FINAL PROJECT – TL234839

DEVELOPMENT OF BIOSUTURE BASED ON NANO CHITOSAN OLIGOSACCHARIDE-POLYLACTIC ACID-POLYCAPROLACTONE

LIDYA NATASYA
NRP. 5011201152

Advisor
Yuli Setiyorini, S.T.,M.Phil.PhD.Eng.
NIP. 197907242005012003
Azzah Dyah Pramata, S.T.,M.T.,M.Eng.,PhD
NIP. 1992202012023

Undergraduate Study Program of Materials Engineering
Departement of Materials and Metallurgical Engineering
Faculty of Industrial Technology and Systems Engineering
Institute Technology of Sepuluh Nopember
Surabaya
2024

(This page is intentionally blank)

FINAL PROJECT – TL234839

DEVELOPMENT OF BIOSUTURE BASED ON NANO CHITOSAN OLIGOSACCHARIDE-POLYLACTIC ACID-POLYCAPROLACTONE

LIDYA NATASYA
NRP. 5011201152

Advisor
Yuli Setiyorini, S.T.,M.Phil.PhD.Eng.
NIP. 197907242005012003
Azzah Dyah Pramata, S.T.,M.T.,M.Eng.,PhD
NIP. 1992202012023

Undergraduate Study Program of Materials Engineering
Departement of Materials and Metallurgical Engineering
Faculty of Industrial Technology and Systems Engineering
Institut Teknologi Sepuluh Nopember
Surabaya
2024

(*Halaman ini sengaja dikosongkan*)

TUGAS AKHIR – TL234839

PENGEMBANGAN *BIOSUTURE* BERBASIS NANO KITOSAN OLIGOSAKARIDA-ASAM POLILAKTAT-POLIKAPROLAKTON

LIDYA NATASYA
NRP. 5011201152

Dosen Pembimbing
Yuli Setiyorini, S.T.,M.Phil.PhD.Eng.
NIP. 197907242005012003
Azzah Dyah Pramata, S.T.,M.T.,M.Eng.,PhD
NIP. 1992202012023

Program Studi Sarjana Teknik Material
DepartemenTeknik Material dan Metalurgi
Fakultas Teknologi Industri dan Rekayasa Sistem
Institut Teknologi Sepuluh Nopember
Surabaya
2024

(*This page is intentionally blank*)

APPROVAL SHEET

DEVELOPMENT OF BIOSUTURE BASED ON NANO CHITOSAN OLIGOSACCHARIDE-POLYLACTIC ACID-POLYCAPROLACTONE

FINAL PROJECT
Submitted to fulfill one of the requirements
for obtaining a degree of Bachelor of Engineering at
Undergraduate Study Program of Material Engineering
Department of Materials and Metallurgical Engineering
Faculty of Industrial Technology and Systems Engineering
Institut Teknologi Sepuluh Nopember

By: **LIDYA NATASYA**
NRP. 5011201152

Approved by Final Project Examiner Team:

1. Yuli Setiyorini S.T., M.Phil., Ph.D.Eng. — Advisor
2. Azzah Dyah Pramata, S.T., M.T., M.Eng., Ph.D. — Co-Advisor
3. Muhammad Bagas Ananda S.T, M.T. — Examiner
4. Haniffudin Nurdiansah, S.T, M.T — Examiner

KEMENTERIAN PENDIDIKAN, KEBUDAYAAN, RISET, DAN TEKNOLOGI
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
FAKULTAS TEKNOLOGI INDUSTRI DAN REKAYASA SISTEM
DEPARTEMEN TEKNIK MATERIAL DAN METALURGI

SURABAYA
July, 2024

(This page is intentionally blank)

LEMBAR PENGESAHAN

ENGEMBANGAN BIOSUTURE BERBASIS NANO KITOSAN OLIGOSAKARIDA-ASAM POLILAKTAT- POLIKAPROLAKTON

TUGAS AKHIR
Diajukan untuk memenuhi salah satu syarat
memperoleh gelar Sarjana Teknik pada
Program Studi S-1 Teknik Material
Departemen Teknik Material dan Metalurgi
Fakultas Teknologi Industri dan Rekayasa Sistem
Institut Teknologi Sepuluh Nopember

Oleh: **LIDYA NATASYA**
NRP. 5011201152

Disetujui Oleh Tim Penguji Tugas Akhir:

1. Yuli Setiyorini S.T., M.Phil., Ph.D.Eng.. — Pembimbing
2. Azzah Dyah Pramata, S.T., M.T., M.Eng., Ph.D. — Ko-Pembimbing
3. Muhammad Bagas Ananda S.T, M.T. — Penguji
4. Haniffudin Nurdiansah, S.T, M.T — Penguji

SURABAYA
Juli, 2024

(This page is intentionally blank)

STATEMENT OF ORIGINALITY

The undersigned below:

Name of Student/NRP	: Lidya Natasya / 5011201152
Department	: Materials and Metallurgical Engineering INDSYS-ITS
Advisor/NIP	: Yuli Setiyorini, S.T., M. Phil., PhD. Eng./ 197907242005012003
Co–Advisor/NIP	: Azzah Dyah Pramata, S.T., M.T., M.Eng., Ph.D../ 1992202012023

Hereby declare that the Final Project with the title of "DEVELOPMENT OF BIOSUTURE BASED ON NANO CHITOSAN OLIGOSACCHARIDE-POLYLACTIC ACID-POLYCAPROLACTONE" is the result of my own work, is original, and is written by following the rules of scientific writing.

If in the future there is a discrepancy with this statement, then I am willing to accept sanctions in accordance with the provisions that apply at Institut Teknologi Sepuluh Nopember.

Surabaya, July 19th 2024

Acknowledged
Advisor

(Yuli Setiyorini, S.T.~~, M. Phil.~~, PhD. Eng.)
NIP. 197907242005012003

Student

(Lidya Natasya)
NRP. 5011201152

(This page is intentionally blank)

PERNYATAAN ORISINALITAS

Yang bertanda tangan di bawah ini:

Nama mahasiswa/NRP	: Lidya Natasya / 5011201152
Departemen	: Teknik Material dan Metalurgi FTIRS-ITS
Dosen Pembimbing/NIP	: Yuli Setiyorini, S.T., M. Phil., PhD. Eng./ 197907242005012003
Dosen Ko–Pembimbing/NIP	: Azzah Dyah Pramata, S.T., M.T., M.Eng., Ph.D./ 1992202012023

Dengan ini menyatakan bahwa Tugas Akhir dengan judul "PENGEMBANGAN BIOSUTURE BERBASIS NANO KITOSAN OLIGOSAKARIDA-ASAM POLILAKTAT-POLIKAPROLAKTON" adalah hasil karya sendiri, bersifat orisinal, dan ditulis dengan mengikuti kaidah penelitian ilmiah.

Bilamana di kemudian hari ditemukan ketidaksesuaian dengan pernyataan ini, maka saya bersedia menerima sanksi sesuai dengan ketentuan yang berlaku di Institut Teknologi Sepuluh Nopember.

Surabaya, 19 Juli 2024

Mengethaui	
Dosen Pembimbing	Mahasiswa
(Yuli Setiyorini, S.T., M. Phil., PhD. Eng.)	(Lidya Natasya)
NIP. 197907242005012003	NRP. 5011201152

(This page is intentionally blank)

DEVELOPMENT OF BIOSUTURE BASED ON NANO CHITOSAN OLIGOSACCHARIDE-POLYLACTIC ACID-POLYCAPROLACTONE

Name of Student / NRP	: LIDYA NATASYA/5011201152
Departement	: Materials and Metallurgical Engineering
Advisor/NIP	: Yuli Setiyorini, S.T.,M.Phil.PhD.Eng./ 197907242005012003
Co-Advisor	: Azzah Dyah Pramata, S.T.,M.T.,M.Eng.,PhD./1992202012023

Abstract

The medical industry is an integral part of medical service delivery and can also be an economic sector associated with the development, production, and distribution of equipment, devices, drugs, and health services used in patient care and medical practice. The largest organ of the body and the one most often affected by surgery is the skin, which covers approximately 3,000 square inches and nearly one-sixth of an adult's total body weight. As the largest organ in the body, the skin serves as a physical barrier to protect the body from environmental elements that may be harmful to the integrity of body tissues. To overcome the healing problems that occur and provide a short recovery of suture wounds, the use of surgical thread material made of chitosan oligosaccharide and Polylactic Acid (PLA)/Polycaprolactone (PCL) is a viable option. Chitosan oligosaccharide is one of the materials that can optimize the healing process of suture wounds. This material is biodegradable and does not cause toxicity to the body. This study aims to develop surgical threads based on Nano Chitosan Oligosaccharide (COS), Polylactic Acid (PLA), and Polycaprolactone (PCL) using extrusion technique. The resulting surgical thread was tested to determine its properties and morphology through Fourier Transform Infrared Spectroscopy (FTIR) testing, tensile test, soaking test, and morphology analysis using Scanning Electron Microscope (SEM). The tensile test results showed that the addition of Nano COS exceeding 10% tends to decrease the tensile strength of surgical threads, as seen in variation C05. In contrast, the PLA-dominated C01 variation showed the greatest tensile strength of 16.88 MPa. The soaking test revealed that the surgical thread swelled with the highest swelling ratio in sample C01 at 25.80 ± 16.16%. The results of morphological analysis showed that the surgical thread underwent significant changes in surface structure after the 16-day soaking test, with PLA material degrading faster than PCL. This study indicates that the combination of PLA, PCL, and Nano COS produces surgical threads with an optimal balance between mechanical strength, flexibility, controlled biodegradation, and antimicrobial properties.

Keywords: Nano Chitosan Oligosaccharide, Polylactic Acid, Polycaprolactione, Surgical suture.

(*This page is intentionally blank)*

PENGEMBANGAN *BIOSUTURE* BERBASIS NANO KITOSAN OLIGOSAKARIDA-ASAM POLILAKTAT- POLIKAPROLAKTON

Nama Mahasiswa / NRP **: LIDYA NATASYA/5011201152**
Departemen : Materials and Metallurgical Engineering
Pembimbing/NIP : Yuli Setiyorini, S.T.,M.Phil.PhD.Eng./197907242005012003
Wakil Pembimbing : Azzah Dyah Pramata, S.T.,M.T.,M.Eng.,PhD./1992202012023

Abstrak

Industri medis merupakan bagian integral dari pemberian layanan medis dan juga dapat menjadi sektor ekonomi yang terkait dengan pengembangan, produksi, dan distribusi peralatan, perangkat, obat-obatan, dan layanan kesehatan yang digunakan dalam perawatan pasien dan praktik medis. Organ tubuh terbesar dan yang paling sering terkena dampak pembedahan adalah kulit, yang mencakup sekitar 3.000 inci persegi dan hampir seperenam dari total berat badan orang dewasa. Sebagai organ terbesar dalam tubuh, kulit berfungsi sebagai penghalang fisik untuk melindungi tubuh dari unsur-unsur lingkungan yang mungkin berbahaya bagi integritas jaringan tubuh. Untuk mengatasi masalah penyembuhan yang terjadi dan memberikan pemulihan yang singkat pada luka jahitan, penggunaan material benang bedah yang terbuat dari kitosan oligosakarida dan Polylactic Acid (PLA)/Polycaprolactone (PCL) menjadi pilihan yang tepat. Kitosan oligosakarida ini merupakan salah satu bahan yang dapat mengoptimalkan proses penyembuhan pada luka jahitan. Material ini bersifat biodegradable dan tidak menimbulkan toksisitas pada tubuh. Penelitian ini bertujuan untuk mengembangkan benang bedah berbahan dasar Nano Chitosan Oligosaccharide (COS), Polylactic Acid (PLA), dan Polycaprolactone (PCL) dengan menggunakan teknik ekstrusi. Benang bedah yang dihasilkan diuji untuk menentukan sifat dan morfologinya melalui pengujian Fourier Transform Infrared Spectroscopy (FTIR), uji tarik, uji perendaman, dan analisis morfologi menggunakan Scanning Electron Microscope (SEM). Hasil uji tarik menunjukkan bahwa penambahan Nano COS yang melebihi 10% cenderung menurunkan kekuatan tarik benang bedah, seperti yang terlihat pada variasi C05. Sebaliknya, variasi C01 yang didominasi oleh PLA menunjukkan kekuatan tarik terbesar sebesar 16.88 MPa. Uji perendaman mengungkapkan bahwa benang bedah mengalami pembengkakan dengan rasio pembengkakan tertinggi pada sampel C01 sebesar 25.80 ± 16.16%. Hasil analisis morfologi menunjukkan bahwa benang bedah mengalami perubahan struktur permukaan yang signifikan setelah uji perendaman selama 16 hari, dengan degradasi material PLA lebih cepat dibandingkan PCL. Penelitian ini mengindikasikan bahwa kombinasi PLA, PCL, dan Nano COS menghasilkan benang bedah dengan keseimbangan optimal antara kekuatan mekanik, fleksibilitas, biodegradasi terkontrol, dan sifat antimikroba.

