Young's modulus, tensile strength, and elongation of natural plant fibers

The degree of resistance the fiber has to deformation under load is indicated by its Young's modulus. The stiffness of the fiber is another name for its Young's modulus. Young's modulus describes tensile elasticity, or an object's tendency to flex along an axis when opposing forces are applied along that axis (Adeniyi et al., 2022). As the amount of cellulose in plant fibers increases, so do their tensile strength and Young's moduli (Mohanty et al., 2000). The lignin content determines the fiber's failure strain, whereas the cellulose content dictates the fiber's strength and stiffness (Komuraiah et al., 2014). The maximum stress that a material can withstand before breaking when stretched or pulled is known as its tensile strength (Ansong et al., 2023). One crucial factor in determining the fiber tensile strength is the cross-sectional area. (Ali Munawar et al., 2007). The amount that a material can be stretched, expressed as a percentage of its initial dimensions, before breaking is known as its elongation at break. The quantity of material that will undergo plastic and elastic deformation up to fracture is measured by the percentage elongation. It is determined by contrasting the material's initial length with the length that changed during the tensile process (Ansong et al., 2023). Table 4 shows the Young's modulus, tensile strength, and elongation of natural plant fibers.

Table 4. Young's modulus, tensile strength, and elongation of natural plant fibers *(Mahmud et al., 2021).*

Plant fibers	Density (g/cm^3)	Young's modulus (GPa)	Tensile strength (MPa)	Elongation (%)
Sugarcane	1.25	17	290	_
Pineapple	0.8-1.6	1.44	400-627	14.5
Abaca	1.5	12	430-760	3-10
Hemp	1.48	70	690	1.6
Jute	1.3	26.5	393-773	1.5-1.8
Flax	1.4-1.5	27.6-103	343-2000	1.2-3.3
Cotton	1.5-1.6	5.5-12.6	287-597	7-8
Bamboo	0.6-1.1	11-17	140-230	_
Sisal	1.33-1.5	9-38	363-700	2-7
Coir	1.15	4-6	131-175	15-40
Ramie	1.0-1.5	24.5-128	400-1000	1.4-4.0
Kenaf	1.4	53	930	1.5

Notwithstanding their comparatively low strength characteristics compared to synthetic fibers, natural plant fibers' potential as a partial or complete replacement of synthetic fibers in fiber composites is determined by their specific modulus and elongation at break. Fibers with higher length-to-diameter (aspect) ratios, lower microfibrillar angles, and higher levels of cellulose and/or crystallinity have generally been found to have better mechanical qualities (Mwaikambo & Ansell, n.d.-a).

2.1.4. Methods for extraction of plant fiber

In fiber research, fiber extraction is a crucial first step that involves using the right tools to separate or detach the fibers from their source. Fiber extraction is accomplished via mechanical, chemical, and retting techniques; the type of plant material dictates which technique is utilized (Divya et al., 2022). Different plant parts contain natural plant fibers. As a result, many extraction techniques have been investigated according to their convenience of use and impact on the fiber's mechanical characteristics.

2.1.4.1 Manual Extraction

Traditionally, the hand-pulling technique has been employed to remove natural plant fibers from plants. The fibers are extracted by hand from the plants.

2.1.4.2 Retting Process

Retting is the method of removing the fiber from the woody tissue (Adeniyi et al., 2019). Retting may be mechanical, chemical, biological, or physical. There are two types of biological retting: artificial and natural. The dew or cold-water processes are utilized for natural retting. The canal procedure or the hot-water procedure is employed for the artificial procedure (Mohanty et al., 2000). All biological retting procedures, whether synthetic or natural, use microbes or enzymes. When the fibers are firmly attached to the remainder of the plant, decortication would be less effective; therefore, it would take more work to separate the fibers. A lengthy retting procedure is sufficient to simply, economically, and effectively separate all the fibers from the material (Meijer et al., 1995). All the non-cellulosic materials that are affixed to the fibers can be broken down by natural enzymes. Despite this, a few non-enzymatic retting techniques have additionally been developed regarding the separation procedure. But compared to typical enzymatic approaches,

these practices are less well understood (Divya et al., 2022). Figure 2 depicts different techniques involved in the extracting process of fibers.

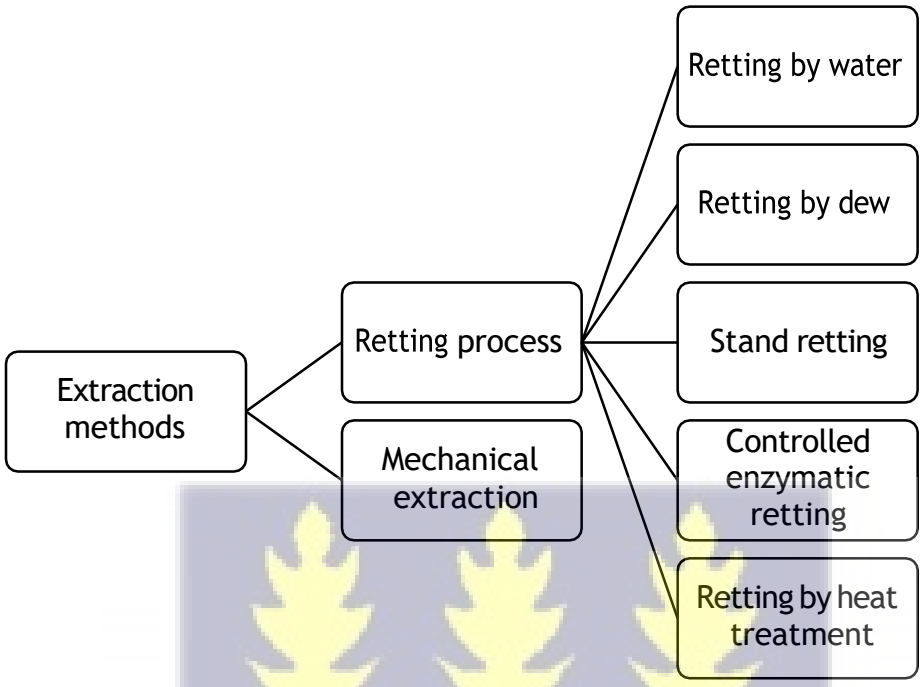

Figure 2. Wide range of techniques employed in the extraction process of fibers (Divya et al., 2022).