Kata Kunci: Asam Polilaktat, Benang Bedah, Nano Kitosan Oligosakarida, Polikaprolakton.

(*This page is intentionally blank)*

FOREWORD

Praise to God Almighty for His mercy and grace, so that the author can complete the seminar proposal entitled “Development of Biosuture Based on Nano Chitosan Oligosaccharide-Polylactic Acid-Polycaprolactone”. During the preparation, the author would like to thank various parties who have helped and provided support to the author, among them are:

1. Mrs. Yuli Setiyorini, S.T., M.Phil., Ph.D.Eng., and Mrs. Azzah Dyah Pramata, S.T., M.T., M.Eng., Ph.D., as the supervisors who has devoted all the time, energy, and thoughts to guide the author in this research, as well as providing constructive motivation.
2. Sir Sigit Tri Wicaksono, S.Si., M.Si., Ph.D. as Head of the Department of Materials Engineering and Metallurgy FTIRS-ITS and Academic Advisor.
3. The author’s parents who never stop praying and providing support to the author.
4. Other parties who contributed to the author’s Final Project that the author has not been able to mention one by one..

The author realizes that the writing of this report is far from perfection. Therefore, the author expects constructive criticism and suggestions from readers. Hopefully this report can be useful for the author and all related parties.

Surabaya, 29 July 2024
Author

Lidya Natasya

(*This page is intentionally blank*

TABLE OF CONTENT

LIST OF FIGURES

(This page is intentionally blank)

LIST OF TABLE

(*This page is intentionally blank*)

CHAPTER I
INTRODUCTION

1.1 Background

Surgical sutures are one of the three major categories of wound closure biomaterials, alongside staplers or ligating clips and tissue adhesives. Among these, sutures have the longest history, are the most widely used, and have received the most attention. A suture is a strand of fibrous material used to ligate blood vessels and approximate tissues together, often applied with a metallic needle to sew tissues. Suture materials are the earliest and most frequently used textile materials for wound closure. They have been an essential tool in surgery for thousands of years, with their development paralleling advancements in medical technology and surgical practices (Chu, 2019).

The skin is the largest organ in the body, covering its entire external surface. The skin has 3 layers—the epidermis, dermis, and hypodermis, which have different anatomical structures and function. The skin's structure comprises an intricate network that serves as the body's initial barrier against pathogens, ultraviolet (UV) light, chemicals, and mechanical injury. This organ also regulates temperature and the amount of water released into the environment.. When the skin is injured, surgical sutures become essential for stitching and repairing damaged tissue. Sutures have evolved from natural materials like silk and catgut in the 19th century to modern synthetic polymers. Nonetheless, the search for the ideal suture material biocompatible, easy to use, and supportive of optimal healing—continues (Hani et al., 2019).

Sutures are considered the gold standard for most surgical closures and repairs, such as approximating tissues or attaching prostheses. The success of a suture depends on the material's behavior in a biological environment, which is influenced by its intrinsic mechanical properties and chemical composition. The ideal suture material should exhibit favorable handling characteristics (strength and flexibility) and superior biological properties (biocompatibility and resorption capacity). It should be accepted by the patient's body without causing rejection or chronic inflammation, resist infection, and be integrated and remodeled by the patient’s tissues.(Borchiellini et al., 2023).

The polymers that will be used in this study are Poly(lactic acid) (PLA), Polycaprolactone (PCL), and chitosan oligosaccharide(COS). Chitosan has been used as a wound dressing material due to its superior tissue- or mucoadhesive property, hemostatic activity, low toxicity, relevant biodegradability and anti-infection activity (Kong et al., 2019).

In recent years, PLA and PCL have been extensively explored for biomedical applications due to their promising characteristics, such as biodegradability and biocompatibility, which have been recognized by the United States Food and Drug Administration (Guo & DiPietro, 2019). PLA is a thermoplastic material derived from naturally existing biomass like corn, potatoes, sugar beets, and sugar cane, which are fermented with glucose to produce PLA. Its high potential is attributed to its superior properties, including good mechanical strength and modulus, ease of processing, and excellent degradability ((Atnurkar et al., 2023). However, PLA exhibits poor wettability but demonstrates accelerated biodegradation rates compared to PCL. Incorporating PCL serves to adjust the desired characteristics. Blending PLA and PCL is a preferred strategy for modulating degradation kinetics and other essential attributes (Łysik et al., 2022). PCL features notable elongation at break and controlled release capabilities, although it has prolonged degradation timelines extending up to four year (Liu et al., 2020). The PLA-PCL composite is sought after to achieve an optimal synergy of biomedical and mechanical properties (Vieira et al., 2021), garnering substantial consideration for tissue engineering applications. PLA contributes superior mechanical robustness, while PCL enhances strain tolerance, promotes increased permeability, and mitigates degradation rates (Hou & Qu, 2019).

The combination of PLA, PCL, and Chitosan for surgical threads offers significant potential advantages over commercial surgical threads. The combination provides high mechanical strength and flexibility, reducing discomfort and improving compliance with body tissue movement. Controlled biodegradability allows the surgical thread to remain strong during the healing process and degrade gradually after the tissue has healed, unlike some commercial threads that may degrade too quickly or too slowly. The natural antimicrobial properties of Chitosan help reduce the risk of post-operative infection without the need for additional treatment (Li et al., 2020).

This synergy not only improves wound healing outcomes but also minimizes the risk of infection and adverse reactions, making PLA/PCL/Nano COS sutures a valuable option in modern surgical practices.

1.2 Problems

Based on the existing background, the problem formulation in this study is as follows: What is the effect of PLA/PCL/CS ratio to the the mechanical properties and morphology of the biosuture material?

1.3 Limitation aspects

Due to not all condition become parameters during the research activity, the set-up of limitation become as consideration such as;

1. Effect of extruder pressure on surgical sutures
2. Effect of dichloromethane on the porosity of surgical sutures leading to increased fragility

1.4 Research Objectives

Due to achieve the goal of research activities, several objective divided into several purposes:
Understanding the correlation about effect of ratio PLA/PCL/CS as biosuture to the properties and morphology

1.5 Benefits - Contribute

This study aims to investigate the characteristics of suture material made from nano COS/PLA/PCL. The findings from this research are anticipated to significantly contribute to the development of advanced suture materials, particularly in enhancing the healing process and minimizing the risk of skin infections. The insights gained will be instrumental in guiding future studies focused on optimizing suture thread performance using nano COS/PLA/PCL composites.

CHAPTER II
LITERATURE STUDY

2.1 Skin

As the largest organ in the body, the skin serves as a physical barrier to protect the body from environmental elements that may be harmful to the integrity of the body's tissues. This intricate organ consists of multiple layers and cells that are constantly under attack from various external sources, including UV rays, injuries and harmful infections. Wound healing is a complex and well-coordinated process to restore tissue form and function following damage to the skin. The intricate process of wound healing can be hampered by age, wound location and lifestyle choices. Various external causes can injure the skin and result in various forms of wounds, including toxins, irritants, corrosive materials, heat, dryness, UV radiation and pathogen invasion. Healing of skin wounds begins soon after the injury occurs. However, the age of the patient, the location of the wound, the composition of the skin, and the amount of tissue that has been damaged can have an impact on this process. Wound healing in human skin typically takes 10-12 days, longer than other creatures including rodents, non-human primates, and domestic animals (León-Sosa et al., 2022).

2.1.1 Skin Structure

The skin consists of three layers are the subcutis, dermis and epidermis. The deepest layer is the subcutis (hypodermis, subcutaneous fat) which is adipose tissue that helps to cushion and protect the body. This layer serves as energy storage and allows for skin mobility in the underlying structures.

The dermis is the largest structure of the skin. The main component of the dermis is the extracellular matrix which attracts and retains water due to the hygroscopic molecules, proteoglycans. The dermis is traversed by nerves, blood vessels and includes hair, sweat glands and sebaceous glands. The dermis contains various types of cells such as fibroblasts, macrophages, mast cells and immune system cells. The epidermis is a multilevel structure that continuously renews itself, mostly composed of keratinocytes which account for at least 80% of the total cells. Therefore, the nature and function of keratinocytes reveal the condition of the epidermis. Stratum basale is the lowest layer of the epidermis. The basal cell layer protects the epidermis by continuously renewing its cells. Stratum spinosum is the second-lowest layer of the basal cell layer that contains prickle cells. Prickle cells are polyhedral with round nuclei and are the result of division of basal cells that move upwards and are interconnected with desmosomes. The granulosum layer consists of keratohyaline granules in the cells. In this layer, the cells are flat and non-nucleated. The most superficial layer, the stratum corneum, provides mechanical protection to the skin and prevents transepidermal water loss (TEWL). (Kinanoro, 2021).

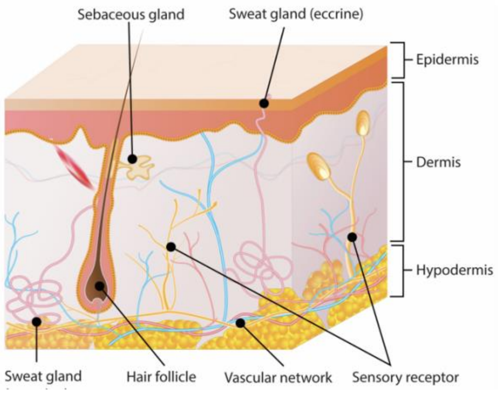


Figure 2.1 Skin Structure (Macedo et al., 2021)

2.1.2 Skin Problem that need Surgical Suture Threrapeutic

A wound is a condition commonly encountered in daily life, characterized by damage to the protective function of the skin and loss of epithelial tissue continuity, which may be accompanied by damage to other tissues such as muscles, bones, and nerves, caused by various factors such as ;

a. Friction and shear forces

These are factors contributing to ischemic wounds (Suriadi, 2020). This typically occurs when a patient slides on the bed, leading to stretching and pressure on the skin, resulting in ischemia in the tissues.

b. Incisions or surgical procedures

A wound is a disruption or damage to the integrity of skin tissue (Arisanty, 2019). Wounds also involve damage to the structure, function, and normal appearance of the skin.