2.1.4.3 Effect of extraction process on mechanical properties of natural plant fiber

One of the elements affecting the mechanical characteristics of natural plant fiber is the extraction process. When compared to retting and mechanical methods, the mechanical properties of natural plant fibers exhibit worse results for hand extraction (Rafiqah et al., 2020). When natural plant fibers are extracted by hand, the force applied to them is not uniformly distributed along their length, which may cause damage and breakage at specific points. Consequently, the tensile characteristics of the fiber are impacted (Mohamed et al., 2010).

2.1.5 Treatment techniques for improving the properties of plant fibers.

2.1.5.1 Chemical treatment of plant fiber

Using efficient chemical agents to treat natural fibers significantly changes a few of their characteristics; this was the traditional approach that was widely employed in the past (Divya et al., 2022). The hydrophilic fiber and hydrophobic matrix are the main causes of the issues with natural fiber composites. Weakening bonding at the interface is the outcome of these two phases' inherent incompatibility. Reinforcing fiber's hydrophilic inclination can be decreased by chemical treatments, improving matrix compatibility (Stana-Kleinschek et al., 2003). Natural fibers are frequently treated with sodium hydroxide (NaOH) to change the molecular structure of the cellulose material. It creates an amorphous area and shifts the orientation of the densely packed crystalline cellulose arrangement (Kabir et al., 2012). This makes it easier to get chemicals through. Large distances separate the cellulose micromolecules in the amorphous zone, and water molecules fill in the gaps. When the molecules' alkali-sensitive hydroxyl (OH) groups are broken down, they react with water molecules (H-OH) and leave the fiber structure. The remaining reactive molecules join the cellulose molecular chains to generate fiber cell-O-Na groups (John & Anandjiwala, 2008). Researchers have been investigating several chemical treatment options to enhance fiber's mechanical qualities and alter the plant fiber surface for a favorable fiber-matrix interaction (Siakeng et al., 2018). Table 5 shows the various chemical treatments and their effects on natural plant fibers.

Table 5. Various chemical treatments and their effects on natural plant fibers (Sanjay et al., 2019).

No.	Chemical Treatment	Effects
1	Sodium hydroxide treatment	Enhance surface roughness, eliminate non-cellulosic components from the fiber, and promote strong interfacial Adhesion
2	Acetic acid treatment	Enhance fiber performance and tensile properties
3	Silane treatment	Improve the fiber's physicochemical characteristics and interfacial adhesion
4	Benzoyl peroxide treatment	Provide greater adherence between the matrix and the Fiber
5	Potassium permanganate treatment	Drop wax and additional cementing agents are used to improve the physicochemical characteristics
6	Stearic acid treatment	Leads to better physicochemical characteristics
7	Seawater treatment	Eliminates hemicellulose and permits the fibrillation of natural fibers
8	Cellulose powder treatment	Provides favorable wetting chemistry between the fiber and matrix.
9	Polymer coating	Enhances the matrix and fiber compatibility
10	Bleaching	Improves the fibers' tensile and thermal properties
11	Graft copolymerization	Enhances thermal characteristics and lessens fiber Swelling
12	Isocyanate treatment	Improves the fiber's mechanical and hydrophobic qualities.

2.1.5.2 Effect of chemical treatment on the mechanical properties of natural plant fiber

Natural fibers' hydrophilic qualities and the polymer matrix's hydrophobic qualities are the main underlying problems with using them as reinforcement for polymer composites. Nevertheless, the hydrophilic qualities of the natural fibers can be reduced by applying a chemical

treatment.(Mwaikambo & Ansell, n.d.-b). Chemical processing was found to have a vital impact on the mechanical characteristics of natural plant fibers (Asumani et al., 2012). This is because the soluble components of the fiber (hemicellulose and lignin) degrade because of the reaction between the ions and the plant fiber.

2.2 Biodegradation of natural plant fibers

Mohanty et al. define biodegradation as an occurrence that occurs because of enzyme activity and/or chemical breakdown of polymer chains linked to living organisms (fungi, bacteria, etc.) and the products of their secretions (Mohanty et al., 2000). A chemical process known as biodegradation results in a substantial alteration of the material's structure, marked by fragmentation and a decline in its molecular weight, tenacity, tensile properties and other characteristics. Eventually, a material breaks down into carbon dioxide, water, methane, biomass, and humic matter (Brunšek et al., 2023). Guambo et al reported on the biodegradability of sisal and coconut fibers. After 21 days, the mechanical properties of these fibers were contrasted with those of a commercially available silk suture. The ultimate tensile strength of commercially available silk suture is 217.55 MPa, and Young's modulus is 5.00 GPa; coconut fiber has ultimate tensile strength and Young's modulus is 18.72 MPa and 0.04 GPa, respectively. For sisal, ultimate tensile strength and Young's modulus were 138.84 MPa and 2.75 GPa, respectively. The research found out that the coconut exhibited rapid biodegradation behavior, concluding that the fibers' uneven surface and porosity were the drawbacks that facilitated the biodegradation (Guambo et al., 2020).

2.3 Methods of studying biodegradation of plant fiber

A biodegradability study is done to determine the mass or strength loss of plant fiber. The methods used to determine the biodegradation of plant fibers are Scanning Electron Microscope (SEM) and tensile testing. The morphological changes before and after the composites' biodegradation are examined using a SEM characterization tool (Luthra et al., 2020). SEM creates images by employing a concentrated electron beam to scan the fiber surface. Upon hitting the fiber surface, the electrons are reflected and detected as signals to form images. The surface makeup of the fiber determines the electrons that are reflected (Mahltig & Grethe, 2022). The tensile testing method measures mechanical properties such as the ultimate strength, yield strength, Young's modulus, and elongation of plant fiber using a tensile test device.

2.4 Phosphate-buffered Saline (PBS)

PBS with pH 7.4 is one of the most used buffers in different biological research applications for maintaining the pH of a solution. The process of making PBS solution involves dissolving weighed amounts of solid salts (NaCl, KCl, Na2HPO4 and KH2PO4) in deionized water (Gudić et al., 2021).