2.2 The Surgical Suture

The use of surgical suture is one of the main techniques for wound closure. Surgical suture is a strand of material used to bind exposed tissue and blood vessels. Wound closure using suture thread and needles has been used for several thousand years. Surgical thread has several functions. One of the most important functions is to cover the wound edges. It holds the tissue together and brings the opposing edges of the wound closer together. The use of surgical thread can also help in the process of hemostasis. When the flap has been accessed, sewing it back into position helps to stop the bleeding (Kum Bora & Mayur Choudhury, 2021). An ideal suture should have high tensile strength, elasticity, capillarity, non-toxic properties, not cause significant tissue reactions, and be economically affordable. The surgical thread of surgery is determined by several things, namely:

1. The body's ability to absorb
2. The type of polymer material used
3. Filament arrangement

Materials that have been widely used in medicine are threads that can be absorbed through enzymatic fluids in the body. Meanwhile, threads that cannot be absorbed by the body are generally made of materials that do not cause a reaction by the tissue. Threads that cannot be absorbed will remain in the body's tissues and are usually used in tissues that are difficult to heal. If infection occurs, a new fistel will form and can heal after the foreign thread is removed. (Sjamsuhidayat, 2021). Thread size can affect suture strength. Therefore, it is important to consider the thread size for suturing surgical wounds depending on what tissue is being sutured.

Meanwhile, the suture strength is affected by the number, spacing of sutures, and type of thread used. Below is a table of ideal surgical thread sizes based on the suture location:

Table 2.1 Surgical Suture Sizes (Sjamsuhidayat, 2021).

Suturing locations	Size (USP)
Fascia	2-0
Muscle	3-0
Skin	2-0 until 6-0
Fat	2-0 until 6-0
Liver	2-0 until3-0
Kidney	4-0
Pancreas	3-0
Small intestine	2-0 until 3-0
Large intestine	4,0
Tendon	5-0 until 3-0
Joint capsule	3-0 until 2-0
Peritoneum	3-0 until 2-0
Microsurgery	7-0 until 11-0

Surgical threads can be categorized into two types:

1. Monofilament

Monofilament suture is a single strand structure with a small microbial contact area, which can effectively reduce the possibility of bacterial growth. When using a monofilament suture to close a wound, multiple knots are required. In addition, only a low knotting force can be used, otherwise it is easy to break. Its advantages are that the surface is smooth and relatively easy to be knotted. Moreover, there is less resistance when passing through the tissue, which is less damaged to the tissue. Therefore, monofilament sutures are suitable for suturing contaminated wounds (Pillai & Sharma, 2019). Current manufacturing techniques for the production of pharmaceutical elution sutures include these methods:

a) Extrusion method

Extrusion refers to a process by which dry or semi-moist ingredients with varying in-barrel moisture are forced through varying barrel temperature, screw speed and screw configuration through a die opening of the desired cross section. In other words, extrusion is predominantlya thermos-mechanical processing operation that combines several unit operations, including mixing, coating, kneading, venting, shearing, heating, forming, partial drying or puffing, depending on the material andequipment used (Singh et al., 2019).

b) Electrospinning

Electrospinning is widely used to prepare nanofibers. The above parts are organized together to manipulate the interactions between the electrostatic energy and the working fluids. Its working principle is that under a constant high-voltage power field, the syringe equipped with a polymer solution is placed in the field, and the nozzle of the syringe is subject to the action of the high-voltage electric field, pushing the solution to be continuously spun. During the working process, when the applied high voltage is enough to overcome the surface tension of the solution at the nozzle, the so-called “Taylor cone” will be formed at the tip of the needle, and the voltage will be continuously increased. When the electric field is large enough, the solution can be sprayed in the form of a trickle, and the solution continues to evaporate the solvents and solidify during the spraying process. Finally, a nonwoven fabric-like fibrous web is deposited on the collector (Xu et al., 2022a)

Table 2.2 Disadvantages and advantages of monofilament yarns

Advantages	Disadvantages
Minimal reaction to tissue	Low node strength
Makes it easy to make knots on the body	Less flexible

2. Multifilament

This type of yarn combines more than one polymer to create a braided yarn. It has a rough surface which causes the tissue to pull higher. What can be done is to apply lubricant so that the tissue fibers decrease and possibly give a better knot result.

Table 2.3 Disadvantages and advantages of mulitifilament

Advantages	Disadvantages
Has high flexibility	Rough surface
High knot strength	May harbor bacteria

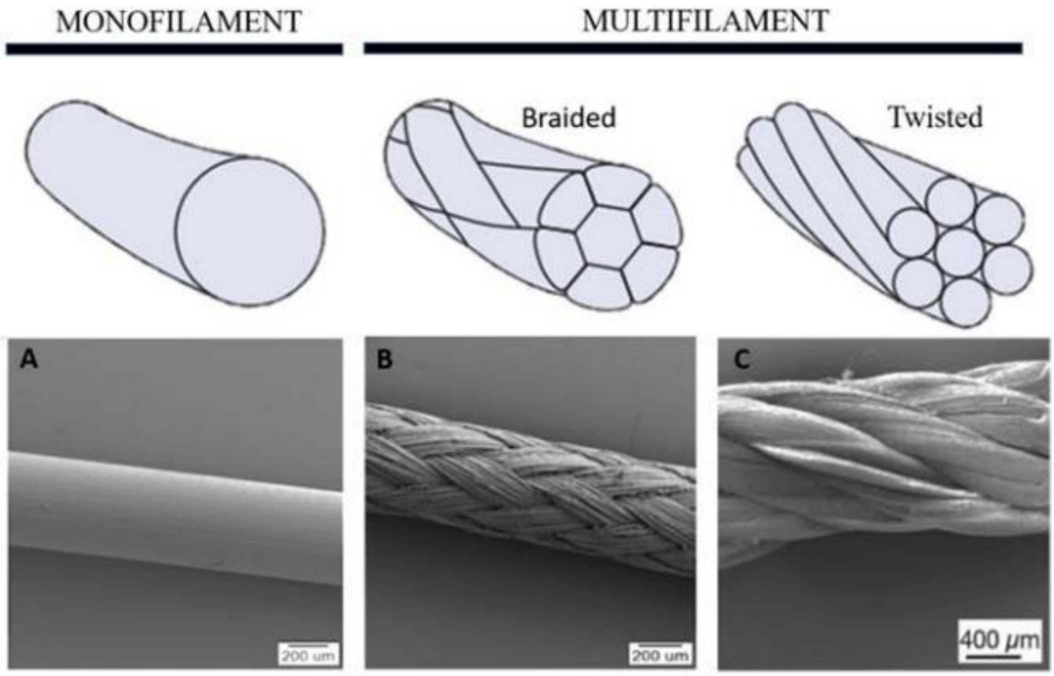


Figure 2.2 Structure of monofilament and multifilament sutures. SEM micrographs of (A) monofilament PDO suture, (B) braided PGA suture, and (C) twisted PDO suture. (Sabu Thomas, 2023)

2.2.1 The Surgical Wound Healing Process Skin

Hemostasis, inflammation, proliferation, and tissue remodeling or resolution are the four highly interwoven and overlapping phases of the wound-healing process (Guo & DiPietro, 2010). The immediate response to surgical injury is vasoconstriction of blood vessels at the point of injury. Vasoconstriction reduces the volume of blood flow, which is part of the blood clotting mechanism to limit blood loss. Blood flows into the gap created by the cutting tool, fills the space, and coagulates, bringing the wound edges together. Wound healing begins with an inflammatory process. Inflammation brings nutrients to the surgical area, removes debris and bacteria, and provides stimulation for wound repair. 9,10 Immediately after injury, changes in vascular fluid and cells occur in the area adjacent to the injury site. Repair processes begin immediately after surgery and are rapid. These processes are epithelialization and fibroplasia, which also involve capillary proliferation to the healing area. 14 Epithelial migration and proliferation are the first signs of wound repair. In general, the epidermal response to trauma includes mobilization of basal cells from dermal attachments, migration of cells to cell-deficient sites, proliferation through mitosis of pre-existing cells, and differentiation to restore cellular function in new cells. For a wound to heal, all four phases must occur in the correct order and timeframe(Guo & DiPietro, 2010).

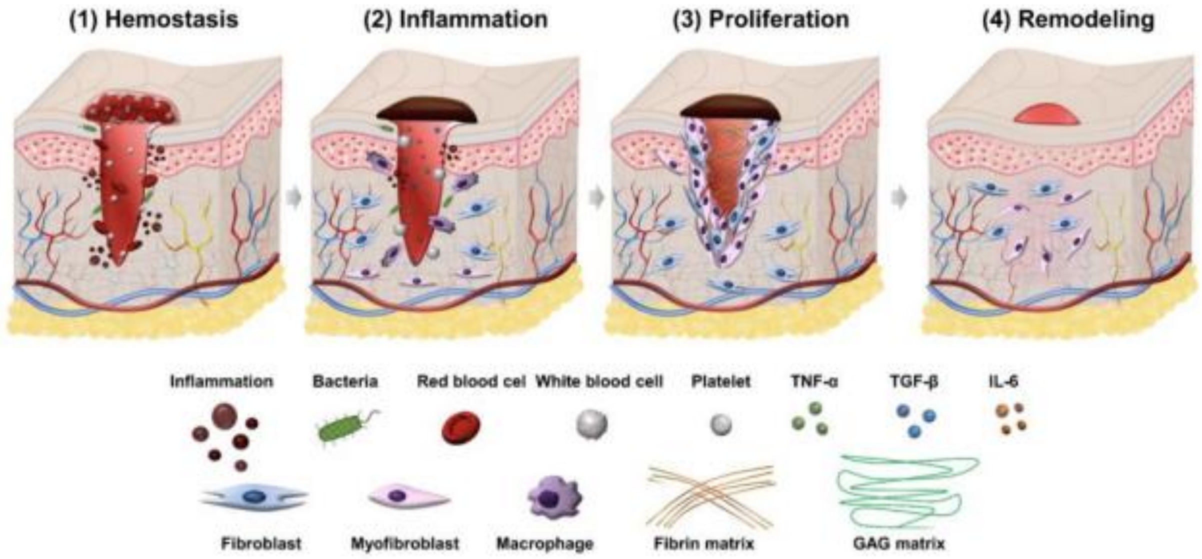


Figure 2.3 Wound healing process (Trinh et al., 2022).

a. Hemostasis & Coagulation Phase

After an injury, hemostasis and coagulation mechanisms activate to prevent excessive bleeding. These processes involve the formation of a fibrin clot that stabilizes the vascular structure and reduces blood loss (Broughton et al., 2006). Initially, damaged blood vessels constrict due to reflex mechanisms involving smooth muscle contraction, temporarily reducing blood flow, but this effect diminishes as hypoxia and acidosis in the wound area relax smooth muscle tone (Pool, 1977). Platelets become activated upon contact with exposed collagen, triggering the release of clotting factors and the formation of a blood clot composed of fibrin and other proteins (Pool, 1977). This clot not only stops bleeding but also serves as a scaffold for cell migration during later stages of healing. Furthermore, platelets release growth factors and cytokines that attract neutrophils, macrophages, endothelial cells, and fibroblasts to the wound site, initiating the inflammatory response crucial for clearing debris and starting tissue repair (Lawrence, 1998). Additionally, vasoactive substances like serotonin from platelets contribute to vasodilation and increased vascular permeability, leading to edema, while eicosanoids and other products from arachidonic acid metabolism play roles in the inflammatory response by influencing immune cell activity and vasodilation (Toy, 2005)

b. Inflammation Phase

Early Inflammatory Phase

During the later stages of coagulation, the early inflammatory response plays several crucial roles. It initiates the complement cascade and triggers molecular events that lead to the infiltration of neutrophils into the wound site, whose primary role is to prevent infection (Broughton, 2006). Neutrophils initially engage in phagocytosis to eliminate bacteria, foreign particles, and damaged tissue, which is essential for subsequent healing processes, particularly in cases of acute wounds with bacterial imbalance (Robson, 2001).

Neutrophils are attracted to the wound site within 24-36 hours after injury by various chemotactic agents, including TGF-, complement components such as C3a and C5a, and formylmethionyl peptides produced by bacteria and platelet products (Robson, 2001). They undergo changes in surface adhesion molecules, becoming sticky and marginating to the endothelial cells in the post-capillary venules surrounding the wound (Lawrence, 1998). Subsequently, neutrophils roll along the endothelial surface propelled by blood flow. These interactions are mediated by selectin-dependent adhesion and are considered weak attachments. Endothelial cell-derived chemokines quickly activate a stronger adhesion system mediated by integrins. Neutrophils cease rolling and migrate out of the venules, squeezing between endothelial cells through a process known as diapedesis. Their subsequent movement depends on chemokines and other chemotactic agents. Once in the wound environment, neutrophils phagocytose foreign material and bacteria, destroying them by releasing proteolytic enzymes and oxygen-derived free radicals (Skover GR, 1991).

Neutrophil activity gradually diminishes over several days as microbial contaminants are cleared (Skover GR, 1991). Upon completing their task, neutrophils need to be cleared from the wound before progressing to the next stage of healing. Excess cells are removed via extrusion onto the wound surface as pus and through apoptosis, facilitating the elimination of the entire neutrophil population without tissue damage or exacerbating the inflammatory response (Hart J, 2002). The remaining cellular debris and apoptotic bodies are then phagocytosed by macrophages (Robson, 2001).

Late Inflammatory

During the late inflammatory stage, typically 48-72 hours after injury, macrophages appear at the wound site and continue the process of phagocytosis (Hart, 2002). These cells originate as blood monocytes that undergo phenotypic changes upon entering the wound, transforming into tissue macrophages. Attracted by a variety of chemotactic agents including clotting factors, complement components, cytokines such as PDGF, TGF-, leukotriene B4, platelet-derived growth factor IV, as well as breakdown products of elastin and collagen, macrophages have a longer lifespan than neutrophils and operate effectively in an acidic environment (Rumasastry, 2005).

Macrophages are crucial for the later stages of the inflammatory response, acting as key regulatory cells and providing a rich source of potent tissue growth factors, particularly TGF-, along with other mediators (TGF-, heparin-binding epidermal growth factor, fibroblast growth factor [FGF], collagenase). They stimulate the activity of keratinocytes, fibroblasts, and endothelial cells. Depletion of monocytes and macrophages from the wound leads to significant healing disruptions due to poor wound debridement, delayed fibroblast proliferation and function, as well as delayed angiogenesis, resulting in inadequate fibrosis and poorly healed wounds (Broughton, 2006).

Lymphocytes are the final cells to arrive at the wound site during the late inflammatory stage, typically drawn in around 72 hours after injury by interleukin-1 (IL-1), complement components, and breakdown products of immunoglobulin G (IgG). IL-1 plays a crucial role in collagen regulation, which is essential for collagen remodeling, the production of extracellular matrix components, and their breakdown (Hart, n.d.)

c. Proliferation Phase

Progressing harm has ceased, hemostasis has been accomplished and an immune response effectively set in put, the intense wound shifts toward tissue repair. The proliferative stage begins on the third day after injuring and endures for almost 2 weeks from there on. It is characterized by fibroblast movement and testimony of recently synthesized extracellular lattice, acting as a substitution for the temporary organize composed of fibrin and fibronectin. At the plainly visible level, this stage of wound recuperating can be seen as an inexhaustible arrangement of granulation tissue. The different forms that take put within the proliferative stage are briefly talked about below (Landén et al., 2016)

Fibroblast Migration

After damage, fibroblasts and myofibroblasts within the encompassing tissue are stimulated to multiply for the primary 3 days. They at that point relocate into the wound, being pulled in by components such as TGF-and PDGF, that are discharged by inflammatory cells and platelets. Fibroblasts to begin with show up within the wound on the third day after injury and their amassing requires phenotypic balance. Once within the wound, they multiply lavishly and create the network proteins hyaluronan, fibronectin, proteoglycans and sort 1 and sort 3 procollagen. All of their items are stored within the neighborhood milieu (Ramasastry, 2020).

By the conclusion of the primary week, copious extracellular framework gathers, which assist bolsters cell relocation and is basic for the repair process. Presently, fibroblasts alter to their myofibroblast phenotype. At this organize, they contain thick actin bundles underneath the plasma film and effectively expand pseudopodia, connecting to fibronectin and collagen within the extracellular matrix (Ramasastry, 2020). Wound withdrawal, which is an important event within the reparative process that makes a difference to surmise the wound edges, at that point takes out as these cell expansions withdraw. Having finished this errand, repetitive fibroblasts are dispensed with by apoptosis (Greenhalgh, 2019).

Collagen Synthesis

Critical component in all stages of wound mending. Synthesized by fibroblasts, they confer keenness and quality to all tissues and play a key part, particularly within the proliferative and renovating stages of repair. Collagens act as a establishment for the intracellular network arrangement inside the wound. Unwounded dermis contains 80% sort 1 and 25% sort 3 collagen, though wound granulation tissue communicates 40% sort 3 collagen (Robson, 2021).

Angiogenesiss and Granulation Tissue Formation

Foundation of unused blood vessels is basic in wound recuperating and takes put concurrently amid all stages of the reparative handle. In expansion to pulling in neutrophils and macrophages, various angiogenic components emitted amid the hemostatic stage advance angiogenesis (Servold, 2022).

Endothelial cells in tissues respond to angiogenic factors like FGF, VEGF, PDGF, and others, balanced by inhibitors such as angiostatin and steroids. These factors stimulate endothelial cell mitosis, migration, and growth, crucial under hypoxic conditions. The process involves protease production, chemotaxis, proliferation, and remodeling. Initially lacking vascular supply, wound edges are perfused by intact vessels and interstitial diffusion. Capillary growth from edges into the wound clot forms a new microvascular network within days (Folkman, 2021), vital for ongoing tissue repair.

Chemotaxis is the ability of cells to move in response to chemical gradients, crucial for processes like angiogenesis during wound healing (Hsu, 2019). Key mediators such as endothelial growth factor, TGF-, VEGF, and others play vital roles in neovascularization and vessel repair at the injury site (Grotendorst, 2020). Cellular migration, driven by chemotactic signals, is essential for angiogenesis, involving coordinated changes in cytoskeletal organization, signal transduction, and cell adhesion regulated by vascular system cues.

Cell motility involves three main actions: protrusion at the cell front, attachment of the actin cytoskeleton to the substratum, and traction to propel the cell forward (Holly, 2023).

Protrusion

Three sorts of interconnected fibers, the cytoskeleton is tied down at cell–cell intersections and cell–extracellular framework attachments, giving mechanical bolster for the cell. The actin organize is well known for its energetic reorganization, it acts as a mechano-effector and it is vital for co ordinating cell relocation. Amid the primary step of movement, actin polymerization takes put at the driving edge, decided by the most noteworthy concentration of chemoattractive substance, pushing the plasma layer outward. A protruding structure shapes, within the case of the endothelial cell these are known as filopodia, and they are filled with filamentous actin. Unidirectional development of the cell is kept up through the activity of a cyclic get together and dismantling of actin fibers before and well behind the leading edge, respectively. Numerous flagging pathways and administrative proteins control actin flow and the changes of cell morphology (Li S, 2021).

Adhesion

Grip to a strong substratum may be a especially vital step in cell migration. It is interceded by integrins, which act as the essential receptors for extracellular lattice proteins and are thus required for cell motility. In expansion, these atoms are moreover included in flag transduction, and in directing and invigorating migration. Grip and relocation are contrarily relative; an ideal rate of relocation is accomplished with expanding grip, but portability is diminished with encourage attachment (Bokel C, 2018).

Endothelial cells can alter their attachment concentrated, with feebly cement cells moving speedier than profoundly cement ones. After connection to the extracellular network, the cell changes its morphology from an oval- or spindle-shape to an sporadic, straightened one. These modifications in shape are represented by integrin flagging and depend on integrin contacts with the extracellular network in central complexes, shaping at first at the closes of the filopodia. Endothelial cells move fastest immediately after harm, at that point they enter a slower movement rate, which is kept up amid the recuperating process (Herman, 2022).

Traction

Contractile powers, transmitted through the integrin–cytoskeletal associations, permit the cell to drag the cytoplasm forward by creating footing to the substratum (Li S, 2021). The drive for development is given by myosin engine proteins, connected to contractile actin bundles along the cell. Intuitive between myosin and actin strands drag the cell body advances. At the same time, the extracellular matrix-binding proteins on the trailing edge of the moving cell must discharge their connections (Bokel C, 2018).

The degree of quality of the integrin coupling to the cytoskeleton is impacted by the inflexibility of the substratum. With more grounded couplings to a firm surface, constrain can be transmitted through the relocating cell more efficiently (Bokel C, 2018). Amid movement, the footing powers produced at the locales of contact can be tall sufficient to misshape the extracellular lattice and to modify it significantly. The course of relocation requires introductory polarization of the cell and both physical and chemical jolts impact it, as has been talked about above (Dowsett C, 2020).

Macrophages, multiplying fibroblasts and vascularized stroma, beside collagen framework, fibrinogen, fibronectin and hyaluronic corrosive, constitute the intense granulation tissue that replaces the fibrin based temporary matrix (Baum, 2005). With collagen amassing, the thickness of the blood vessels lessens and the granulation tissue continuously develops to deliver a scar (Ganz T, 2018).

Epithelialization

Relocation of epithelial cells begins from the wound edges inside a couple of hours of injuring. A single layer of cells at first shapes over the deformity, went with by a checked increment in epithelial cell mitotic action around the wound edges. Cells moving over them join to the temporary network underneath. When the progressing epithelial cells meet, movement stops and the storm cellar layer begins to form (Hunt TK, 2019).

d. Remodellling Tissue

As the final stage of wound healing, the remodeling stage is crucial for the development of new epithelium and the formation of scar tissue (Rumasastry, 2021). This stage, which can last up to 1-2 years or longer, begins concurrently with the development of granulation tissue. During wound remodeling, there is a delicate balance maintained between collagen synthesis and degradation to achieve normal healing. Collagen bundles increase in diameter, while hyaluronic acid and fibronectin are degraded, gradually improving the flexibility of the wound as collagen accumulates (Baum et al., 2021).

The turnover of collagen and remodeling of the extracellular matrix occur continuously, reaching a steady state about three weeks after injury. Matrix metalloproteinases, produced by neutrophils, macrophages, and fibroblasts in the wound, are responsible for collagen degradation and are tightly regulated by inhibitory factors. Over time, tissue inhibitors of metalloproteinases increase, leading to a decrease in metalloproteinase activity and promoting new tissue formation (Clark, 2018).

Initially disorganized, collagen fibers become more organized and cross-linked over time, influenced by wound contraction initiated during the proliferative stage. This process brings wound edges closer together through fibroblast interaction with the extracellular matrix, regulated by factors such as PDGF, TGF-, and FGF (Clark, 2018). As healing progresses, the density of fibroblasts and macrophages decreases through apoptosis (Greenhalgh, 2019)Capillary growth ceases, blood flow diminishes, and metabolic activity in the wound area decreases, resulting in a fully matured scar with reduced cellularity, blood vessels, and increased tensile strength (O’Kane, 2019).