2.5 Polylactic acid (PLA) polymer

PLA is a thermoplastic with excellent mechanical qualities, compatibility, and high biodegradation. (Auras et.al., 2004). Lactic acid is the source of PLA, which is broken down by hydrolysis. Sugars derived from renewable resources, like sugarcane, can ferment to produce lactic acid, a naturally occurring organic acid (Hamat et al., 2023). Corn or potato starch could be fermented by microbes to create PLA (Babu et al., 2013). PLA can be made and used in a cycle that is good for the environment (Seyed et.al., 2015). Applications for PLA, an aliphatic polyester, include drug delivery, orthopedics, scaffolding and sutures, 3D printing, disposable dinnerware,

and packaging. However, the PLA uses are restricted to lower temperatures because of its low glass transition temperature (Graupner et al., 2023). PLA is currently used commercially in short-lived applications such as biodegradable packing materials (Baghaei & Skrifvars, 2016). PLA may be the most promising member of the biopolymer family due to its inherent qualities, which include improved mechanical qualities, transparency, biodegradability, and ease of processing in most equipment (Nirmal Kumar et al., 2022). Table 6 shows the physical and mechanical properties of polylactic acid (PLA).

Table 6: Physical and mechanical properties of polylactic acid (Nirmal Kumar et al., 2022)

Properties	Unit	Value
Density	g/cm^3	1.21-1.25
Melt density	g/cm^3	1.0727
Glass transition temperature	˚C	45-60
Melting temperature	˚C	150-165
Tensile strength	Mpa	21-59
Elongation at break	%	2.5-7.0
Young's modulus	Mpa	350-3500
Shear modulus	Mpa	1287
Poisson's ratio	–	0.36
Yield strength	Mpa	70
Flexural strength	Mpa	106
Notched Izod impact	J/m	26
Rockwell hardness	HR.	88
Ultimate tensile strength	Mpa	73
Percent of elongation	%	11.3

The main factors influencing PLA degradation include temperature, pH, purity, crystallinity, and molecular weight (Nirmal Kumar et al., 2022). Hydrolysis initiates PLA degradation, which is followed by bacterial action on the leftover broken particles (Khan et al., 2011).

2.6 Polyglycolic acid (PGA) polymer

Most known for its application in biodegradable surgical sutures, polyglycolic acid (PGA) is a hydrolytically degradable, thermoplastic, highly crystalline polymer with a crystallinity of

approximately 40–50% (Arakawa & DeForest, 2017). PGA is a significant biopolymer due to its appropriate mechanical, biocompatible, and biodegradable qualities, particularly in medical applications (Vildan et.al., 2019). PGA was initially produced as a synthetic absorbable suture material and has been developed for use in scaffolding, orthopedic fixing, and controlled medication release systems, among other medical applications (Shawe et al., 2006; Boehm et al., 2015). Human bodily fluids can convert PGA into carbon dioxide and water (Shen & Yang, 2013; Fu et al., 2004). Around 231 °C is the melting point of PGA, while between 35 and 40 °C is the glass transition temperature (Göktürk et al., 2015). With a degradation temperature of 255°C, PGA has poor thermal stability (Gautier et al., 2009).

2.7 Characterization technique for plant fibers

2.7.1 Fourier Transform Infrared Spectroscopy (FTIR) of plant fibers

FTIR is a widely used technique for identifying the various functional groups that make up a chemical (Hospodarova et al., 2018). FTIR is a widely used technique for identifying the various functional groups that make up a chemical (Vârban et al., 2021). Plants and their components have been successfully characterized using FTIR (Gorgulu et al., 2007).

CHAPTER THREE

MATERIALS AND METHOD

3.0 Introduction

The chapter provides relevant information on the materials and the method used to measure, analyze and the various tools and application software. It starts by identifying the diverse materials and measuring procedures that were used for data collection, processing, and analysis. It describes the study design. This chapter discusses the extraction and treatment of the coconut fibers, coating of the fibers with PLA, PGA, and their blend, immersion of the fibers in phosphate- buffered saline (PBS), and tensile test and biodegradability analysis of the fibers.

3.1 Materials

Matured coconut (cocos nucifera), specifically the West African Tall species mesocarp, was obtained from a coconut plantation in Tema Community Six, which is found in the Greater Accra Region. A commercial, biodegradable PLA and PGA were purchased from Shannxi Xinyide and Siweitu New Material, respectively, in China. PLA (1 kg) and PGA (500 g) were purchased in the form of powder and grains respectively. 100 gram of NaOH pellet was kindly supplied by the Material Science Department in the School of Engineering Sciences, University of Ghana. Phosphate Buffered Saline (PBS) with a pH of 7.4 was supplied by the Cell and Molecular Biology Lab in the Department of Biomedical Engineering, University of Ghana.

3.2 Method

3.2.1 Extraction and Alkali Treatment of Coconut Fibers

Matured mesocarp fibers from harvested coconut (**Figure 3a**) were soaked in clean water for 21 days at room temperature (26 ℃) to soften the fiber for easy isolation (Jawaid et al.,2020). This approach broke down the hemicellulose cement matrix, allowing bacteria and fungi to release the fiber bundle and enhance fiber isolation **(Figure 3b**). To remove contaminants, the fibers were cleaned with distilled water and immersed in 20% NaOH solution at room temperature for 60 mins **(Figure 3c)**. Finally, the fibers were rinsed with distilled water to remove residual alkaline solution. The fibers were air-dried for thirty minutes at 26 ℃. The tensile strength of four samples of the fibers, each with a length of 60mm, was tested before coating. The coated fibers were utilized to investigate the effect of PGA, PLA, and PGA/PLA copolymer on their biodegradability properties.

(a) **(b)** **(c)**

Figure 3. (a) matured coconut mesocarp: (b) soaking coconut mesocarp fibers in water: (c) Treating fibers with NaOH.

3.1.2 Coating Process of the Fibers

The PGA (50mg), PLA (50 mg), and PGA/PLA (50/50 mg) were melted at 198, 160, and 198/160 degrees Celsius, respectively, on an electric burner in a separate metal container. Coconut fibers were fully immersed and slowly pulled out to coat them with the melted polymers. This process helps coat the fibers with a thin layer of polymer.

3.2 Fibers Tensile Test

Tensile tests using a 1.5 KN load capacity Mark-10 ESM301 Force Test Stand in basic mode were carried out on fibers treated with 20% NaOH and samples of fibers coated with PLA and PGA polymers with their copolymer in compliance with ASTM C1557-14 (ASTM, 2014) (**Figure 4c**).