2.3 Potential Materials for Suture Surgical

Exploring potential materials for surgical sutures is essential in enhancing the efficacy and safety of surgical procedures. As the demand for biocompatible, durable, and multifunctional sutures increases, the development and characterization of new suture materials become crucial. This section discusses materials with the potential to revolutionize suture technology and their clinical application potential. Below are **Table 2.4** and **Table 2.5** of materials that are potentially suitable for surgical sutures.

Table 2.4 Absorbable Suture Materials (Xu et al., 2022b)

Natural Fibers	Synthetics	
	Monofilament	Multifilament
Surgical gut Plain (Chromic)	**Polydioxanone** (PDS; Ethicon) (PDS II; Ethicon) **Polyglyconate** (Maxon; Davis & Geck) **Poliglecaprone 25** (Monocryl; Ethicon) **Polylactic Acid** (Polysorb; Vicryl) **Polycaprolactone**	**Polyglycolid Acid** (Dexon; Davis & Geck) (Dexon II; Davis & Geck) **Polyglactin 910** (Vicryl; Ethicon)

	(Monomax; Caprolon)	

Table 2.5 Non-Absorbable Suture Materials

Natural Fibers	**Synthetics**	
	Monofilament	**Multifilament**
Silk (Mersilk; Ethicon)	**Nylon 66 and nylon 6** (Ethilon; Ethicon) (Dermalon; Davis & Geck)	**Polyester** (Mersilene; Ethicon)
	Polypropylene (Prolene; Ethicon)	**Nylon** (Surgilon; Davis & Geck) (Supramid; Bayer)
	Polybutester (Novafil; Davis & Geck)	

2.3.1 Polycaprolactone (PCL)

Polycaprolactone (PCL) is a unique biodegradable polymer in the aliphatic polyester class with hexanoate repeating units that has wide applications in the pharmaceutical and biomedical fields. PCL has gained importance due to its customizable mechanical properties, compatibility with a variety of other polymers and biocompatibility, good solubility, very low Tg, and semi-hardness at temperature. room temperature. The hydrophobic, semi-crystalline, and highly customizable nature of PCL has motivated researchers to focus on its potential biomedical and pharmaceutical applications. Two of its properties, namely molecular weight and degree of crystallinity, can be adjusted to obtain different physical, thermal and mechanical properties of PCL, which in turn can also be varied. Change the degree of decomposition by hydrolysis of esters or by enzymatic processes (Guarino, 2019).

PCL has been thoroughly researched in the development of controlled drug delivery systems. However, due to its very slow degradation (2 to 3 years), hydrophobicity, and lack of solubility, PCL is more suitable for the fields of tissue engineering/bone regeneration/tissue regeneration as implants or matrices. scaffold. The degradation/degradation properties of PCL have been modified by combining it with other polymers [e.g., polylactic acid (PLA), polylactic-co-glycolic acid (PLGA), and polyethylene glycol (PEG)]. improve its degradation reactivity through the introduction of amphiphilic structures. PCL is very influential to complement the shortcomings of PLA. Since PLA has brittle mechanical properties, PCL helps to reduce its brittleness because PCL has high flexibility and high tensile properties. In addition, the addition of PCL with PLA can also increase its crystallinity (Ulery,2011). Also from a regulatory perspective, PCL has positive signs with US FDA approval and European Community registration for its clinical application as part of drug delivery systems, medical devices, etc. PCL has gained great importance in the design of biomaterials/green materials with various compositions and properties in areas such as wound dressings, contraception and dentistry as well as in non-medical areas such as food, packaging and the environment (Estelle, 2020).

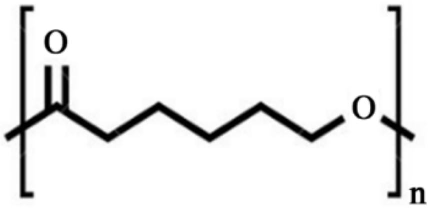


Figure 2.4 Structure of Polycaprolactone (PCL) (King et al., 2021)

2.3.2 Polylactid Acid (PLA)

Polylactic acid (PLA) is a thermoplastic aliphatic polyester that is biodegradable to heat, light, bacteria, as well as by hydrolysis process. In addition, PLA also has biocompatible properties, i.e. it can be degraded in the body without causing harmful effects. This polymer insoluble in water, but soluble in organic solvents such as chloroform and dichloromethane (Robani, 2019).

In general, PLA has a high melting point (around 175^{o}C) and can be synthesized into transparent film sheets. The physical properties of PLA are presented in **Table 2.6** The physical and mechanical properties of PLA can be reduced when it is blended with other polymers that have lower physical and mechanical properties (Lukmana, 2021).

Table 2.6 Physical properties of Polylactic Acid (PLA) (Lu & Chen, 2020)

Physical Properties	PLA
Glass transition temperature (^{o}C)	55-70
Melting Point (^{o}C)	130-215
Tensile Strength (MPa)	49
Elongation (%)	2,5
Density (g/cm^3)	1,25

The advantages of PLA compared to plastics made from petroleum are as follows:

1. Biodegradable, meaning that PLA can be broken down naturally in the environment by a microorganism.
2. Biocompatible, meaning that under normal conditions, this type of polymer can be accepted by biological cells or tissues.
3. Produced from renewable materials (including industrial residues) and not from petroleum.
4. 100% recyclable, in hydrolysis lactic acid can be obtained and reused for different applications or can be combined to produce other products (Botelho, 2020).
5. No use of organic or toxic solvents in producing PLA.
6. Can be burned completely and produce CO_2 and H_2O gas

PLA is an amalgamation of the best properties of natural and artificial materials. Because it is made from plant sugars, the materials it is made from are uses a renewable source and can be completely biodegraded. In addition, it also has the same properties as plastics made from hydrocarbons, which are strong, flexible and cheap. After environmentalists began to show concern about the dwindling fuel supplies and the disappearance of landfills, manufacturers have tried to develop alternative manufacturers have tried to develop some alternative materials as substitutes for ordinary plastics made from hydrocarbons.

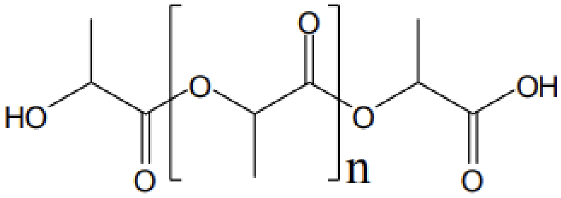


Figure 2.5 Structure of biopolymer Polylactic Acid (PLA)

2.4 Chitosan

Chitosan is produced by deacetylation of chitin; in this process, some N-acetylglucosamine moieties are converted into glucosamine units, (β1 → 4) residu terkait N-asetil-2 amino-2-deoksiD-glukosa (glukosamin, GlcN) dan residu 2-amino-2-deoksi-D-glukosa (N-asetil-glukosamin, GlcNAc) residu. The presence of large amounts of protonated -NH2 groups on the chitosan structure accounts for its solubility in acid aqueous media since it is pKa value is approximately 6.5. When around 50% of all amino groups are protonated, chitosan becomes soluble (Teguh, 2003). Chitosan and chitin have characteristics that include non-toxicity, biocompatibility, hygroscopicity, stability to heat and oxidation, and emulsification ability (Rinaudo, M.,2006).

Chitosan is the only polycation in nature and its charge density depends on the degree of acetylation and pH of the media. The solubility of the polymer depends on the acetylation degree and molecular weight. Chitosan samples with higher Mw are only soluble in acidic aqueous media even at high deacetylation degrees. This lack of solubility at neutral and basic pH has hindered the use of chitosan in some applications under neutral physiological conditions (i.e., pH 7.4). This is the reason why a great number of chitosan derivatives with enhanced solubility have been synthetized (Wang et al., 2020)

Table 2.7 Characteristics from Chitosan (Wang et al, 2020)

Films	Chitosan
Thickness (mm)	0,06
Water Solubility (%)	25,60
Water Activity	0,571
Tensile Strength (Mpa)	15,45
Elongation at Break (%)	7,83
Puncture Force (N)	7,17

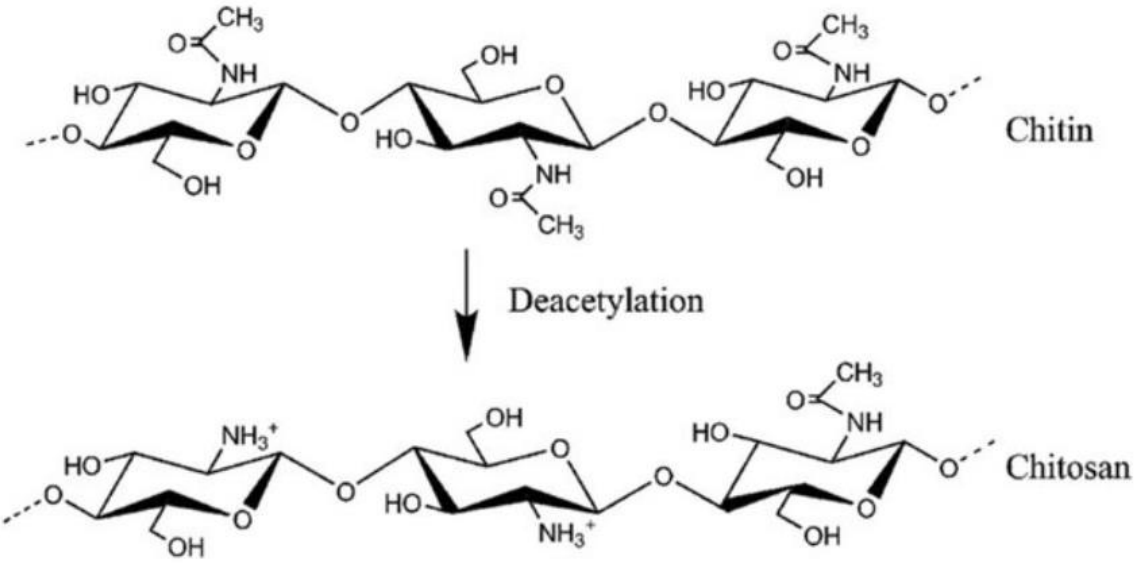


Figure 2.6 Chemical Structure of Chitin and Chitosan (Shahbaz et al., 2023)

2.4.1 Chitosan Oligosaccharide (COS)

Chitosan oligosaccharide (COS) is a hydrolysis product of chitosan composed of 2–10 D glucosamine (Kuo et al., 2021) COS can be produced by chemical and enzymatic hydrolysis. Chitosan Oligosaccharides have biological activities, some of which are antibacterial, stimulating, immunomodulatory, and anti-cance. Chitosan oligosaccharide (COS) is a chitosan-derived compound obtained by deacetylation of chitin and is a complex of the glycoprotein group with a 1,4 glucosamine linkage and has antibacterial properties, reducing the concentration of and has immunostimulating properties (Harti, 2021) Chitosan oligosaccharides have a structure similar to chitosan and possess good biocompatibility. They are non-toxic, non-allergenic, and harmless to the body. Shrimp waste, which constitutes 35% to 50% of its body weight, consists of the head, shell, legs, and tail. The protein content in shrimp shells ranges from 25% to 40%, chitin from 15% to 20%, and calcium carbonate from 45% to 50%. In crabs, the protein content ranges from 15.6% to 23.9%, calcium carbonate from 53.7% to 78.4%, and chitin from 18.7% to 32.2% (Mahatmanti et al., 2022). Due to its high crystallinity and strong hydrogen bonds, chitin, a natural polymer, is not easily soluble in water, acids, or organic solvents. As a result, it is very difficult to process on an industrial scale. Compared to chitosan, COS has higher water solubility and lower viscosity, making it easier to use (Muanprasat & Chatsudthipong, 2022).

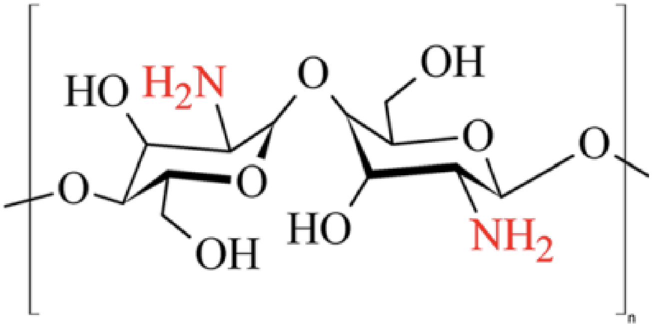


Figure 2.7 Chemical Structure of Chitosan Oligosaccharide (COS) (Abrica-González et al., 2019)

Although their chemical structure is similar to chitosan, they have a lower molecule weight (MW) and degree of polymerization (DP) than chitosan, making them soluble in water and at neutral pH. Generally, molecule weight (MW) and degree of polymerization (DP) below 10 kDa and 20, respectively, are considered as COS. However, those with a MW of 24 kDa and DP of 62 are still considered as COS due to their solubility in water. COS with lower DPs (DP 2-12) are of great interest due to their potential health benefits (Razi, 2022). COS are positively charged from the free amino group in the Glc unit, which allows them to bind to negatively charged molecules and promote biological applications. In addition, in **Figure 2.8**, COS have been produced by hydrolyzing chitosan using physical (microwave and ultrasonic treatments), biological (chitosanase and cellulose), and chemical (acid hydrolysis and oxidative degradation) methods (Yuan et al., 2019). COS with predetermined MW, DP, degree of acetylation (DA), and acetylation pattern (AP), are desirable due to their biological and physiological activities (Razi, 2022).

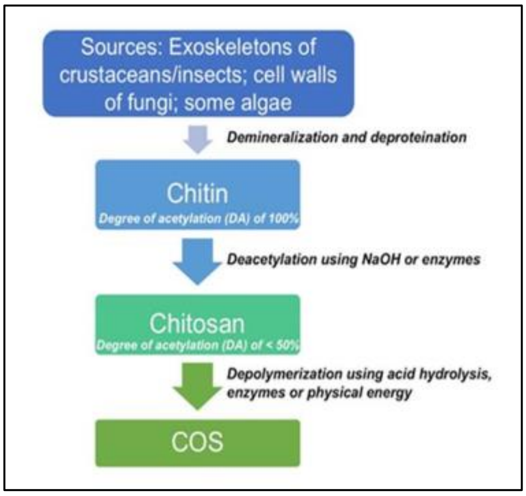


Figure 2.8 Method of making COS (Yuan et al., 2019)

Compared to chitosan, there are chitosan oligosaccharides that have the ability to dissolve completely in water and low viscosity. This is due to the shorter chain of chitosan oligosaccharide and the presence of free amine groups in the D-glucosamine unit. Chitosan oligosaccharide is obtained from the degradation process of O-glycosidic linkages of chitosan which results in the degree of polymerization such as the number of glucosamine and N-acetyl-D glucosamine units varying (Niu et al., 2020). Chitosan oligosaccharide is similar in structure to chitosan, has good biocompatibility, non-toxicity, and non-allergenic properties. Chitosan oligosaccharide consists of glucosamine units, 2 to 7 repetitions and connected by beta bonds (1-4) derived from the deacetylation and depolymerization process of chitosan. Figure 2.7 below is the polymer structure of chitin, chitosan, and chitosan oligosaccharides (Naveed et al., 2019). Chitosan also contains 5-8% nitrogen, which increases the number of primary amine and amide groups that make chitosan suitable for some amine and amide reactions. In addition, chitosan is also highly reactive in chemical reactions due to the presence of primary and secondary hydroxyl functional groups in each repeating unit, as well as amine functional groups in each deacetylene unit.

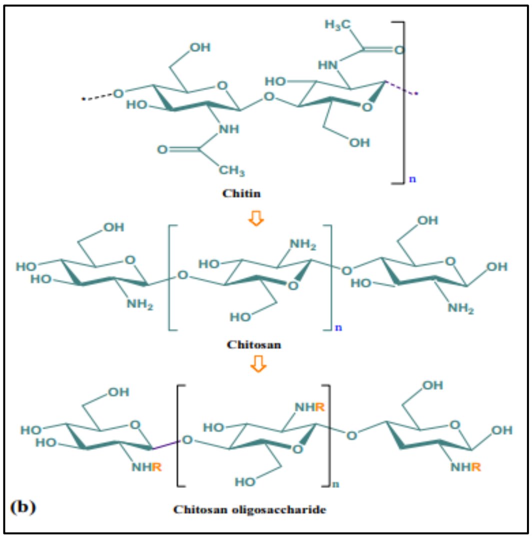


Figure 2.9 Structure of chitin, chitosan, and chitosan oligosaccharides (Naveed et al., 2019)

The functional groups present in chitosan have a very important role in each application. Based on FTIR analysis, there are several functional groups that are at certain wavelengths. The following will show the functional groups possessed by shrimp and crab chitosan (Konne, 2023).

Table 2.8 Chitosan functional groups in shrimp (Konne, 2023)

Shrimp Standard **(cm^{-1})**	**Functional Groups**
3423	(NH2) of amine primers
2923-2880	(OH) of pyranose ring
1667-1629	(CH2) of CH2OH
1422	(C-H) of pyranose ring
1382	(C=O) of NHCOCH3 (amide I band)
1322	(CH2) of CH2OH
1155	(CH3) of NHCOCH3 (gugus Amide)
897	(C-H) of pyranose ring vibrase gugus NHCO (Amide III band)
664	(C-O-C) glycosidic linkage

2.5 Glycerol

Glycerol is a neutral compound, with a sweet taste, colorless, viscous solution with a melting point of 20°C and has a high boiling point of 290°C solution with a melting point of

20^{o}C and has a high boiling point of 290^{o}C with the formula C3H8O3 (Katili et al., 2022). Glycerol, also called 1,2,3-propanetriol, is a viscous, colorless, and odorless liquid with 3 hydroxyl groups and has one -OH group (Fadliyani & Atun, 2021) One molecule of glycerol can bind one, two, or three fatty acid molecules to create esters. These esters are known as monoglycerides, diglycerides, and triglycerides. The glycerol esterification process is one of the most commonly used methods to create glycerol-derived products. The esterification reaction produces a variety of highly useful and higher-value esters. Since the products resulting from glycerol conversion are not derived from petroleum, the products resulting from this process are known as green and renewable chemistry (Hanum Hamzah et al., 2021).

Glycerol can be used as a crosslink agent by being a plasticizer where the addition of plasticizers makes the elasticity increase and weakens the stiffness of the polymer while increasing the flexibility and extensibility of polymers such as glycerol (because glycerol has the ability to reduce internal hydrogen bonds in intermolecular bonds) and other additives such as chitosan (because the hydrophobic nature of chitosan can reduce its hydrophilic properties) (Baskara et al., 2019).

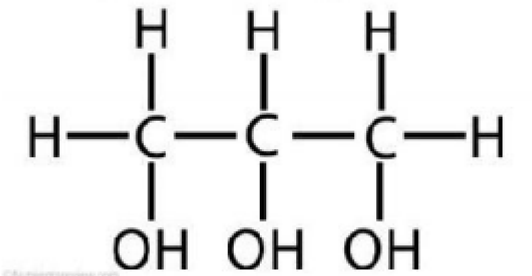


Figure 2.10 Structure of Glycerol (Lazar, 2019)

Glycerol can function as a crosslinking agent and plasticizer, enhancing the elasticity of polymers while reducing their stiffness and increasing flexibility and extensibility. This is achieved by glycerol's ability to disrupt internal hydrogen bonds within intermolecular bonds. Additionally, additives like chitosan can be included to further modify polymer properties; chitosan's hydrophobic nature reduces its hydrophilicity. By creating blends with chitosan fillers, the addition of glycerol plasticizer at varying concentrations alters the physical forms and colors of these blends (Melani et al., 2018).

Table 2.9 Variation of The Ratio of Glycerol (Solekah et al., 2021)

Ratio variation	Results
Chitosan : Glycerol 0,5 gr : 4 ml	The lowest swelling percentage was 21.46%
Chitosan : Glycerol 0,5 gr : 2 ml	The highest swelling and biodegradation percentages were 50.59% and 32.72%, respectively.
Chitosan : Glycerol 1,5 gr : 6 ml	Lowest biodegradable percentage 12.20%

2.6 Manufacture of Suture Surgical

In the surgical suture manufacturing industry, diverse methods such as extrusion and electrospinning have emerged as primary choices for producing suturing threads that meet stringent standards in terms of strength, smoothness, and biological compatibility. These methods underscore the significance of material technology innovation to fulfill the increasingly complex and precise requirements of modern surgical procedures.

a) Electrospinning

Electrospinning is a method or technique widely used for synthesizing nanofibers from polymer solution materials, facilitated by the application of electric charge. This process is favored for its ease, speed, and ability to produce continuous fibers (Subbiah et al., 2023). The straightforward technology known as electrospinning is employed to create fine fibers or continuous fiber materials with diameters in the nanometer range (Kumar Sharma & Rachel James, 2023).

The electrostatic force is utilized to stretch fibers from polymer solutions during electrospinning. Key components include an electric clamp, syringe pump, and static flat or circular collector. To generate a charged polymer jet, the polymer solution is placed in a reservoir and connected to a power source. A syringe needle or metal needle in the polymer solution is used to deposit the polymer solution via injection. The pump on the syringe is used to push the polymer solution and control the flow rate precisely. Applying high voltage to the solution is crucial in electrospinning, where the conductive plates in the collector are negatively charged. Generally, voltages exceeding 6 kV, whether positive or negative, cause the solution to move towards the needle tip and form a Taylor cone during the initial jet formation process (Kumar Sharma & Rachel James, 2023)

Electrospun fibers are termed nanofibers when their diameter is less than 500 nm. The production process involves incorporating particles into an electric spinning solution, mixing them to create nanofiber materials embedded with particles (Xue J et al., 2019). Successful formation of nanofibers using electrospinning methods has been demonstrated in several studies. The formation of the Taylor Cone at the spinneret tip during electrospinning is determined by selecting the appropriate viscosity of the polymer solution to achieve optimal nanofiber production. The formation of the Taylor Cone at the spinneret tip is illustrated in **Figure 2.11**

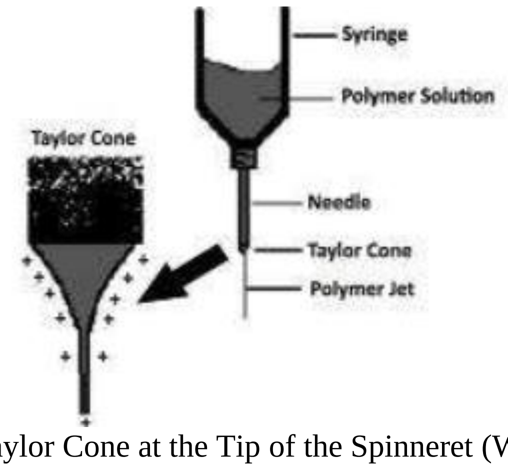


Figure 2.11 Formation of Taylor Cone at the Tip of the Spinneret (Wahyudi et al., 2019)

All electrospinning techniques, whether needle-based or needleless, are grounded in the same principle involving the application of a high electric field to polymer solutions, enabling fibers to form Taylor cones on the electrode (Xue J et al., 2019). The setups for needle-based and needleless electrospinning can be illustrated in **Figure 2.12**