To prevent the fiber from slipping out of the retention grips (mounting tab), Cyanoacrylate was used to attach and align the fiber specimens' ends on cardboard. Tensile testing was carried out at 26 °C, 76% relative humidity, and with 10 mm/min as the constant crosshead displacement rate. Tensile testing was performed on the fibers using a gage length of 60 mm and at least four replicates per sample. The force-displacement data were directly acquired by Mark-10 using the MESUR Lite software to ascertain the tensile characteristics. In general, it turned out that the fiber diameter varied across all the coconut samples. Within the gauge length, the fiber diameter of the fractured end was measured with a vernier caliper (**Figure 4b**). Equation (1) was utilized to determine the initial cross-sectional area of the fractured fiber.

$$A = \pi \frac{d^2}{4} \tag{1}$$

where A represents the fiber's cross-sectional area and d represents its diameter. The tensile strength of each tested fiber was determined using the computed initial fiber cross-section of the surface of the fractured fiber. Equation (2) was employed to calculate each fractured sample's tensile strength using Equation (1), which was based on the average force (F) at which the sample fractured with its initial cross-sectional area (A).

$$\text{Tensile Strength } (\sigma) = \frac{F}{A} \tag{2}$$

3.3 Biodegradability Test of Fibers

The fibers were immersed in 10 mL phosphate buffer solution (1X PBS) with pH value of 7.4 for eight weeks (**Figure 4a**). Weekly solution replacement was made for the ionic activity to be maintained. To assess the tensile strength loss of the fibers, four replicates of each fiber were used, and measurements were conducted for every two weeks to eight weeks (1st day, 14th day, 28th

day, 42nd day and 56th day) to investigate the effect of PGA, PLA and PGA/PLA copolymer on their biodegradability.

(a) **(b)** **(c)**

Figure 4. (a) coconut fibers dipped in PBS: (b) fibers diameter measuring using vernier caliper: (c) fibers tensile strength testing.

3.4 Characterization of the fiber

Fourier transform infrared spectroscopy (FTIR, BRUKER) was used to determine the functional groups of the uncoated and coated fibers. The scan was done from a wavenumber of 500 to 4000 cm^{-1}.

3.5 Analysis of Statistical Data

Excel Data Analysis and Graphing Software and IBM SPSS Statistical Software, version 22, were utilized to organize and analyze the collected data. The tensile properties of the fibers were

evaluated using the Krustal Wallis test and Bonferroni multiple comparison test analysis at a significance level of 0.05.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 FTIR Special Analysis

Figure 5 shows FTIR spectra of uncoated and coated coconut fibers within the range of 4000-500 cm^{-1}. For UTCF, essential peaks are evident at 1020, ~2848, ~2937, and ~3530 cm^{-1}, which correspond to OH bending, CH_2 rocking vibrations, C–H stretching, and OH stretching frequencies, respectively (Guambo et al., 2020). UTCF functional groups verify that the fiber is primarily composed of cellulose, with trace amounts of lignin or hemicellulose remaining as impurities (Guambo et al., 2020). TCPGACPLA has a C-H stretching vibration of ~2955 cm-1, C=O stretching of ~1705 cm1, indicating the presence of carbonyl groups, C-H bending vibrations have a peak of ~1412 cm-1, and C=O stretching of 1102 cm^{-1}. In all compositions, the C-H region exhibits a shift in frequency, as anticipated, signifying a link between the two polymers (Pandey et al., 2008). The spectral characteristics of the C=O bond indicate that the intensities of the doublet around in the parent polymers tend to equalize upon blending (Pandey et al., 2008) TCPLA has C-H at 2955 cm-1 and C=O at 1705 cm-1. The flexural C-H bond vibration and the absorption bands at 1705 cm-1 (caused by alkyl-ketone chain vibration) indicate PLA's crystalline structure. (Carrasco et al., 2010). TCPGA also has O-H, C-H and C=O groups at bands around ~3530, ~2955 and ~1705 cm^{-1}, respectively and thus spectra confirm a successful coating the UTCF.

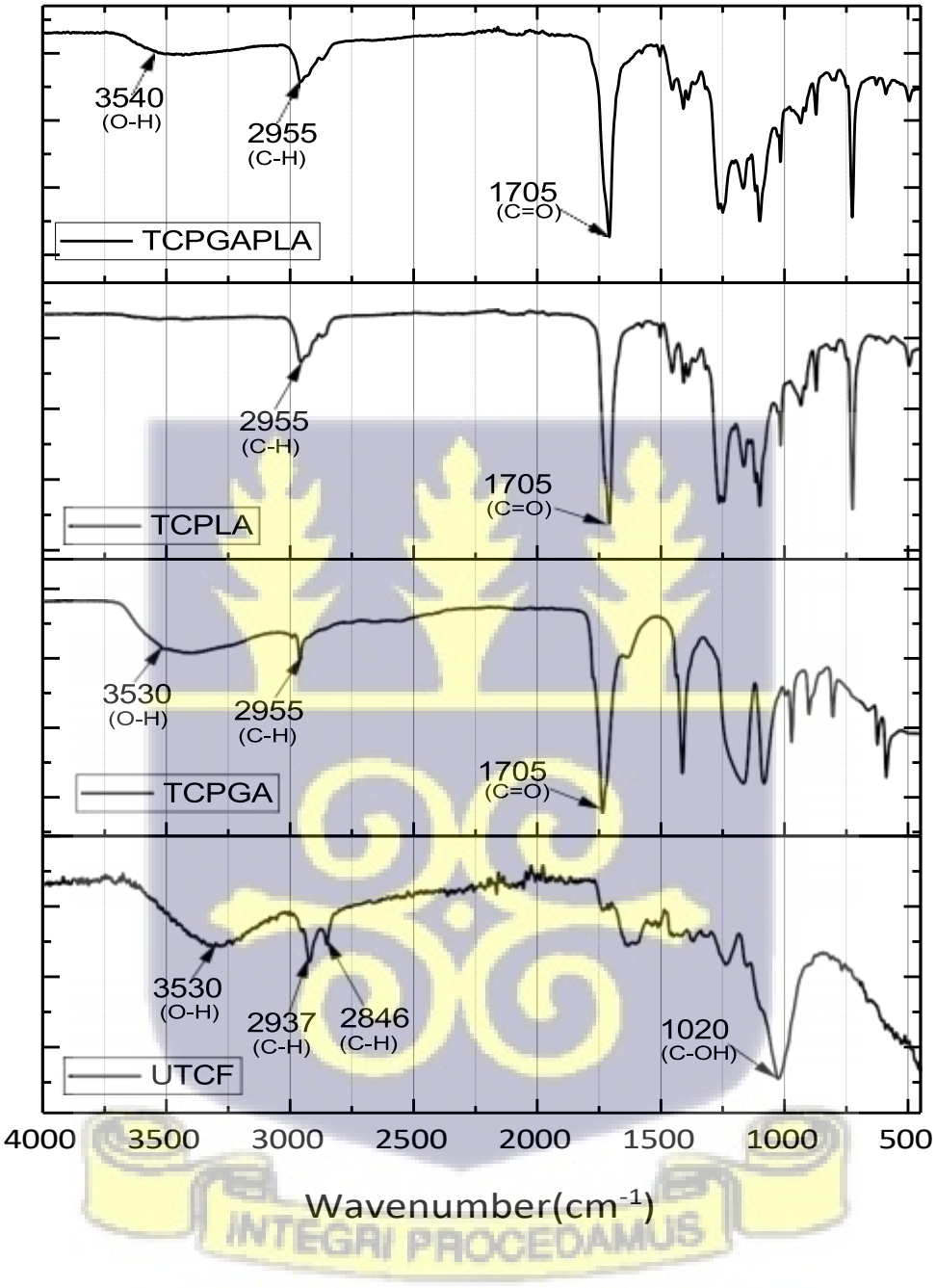

Figure 4. FTIR plot of TCPGA (treated coconut fiber coated with polyglycolic acid (PGA)), TCPGAPLA (treated coconut fiber coated with PGA and PLA blend), UTCF (untreated coconut fiber), and TCPLA (treated coconut fiber coated with polylactic acid (PLA))

4.1 Fiber Tensile Test

4.1.1 Tensile test of treated and untreated uncoated coconut fibers

Figure 6 demonstrates unique stress-strain curves derived from tensile tests conducted on four treated uncoated coconut fibers (TUCF1, TUCF2, TUCF3, and TUCF4) and untreated coconut fiber (UTCF). From literature, the tensile strength of untreated coconut fiber can be 24.03 MPa (Martinelli et al., 2024). In this work, the average value of the untreated coconut fiber, found for tensile strength is lower and this might be because fiber diameter values vary (Martinelli et al., 2024). The diameter of fibers varies both within and between fibers (Martinelli et al., 2024). The result shows an increase in the tensile strength of the fibers after treatment with 20% NaOH. This indicates that the alkali treatment of coconut fiber can increase the tensile strength of coconut fiber (Arsyad, 2019).

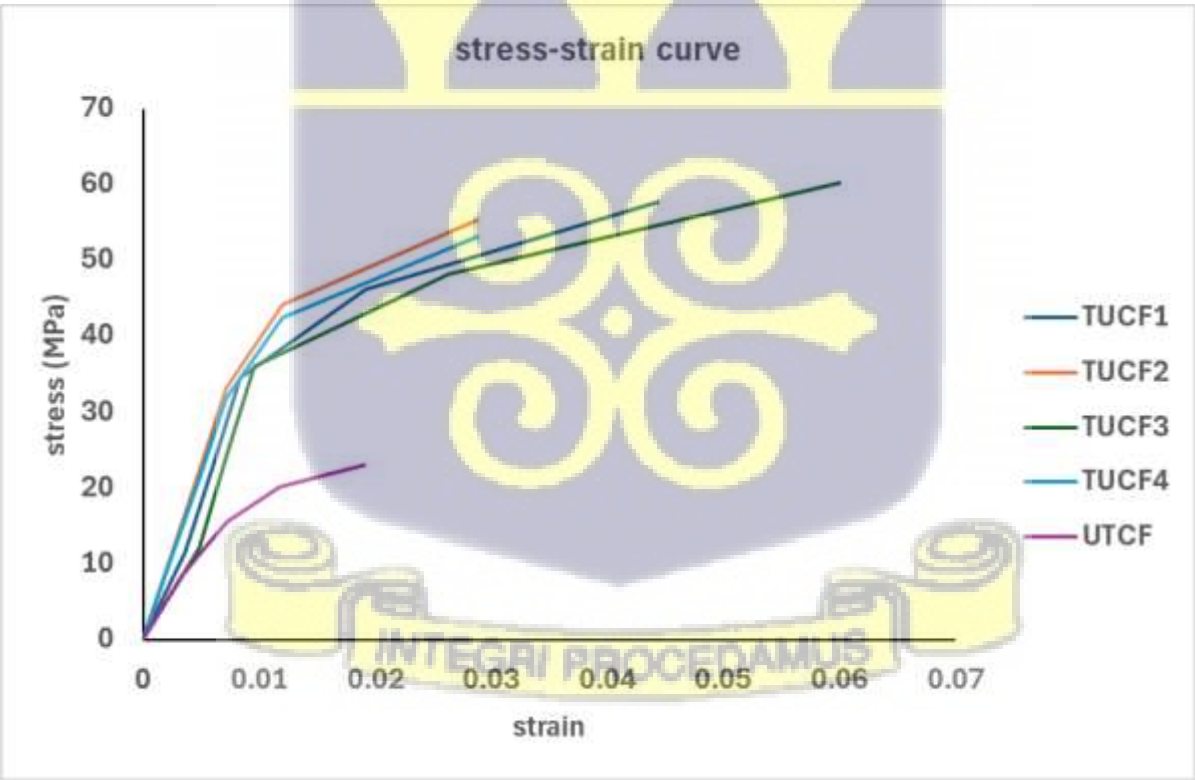

Figure 5. Stress-strain curves of treated uncoated coconut fibers (TUCF1, TUCF2, TUCF3 and TUCF4) and untreated coconut fibers (UTCF)

Table 7 shows the Yield Tensile Strength, Ultimate Tensile Strength (UTS), Young's modulus, and Elongation of all four treated uncoated coconut fibers, the average tensile properties of the uncoated coconut fibers, and the average of the untreated coconut fibers.

Table 7. Summary of tensile properties of treated uncoated coconut fibers (TUCF1, TUCF2, TUCF3, and TUCF4), average of the four treated uncoated coconut fibers (ATUCF), and the average of four untreated coconut fibers (AUTCF).