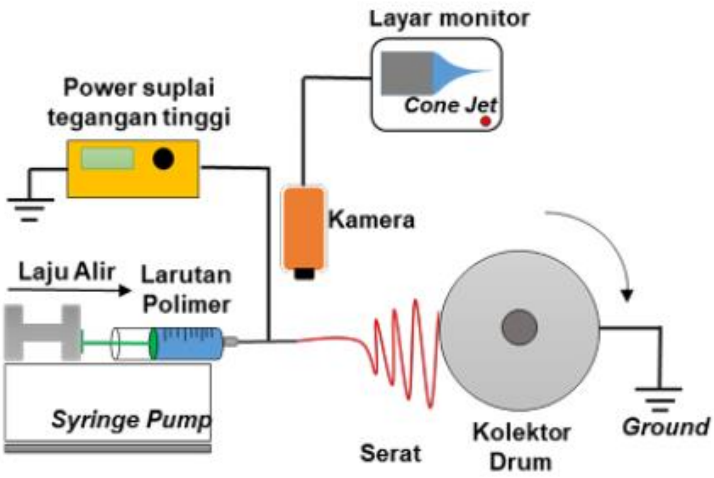


Figure 2.12 General Electrospinning Scheme (Saragih, 2019)

There are two ways to configure standard needle-based electrospinning systems: vertically or horizontally. Needleless electrospinning is categorized into two types: rotating and stationary spinning based on their operating conditions. The quality and productivity of fibers are significantly influenced by the spinner connected to the high voltage power supply and the dosing unit for the spinning solution. Nano fibers can be easily created with controlled and adjustable polymer solution reservoirs, such as a syringe with a small diameter (Zhang & Wang, 2022). Polymers are added to solvents when preparing for the needle-free electrospinning solution, which then dissolve and form the electrospinning polymer solution. Most of the polymers used to make nano fibers are dissolved in highly toxic organic solvents. The process is self-regulated, needleless electrospinning allows nano fibers to be electrospun directly from the open liquid surface. surface of during liquid rotation, thin layers of polymer solution form and rotate occur.

b) Extruder

Extrusion processing involves a combination of transport processes, including flow of materials within the virtually controlled environment system, thermal energy transfer to and within the material, and mass transfer to and within the material during extrusion. The basic structure of the extrudate is formed by transforming and manipulating natural biopolymers as they provide a fluid melt of polymers at high temperatures retain the gases released during the expansion process so as to form expanded foam structures. Puffing of the extrudate is due to the sudden evaporation of the pressurized steam at the die exit. There are generally two main energy inputs to the extrusion process, firstly the energy transferred from the rotation of the screws and secondly the energy transferred from the heaters through the barrel walls. The resulting thermal energy from both the sources causes an increase in the temperature of the material being extrude and subsequently there will be changes in the physical state, such as softening and/or melting of solid material to semisolid fluid (Singh et al., 2019), These are types of extruders:

1. Piston Extruders

   The simplest type, consisting of a single piston or a battery of pistons within a hollow cylinder that forces the material through a capped nozzle or die into a wide conveyor. Used for precise delivery of viscous, shear-sensitive materials, such as in the confectionery industry for depositing center fillings of chocolates, doughnuts, and cupcakes.

2. Roller Extruders

Consisting of two counter-rotating, independently driven drums with a narrow gap in between. The gap is precisely controlled by hydraulic or advanced closed-loop control systems. Used for sticky materials that do not require high-pressure forming, such as producing shaped crackers and hard cookies.

3. Screw Extruders

   The most complex type, using one, two, or multiple screws rotating in a stationary barrel to convey material forward through a product-specific die. Single-screw extruders have a grooved barrel to improve shear ratio and material flow. They are used with materials that have been either premixed or preconditioned.

Extrusion Process

1. Material Collection and Use

   Ingredients are collected and fed into the extruder through a holding bin and feeder, which can be adjusted.

2. Initial Processing

   A preconditioner is used to mix, add water, and cook the ingredients before they are fed into the extruder. This improves the quality and capacity of the extruder.

3. Extrusion Process

   The ingredients are fed into the extruder, where the screw rotates and heats the ingredients to high temperatures (over 150 °C). The resulting plasticized mixture is then forced through the die, causing the sudden reduction in pressure to result in puffing of the product.

4. Product Formation

   The product is cut using a cutter mounted in front of the die. The length and shape of the product can be adjusted by controlling the speed of the cutter and the clearance between the cutter and die.

5. Quality Control

   Product quality is controlled using both subjective and objective methods, such as visual inspection and physical measurements like density, expansion, and surface texture. (Singh et al., 2019)

For yarn manufacturing, the most suitable type of extruder is the screw extruder. Screw extruder is the most complex and commonly used type of extruder in the food industry to produce various products, including yarn. It utilizes one, two, or more screws that rotate in a fixed cylinder to transport materials through a corresponding die. Screw extruder has the ability to compress, agitate, and heat materials well, which is very suitable for yarn manufacturing processes that require high precision and control. A screw extruder finds common use in various extrusion processes, such as those employed in the food industry, injection molding, and plastic production, due to its uncomplicated design, effective management of product quality, and broad applicability (Ficarella et al., 2006). In recent times, this type of screw has also been adapted for use in extraction machines, albeit with some modifications while retaining the same fundamental operating principle. According to Karaj and Müller (2011), a single screw extruder can achieve an oil yield of approximately 89.4% from Jatropha seeds. This extruder features a rotating screw that operates within a barrel, as depicted in **Figure 2.13**

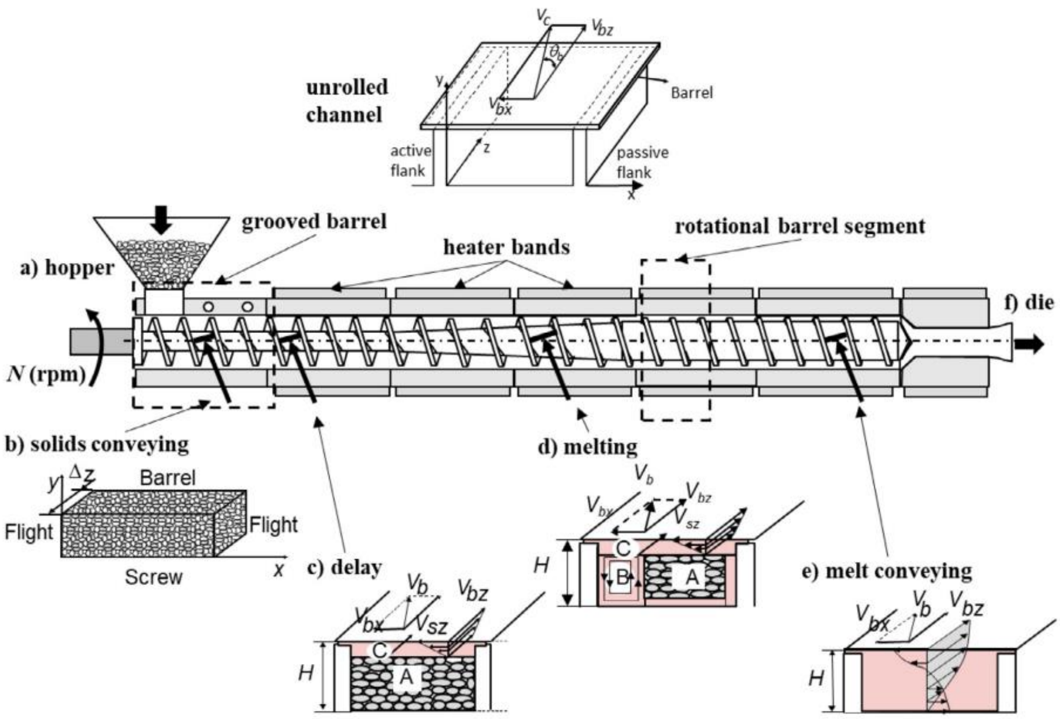


Figure 2.13 Single Screw Extruder (Gaspar-Cunha et al., 2022)

The use of an extruder is preferred over electrospinning for producing monofilament sutures due to its capability to efficiently produce continuous filaments with consistent diameter and mechanical properties. Unlike electrospinning, which involves the application of high-voltage electrostatic fields to draw and collect nanofibers from a polymer solution or melt, extrusion processes polymer materials through a die to form a uniform and smooth filament suitable for medical sutures. This method ensures reliable performance and quality in biomedical applications where uniformity and strength are critical factors.

2.7 Studies of suture surgical

2.7.1 In -Vitro

In-vitro can be defined as biological processes that are made to occur in a laboratory vessel or that are controlled in an experimental environment rather than in a living organism or natural setting. Subsequent efforts are focused on media and experimental conditions that allow continuous culture as well as the development of cell lines that will reveal the differentiation characteristics of tissue types (Mattes, 2020).

In the in-vitro biodegradation experiment, the prepared specimens were soaked in saline at 36oC for two months and then placed in a Thermal Robo. The surgical thread used was then dried at 36°C for 24 hours, and the precision weight was calculated. In vitro degradation was calculated by dividing the weight lost by the initial weight and testing the saline solution after soaking with FTIR and UV-Vis (Wu et al., 2021).

In vivo methods are used to study the wound healing process in living organisms. These methods involve creating a wound on the body's skin and treating the wound with different substances to observe the healing process. The healing process is observed daily and the organism is euthanized when healing is complete. The surface of wounds is examined in vivo using image analysis software for wound healing in rats. Rats are commonly used for in vivo wound healing studies due to their skin characteristics, rapid wound healing, ease of handling, genetic versatility, and cost-effectiveness (Grada et al., 2019)

Table 2.10 Use of test animals as research subjects (Taylor et al., 2008)

Animals	Methods	Review	Results
Rat	In-Vivo	Histology, Physiology	This research highlights the neural responses in muscle contusion.
Mice	In-Vivo and Ex-Vivo	Surgery, Pharmacology, Molecular	Pleiotropic role of tPA-encoding gene for the protection of communication network and improving the outcome functional outcome of the acute and chronic phases Traumatic Brain Injury (TBI).

2.8 Acetic Acid

Acetic acid, also known as ethanoic acid or vinegar, is an organic acid chemical compound that gives a sour taste and aroma to food. Concentrated acetic acid is a colorless hydroscopic liquid and has a freezing point of 16.7°C. Acetic acid has the chemical formula CH3COOH (Kuchel, Ralston, 2008).

Acetic acid is also a chemical reagent and one of the industrial raw materials. In the food industry, acetic acid is made into vinegar, one of which is made into kitchen vinegar (Sutresna, 2008). Kitchen vinegar solution has 25% acetic acid content which is diluted with water. Kitchen vinegar solution is commonly used as a complement to cooking and others. The main component in vinegar solution is acetic acid or also called ethanoic acid (Sutresna, 2008).

2.9 Preminary Research

The following are some research studies that use chitosan, PLA, and PCL for biosuture applications:

Table 2.11 Preliminary Research

Years	Researchers	Descpriptions	Results
2022	Tan et al.	Chitosan with a molecular weight of 1.2 × 10 6 g/mol and a deacetylation level of 85%	Production of fibers with exceptional properties in terms of mechanical strength and biocompatibility.
2020	Mohammadi et al.	Chitosan-coated nylon fiber	Increased growth rate of Vero cells on coated filaments as well as antibacterial activity of the coating.

2021	Prabha S.,et al.	Chitosan-coated filament	Significant reduction in biofilm formation.
2020	Goncharuk O., et al.	PEG Hydrogel and fibrin glue on sciatic nerve repair in rats	Restoration of damaged nerve microstructure as an adhesive, promoting rapid nerve regeneration, innervation of denervated muscles, and restoration of limb function.

CHAPTER III
METHODOLOGY

3.1 Flow Diagram

The following is a flow diagram used in the research as follows.