UCF Samples	Tensile Strength (MPa)		Young's modulus (GPa)	Elongation (%)
	Yield	Ultimate		
TUCF1	11.5	57.6	3.2	4.4
TUCF2	11.1	55	4.6	2.9
TUCF3	12	60.2	2.5	5.9
TUCF4	10.6	53	2.9	2.9
ATUCF	11.3 ± 0.5	56.45 ± 3.1	3.3 ± 0.9	4 ± 1.4
AUTCF	12.2 ± 1.3	22.9 ± 3.5	0.06 ± 0.03	3.4 ± 2.3

4.1.2 Tensile test of treated coated coconut fibers (TCCF)

Figure 6 shows stress-strain curves of treated coconut fibers coated with polymers (PGA, PLA, and PLAPGA). TCPGA (treated coconut fiber coated with polyglycolic acid), TCPLA (treated coconut fiber coated with polylactic acid), and TCPGAPLA (treated coconut fiber coated with polyglycolic acid and polylactic a blend). It is observed that the tensile properties of the treated coconut fibers coated with polymers improve, with TCPLA having the highest tensile properties. Coconut fiber coated with PLA and PGA strengthens the fiber's structure and improves surface bonding, increasing its tensile strength and making it perfect for high-performance uses like medical sutures.

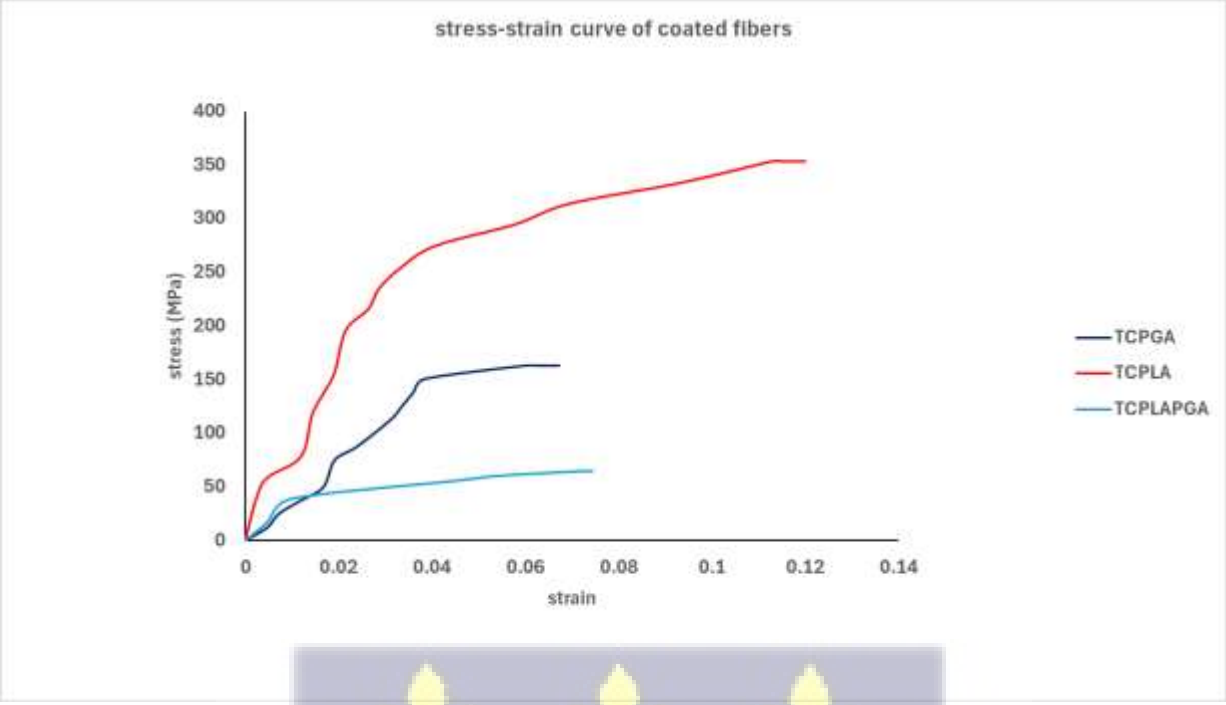

Figure 6. Stress-strain curve of coconut fibers coated with polymers.

Table 8 shows the summary of the yield tensile strength, ultimate tensile strength (UTS), Young's modulus, and elongation of the treated coconut fibers coated with polymers (PGA, PLA, and PGAPLA blend). TCPGA (treated coconut fiber coated with polyglycolic acid), TCPLA (treated coconut fiber coated with polylactic acid), and TCPGAPLA (treated coconut fiber coated with polyglycolic and polylactic blend). It is indicated that treated TCPLA, has the highest tensile strength properties with yield tensile strength of 39.3 MPa, ultimate tensile strength of 350.4 MPa, Young's modulus of 6.0 GPa, and elongation of 12%. The yield tensile strength, ultimate tensile strength, Young's modulus, and elongation of TCPGA have tensile properties of 12.9 MPa, 167.6 MPa, 3.7 GPa, and 6% respectively. The result confirms that TCPGA has the lowest yield tensile strength and Young's modulus of 12.9 MPa and 2.7 GPa respectively among the fibers. TCPGAPLA is found to have tensile properties of yield tensile strength (17.2 MPa), ultimate

tensile strength (67.4 MPa), Young's modulus (3.6 GPa), and elongation (7.2%), with the lowest ultimate tensile strength among the fibers.

Table 8. Summary of tensile properties of treated coated coconut fiber

TCCF Samples	Tensile Strength (MPa)		Young's modulus (GPa)	Elongation (%)
	Yield	Ultimate		
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
TCPGA	12.9 ± 2.9	167.6 ± 37.4	3.7 ± 0.6	6 ± 0
TCPLA	39.3 ± 0.6	350.4 ± 4.2	6.0 ± 0.2	12 ± 0
TCPGAPLA	17.2 ± 0.5	67.4±6.9	3.6 ± 0.1	7.2 ±1.9

4.2 biodegradation of uncoated and coated coconut fibers

Figure 7 shows stress-strain curves of eight weeks of biodegradation of treated uncoated and coated coconut fibers. Figure 8a shows two weeks of biodegradation of the coconut fibers, Figure 8b shows four weeks of biodegradation of the coconut fibers, Figure 8c shows six weeks of biodegradation of the coconut fibers, and Figure 8d shows eight weeks of biodegradation of the coconut fibers. It is observed that within the two to four weeks of biodegradability, the tensile strength of the TUCF reduces, whereas TCPGA, TCPLA, and TCPGAPLA remain the same. The behavior shows that biodegradation did not occur in the treated coated fibers, and in the six and eight weeks, biodegradation in all the samples occurred but slightly in the TCPGA, TCPLA, and TCPGAPLA.

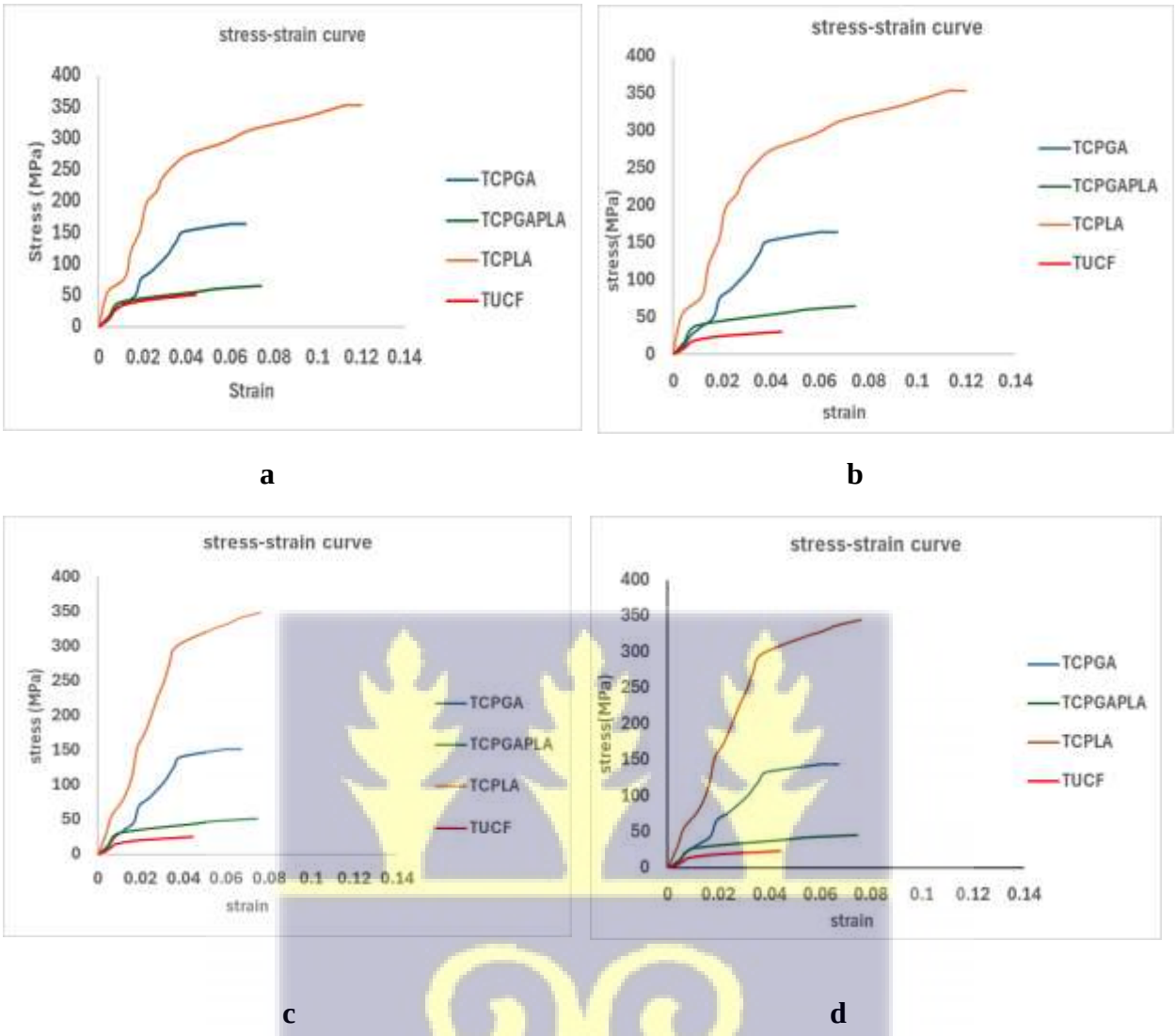

Figure 7. Stress-strain curves of biodegradation of uncoated and coated coconut fibers. TCPGA (treated coconut fiber coated with polyglycolic acid), TCPLA (treated coconut fiber coated with polylactic acid), TCPLAPGA (treated coconut fiber coated with polyglycolic acid and polylactic acid blend) and TUCF (treated uncoated coconut fiber).

Table 9 shows the summary of tensile properties of the biodegradability of treated uncoated and coated coconut fibers. It is observed that after the eight weeks of biodegradability of the treated uncoated and coated coconut fibers, TCPLA has the highest tensile properties recording yield tensile strength of 38.9 MPa, ultimate tensile strength of 350.2 MPa, Young's modulus of 6.0 GPa and elongation of 11.6%.

Table 9. Summary of tensile properties of the biodegradability of treated uncoated coconut fiber (TUCF) and treated coated coconut fibers (TCPGA, TCPLA and TCPGAPLA).

Samples	Tensile Strength (MPa)		Young's modulus (GPa)	Elongation (%)
	Yield	Ultimate		
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
TUCF	7.65 ± 2.5	38.2 ± 12.5	2.1 ± 0.7	4 ± 0
TCPGA	12.2 ± 0.9	157.7 ± 12	2.1 ± 1.1	5.4± 0
TCPLA	38.9 ± 0.6	350.2 ± 4.2	6.0 ± 0.2	11.6 ± 0
TCPGAPLA	14.8 ± 3	57.0 ± 12	3.1 ± 0.6	7 ± 0.1

4.4 Potential Application of the Coconut Fiber

The table 10 compares commercial sutures (Scott Taylor & Shalaby, 2013) to the results of this work. The table compares commercial sutures (upper white section) with the results of this work (lower shaded section) based on ultimate strength, Young's modulus, elongation, and functionality. The commercial sutures have an ultimate strength ranging from 310 to 629 MPa, with PG-Cl having the highest ultimate strength. In contrast, the results of this work show an ultimate strength range of 38.2 to 350.2 MPa, with TCPLA having the highest ultimate strength. In terms of stiffness, commercial sutures have Young's modulus values between 0.8 and 3.4 GPa, with PG-TMC having the highest Young's modulus of 3.4 GPa, while the results of this work have Young's modulus ranging from 2.1 to 6.0 GPa. For elongation, commercial sutures range from 26–39%, whereas the elongation of the results of this work ranges from 4–11.6%. Functionality of the commercial sutures ranges from 1-2 weeks to 6 weeks, with PG-TMC having the highest, with 6 weeks, while the functionality of the results of this work ranges from 2-8 weeks to 6-8 weeks, with TUCF having the lowest functionality.

Table 10. comparison of commercial sutures to this work

Material	origin/ composition	Ultimate strength (MPa)	Young's modulus (GPa)	Elongation (%)	Clinical application	Functionality	Example Device
PDO	p-dioxanone	450-560	1.2-1.7	30-38	"General, cardiovascular, ophthalmic"	4-6 weeks	Ethicon PDS™ II Angiotech PDO
PG-Cl	75/25 Glycolide/ Caprolactone	629	0.8	39	General	2-3 weeks	Ethicon Monocryl™ Angiotech Monosorb
PG-TMC	67/33 Glycolide/ TMC	540-610	3.0-3.4	26-38	General, cardiovascular	6 weeks	Covidien Maxon™
Natural gut	Bovine serosa or submucosa of sheep or goat intestine	310-380	2.4	15-35	General, subcutaneous	1-2 weeks	Ethicon Plain Gut
Chromic gut	Bovine serosa or submucosa of sheep or goat intestine treated in chromium solution	310-380	2.4	15-35	General, subcutaneous	2-3 weeks	Ethicon Chromic Gut
TUCF		38.2	2.1	4.0		2-8 weeks	
TCPGA		157.7	2.1	5.0		6-8 weeks	
TCPLA		350.2	6.0	11.6		6-8 weeks	
TCPGAPLA		57.0	3.1	7.0		6-8 weeks	

In this study, the mechanical properties of the treated coconut fiber coated with polylactic acid (TCPLA) with an ultimate strength of 350.2 MPa show better tensile strength and biodegradation throughout the eight-week biodegradability study. The result suggests that the proposed novel TCPLA could be used for potential suture applications. The suture is strong and suitable for general and subcutaneous surgeries (Scott Taylor & Shalaby, 2013). The yield strength guarantees that the suture will not permanently distort under stress. Under maximum load, the suture's ultimate strength keeps it from breaking. Young's modulus provides suture stiffness for accurate wound closure. Elongation allows the suture to stretch slightly for flexibility and movement.

CHAPTER FIVE

CONCLUSION AND RECOMMEMDATION

5.0 Conclusion

In this work, coconut fibers were successfully extracted from coconut mesocarp treated with 20% NaOH and coated with polymers (PLA, PGA, and PLA/PGA blend). The results indicated that coconut fibers demonstrated enhanced mechanical properties and varying biodegradation rates when coated with the polymers. From the outcomes, the treated coconut fibers coated with PLA, that is, TCPLA, showed higher tensile strength and elongation and controlled the biodegradation rate of the fibers, thereby making the PLA the most competent polymer for controlling coconut fiber for potential suture application. The treated coconut fibers coated with PLA exhibited significant improvements in biodegradation and durability which are properties for efficient suture materials. The research also established that the biodegradation of the treated coated coconut fibers in PBS for eight weeks showed that PLA possessed a better controlled and upheld biodegradation related to PGA and PLA/PGA blend.

5.1 Recommendation

Manually extracting and coating coconut fiber takes a long time, but it preserves the fiber's physical integrity. A mechanized process that preserves the fiber's physical structure should be created to enhance the quantity of coconut fibers removed in each period.

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APPENDICES

Kruskal-Wallis rank sum test

data: PROPERTIES by GROUP

Kruskal-Wallis's chi-squared = 8.5017, df = 2, p-value = 0.01425.

Comparison of x by group (Bonferroni)

Col Mean- Row Mean	CPGA	CPGAPLA
CPGAPLA	-0.391763 1.0000	
CPLA	-2.698115 0.0105*	-2.306351 0.0316

Statistical analysis of the fibers

Examining the assumptions governing statistical parametric tests, the equality of variances and normal distribution assumptions failed; hence, there was a need to resort to the equivalent non-parametric means test. However, the non-parametric equivalence tests the median of the groups (CPGA (coconut fiber coated with polyglycolic acid), CPLA (coconut fiber coated with polylactic acid), and CPGAPLA (coconut fiber coated with polylactic acid and polyglycolic blend)) instead of their means. The output shows the result from the non-parametric test of means known as the Kruskal-Wallis rank sum test. From the Kruskal Wallis rank sum test, the chi-squared value of 8.5017 indicates that there exists a variation between CPGA, CPLA, and CPGAPLA frequencies, indicating a possible variation in the median of CPGA, CPLA, and CPGAPLA. The p-value of 0.01425 is less than the standard p-value of 0.05, indicating that there is a significant difference between the medians produced by the groups (CPGA, CPLA, and CPGAPLA), suggesting a significant difference in the means. Hence, the null hypothesis is rejected with the conclusion that

there is a significant difference between the mean biodegradation of CPGA, CPLA and CPGAPLA for potential suture application. Investigating which of the groups is actively contributing to the difference observed in the result of the Kruskal Wallis test, the Bonferroni multiple comparison test is used. The test is as follows.

Null hypothesis: The mean biodegradation of CPGAPLA and CPGA does not differ significantly

Alternative hypothesis: The mean biodegradation of CPGAPLA and CPGA differs significantly

Null hypothesis: The mean biodegradation of CPGA and CPLA does not differ significantly

Alternative hypothesis: The mean biodegradation of CPGA and CPLA differs significantly

Null hypothesis: The mean biodegradation of CPGAPLA and CPLA does not differ significantly

Alternative hypothesis: The mean biodegradation rates of CPGAPLA and CPLA differ significantly.

From the output, the difference between the means of CPGA vrs CPGAPLA is recorded to be -0.391763 at a p-value of 0.5 is greater than the standard p-value of 0.05, hence the null hypothesis failed to be rejected with a conclusion that there is no significant difference between the mean biodegradation of CPGA and CPGAPLA for potential suture application. Comparing the means of CPLA vrs CPGA gives a difference of -2.698115 and a p-value of 0.0105. This suggests that the p-value is less than the standard p-value of 0.05. Hence, the null hypothesis is rejected with a conclusion that there is a significant difference between the mean biodegradation of CPLA vrs CPGA for potential suture application. Again, comparing CPLA vrs CPGAPLA gives a mean difference of -2.306351 with a p-value of 0.0316. This informs that the p-value observed is less than the standard p-value of 0.05. Hence, the null hypothesis is rejected with the conclusion that there is a significant difference between the mean biodegradation of CPLA vrs for potential suture

application. From the analysis, CPLA is noticed to exhibit longer biodegradability properties and was identified to be the suture material causing the variation in the mean biodegradability of three coconut fibers coated with the polymers. This means that PLA is the polymer that significantly controls coconut fiber than GPA and PGAPLA. Hence PLA is highly recommended over PGA and PGAPLA for controlling the biodegradability of coconut fiber.