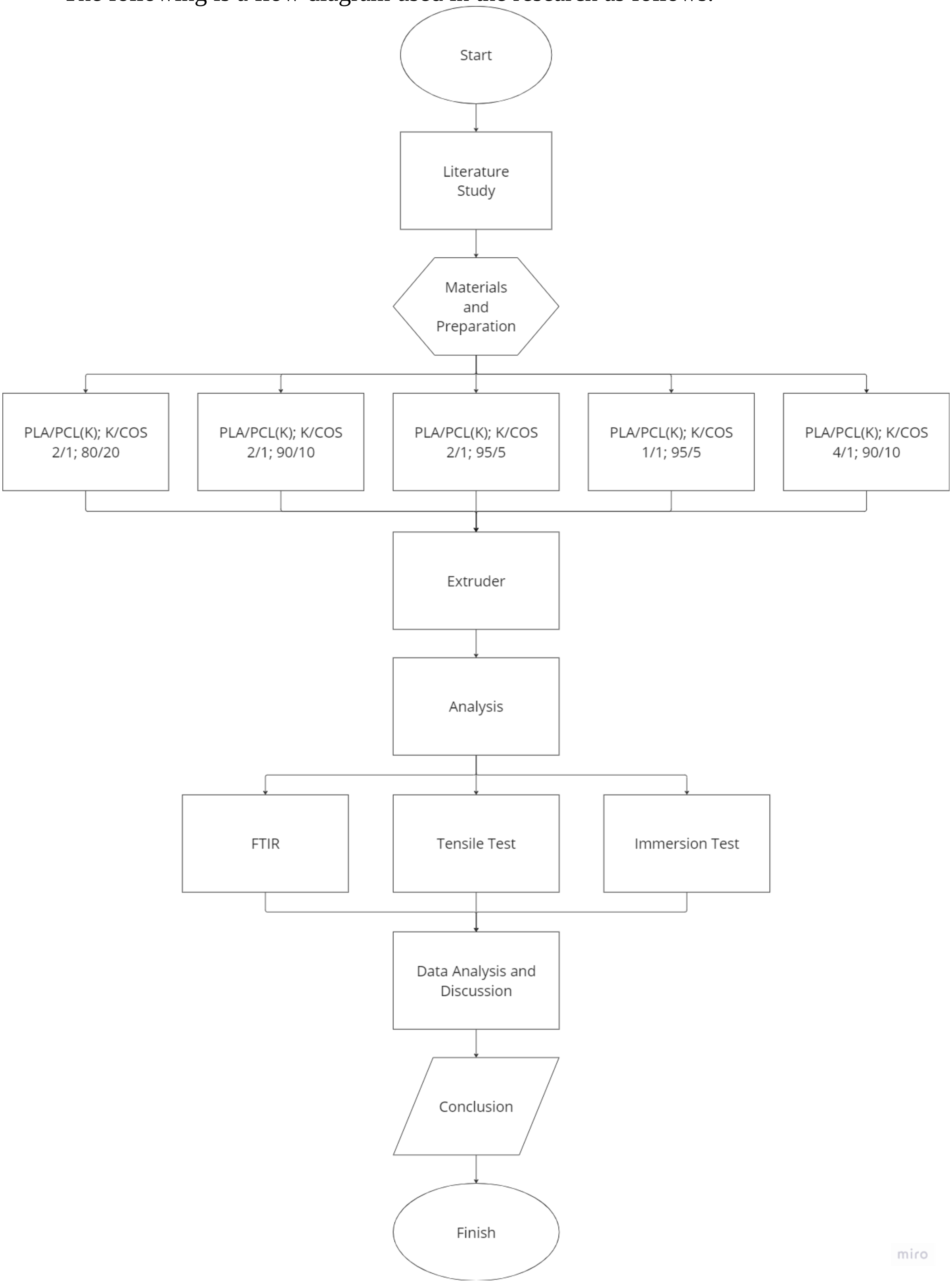


Figure 3.1 Flow Diagram

3.2 Research Materials

The materials used in this study are as follows:

1. Polylactid Acid (PLA)
   The use of polylactid acid in this study is one of the ingredients of suture making.
2. Polycaprolactone (PCL)
   The use of polycaprolactone CAPA-6800 in this study is another polymer of suture making.
3. Chitosan
   Nano chitosan oligosaccharide (COS) was used as another ingredient of suture manufacture. The type of chitosan used had a low molecular weight of 250-300 Da.
4. Saline Solution
   Saline solution is used when performing immersion testing. This solution has a specification of 0.9% NaCl with the brand Otsu.
5. Glycerol
   Glycerol is used as a crosslink agent from chitosan with PLA/PCL by being a plasticizer where the addition of plasticizers makes the elasticity increase and weakens the stiffness of the polymer. The glycerol used uses Merck's product.
6. Acetic Acid 10%
   This 10% acetic acid is used to dissolve the chitosan so that it can be mixed well with the PLA/PCL solution.
7. Dichloromethane (DCM)
   This DCM is used to dissolve PLA and PCL.

3.3 Research Tools

The tools used in this study are as follows:

1. Digital scales
   Used to weigh the weight of chitosan powder
2. Extruder
   Used to make 0.4mm fiber that can be directly nozzle.
3. Spatula
   The spatula in this study is used to pick up and move solid materials. **Figure 3.2** is a tool from Spatula.

Figure 3.2 Spatula

4. Glass Beaker

Beakers were used to dissolve PLA and PCL with dichloromethane (DCM), and chitosan with acetic acid as surgical thread material. **Figure 3.3** is a tool from a glass beaker.

Figure 3.3 Glass Beaker

5. Drip pipette
   Used to take chemical solution
6. Magnetic strirrer
   Magnetic stirrer is a heating and agitation device, where the temperature and agitation speed can be adjusted as indicated on the layer. This tool is used to homogenize the solution as a surgical thread material. **Figure 3.4** is a tool of magnetic stirrer.

Figure 3.4 Magnetic Stirrer

7. Container box
   Used as a research rat cage
8. Measuring cup
   Measuring cup in this study is used as a solution measurement tool. **Figure 3.5** is a tool from a measuring cup.

Figure 3.5 Measuring Cup

9. Stopwatch
   To calculate the time during the mixing process
10. Urine container
   Used as tempat immersion test

3.4 Research Methods

The methods used in this research are as follows:

1. Literature Study
   Literature study is a review process through several sources such as books, journals, papers, and research that has been done before.
2. Discussion
   The discussion process was carried out to further add insight into the research that will be conducted. Discussions can also provide solutions to problems in research conducted.
3. Experiment
   The experimental process begins with the fabrication of surgical suture threads and then suturing the surgical wounds on rats to determine the effect of Nano COS-PLA-PCL.

3.4.1 Suture Preparation

The steps in making biosuture are as follows:

1. Nano COS and 1(one) ml acetic acid 10% are mixed using a magnetic stirrer to homogeneous solution for approximately 5 (five) minutes.
2. After mixing the previous ingredients, add PLA and PCL, also DCM to dissolve them for about 3 (three) hours.
3. Heat the homogenized solution to 100°C to facilitate the evaporation of dichloromethane (DCM).
4. After the dichloromethane (DCM) has evaporated, transfer the solution into a syringe extruder preheated to a temperature of 200-210°C. Then, depress the syringe plunger until the solution is extruded through the nozzle, forming a thread-like structure.
5. The finished suture material will be subjected to several tests to determine the biodegradation and mechanical properties

3.4.2 In-Vitro Test Preparation

The steps in in-vitro testing are as follows:

1. The fabricated surgical suture is inserted into the urine container by hanging from the top.
2. The container was then filled with saline solution to a volume of 15+-5 ml.
3. The urine container is placed on the Thermal Robo to maintain the body temperature of 36° C.
4. Every 3 days, the sample will be checked by weighing and observing using a microscope to examine the changes in the surface morphology of the surgical threads.

3.5 Tests Conducted

The tests carried out aim to find out how the biodegradation performance of surgical suture materials and properties with various compositions and predict treatment optimization through in-vitro observations.

3.5.1 Tests

a) Mechanical test

Tensile Test

Tensile strength test is a mechanical testing method to determine the characteristics of materials, such as yield strength, tensile strength, elongation, and other material properties. In a tensile test, a sample is stretched to break, and the applied strain level must be low so that the results are not distorted. During the tensile test, the force and extension of the sample are measured. Tensile tests provide important information for product design because they yield material strength data. In a tensile test, the result is a curve of the relationship between the pulling force and the change in length, which is indispensable in the design process using the material. Some of the mechanical properties that can be determined from tensile tests include tensile strength, elongation, yield strength, and plasticity of the material.

b) Function group

Fourier Transform Infra Red (FTIR)

FTIR (Fourier Transform Infrared Spectroscopy) is a technique used to obtain the infrared absorption or emission spectrum of a solid, liquid or gas. FTIR spectrometers simultaneously collect high-resolution information over a wide spectral range (between 4000 and 400 cm-1), a distinct advantage over dispersive spectrometers, which estimate power over a narrow frequency range at once. The aim of the spectroscopic technique (FTIR or bright perceptible (UV-Vis) spectroscopy) is to measure how much light the sample absorbs at each frequency (Fadlelmoula et al., 2022).

In the FTIR analysis procedure, the sample is subjected to contact with infrared (IR) radiation. The IR radiation then impacts the vibrations of the molecular atoms in the sample, resulting in the absorption or transmission of specific energy. This makes FTIR useful for determining the vibrations of specific molecules contained in a sample. In this study, FTIR testing was carried out at the Characterization Division of the Department of Materials Engineering and Metallurgy FTIRS ITS using a Thermo Scientic Nicolet IS10 with a wavelength of 500-4000 -1. The FTIR test starts with sample preparation. After that, the sample is cut to size and placed on the sample holder and placed on the FTIR beam path. Then, testing is carried out so that the spectra of the sample are produced.

Figure 3.6 FTIR Tool

In infrared spectroscopy, radiation is passed through a sample where it is partially absorbed and the other part will be passed (transmitted). The infrared spectrum creates a molecular fingerprint with absorption peaks that correspond to the frequency of vibrations between the bonds of the atoms that make up the material. In addition, infrared spectroscopy can result in positive identification of each type of material. Therefore, FTIR is referred to as an excellent tool for quantitative analysis. FTIR spectra are measured as wave numbers because they are directly related to energy and frequency. In general, the infrared region on the x-axis is divided into 3 main parts: near area (400-10 cm-1), mid area (4000-400 cm-1), and far area (14,000-4000 cm^{-1}). As the compound absorbs energy, the molecules vibrate more, then stretch and bend depending on their geometry. The frequency of infrared absorption depends on the mode of vibration, while the intensity depends on: (1) how effectively energy is transferred to the molecule which corresponds to the dipole moment changes that occur during vibration, (2) how much energy is transmitted, and (3) the detector. All covalent compounds, except diatomic gases such as N2, H2, and O2 have characteristic infrared spectra. (Guerrero-Pérez & Patience, 2020)**.**

c) Immersion test

The salt soaking test of surgical threads is a test method used to evaluate the resistance of surgical threads to salt-containing environments, such as the human body environment or environments exposed to body fluids. Surgical threads immersed in saline solution will undergo several changes, such as thread tensile resistance, absorption time because saline solution affects the absorption time by surgical threads and affects the performance of threads in medical applications. Then evaluating the thread breaking strength, saline solution can affect the breaking strength of surgical threads, which may result in faster thread breakage in a saline environment.

3.6 Test Plans

The following is the test and test design and research schedule in this research:

Table 3.1 Material Composition of all the samples

Sample	Material Composition	
	(PLA / PCL) : COS	PLA : PCL
C01	90 : 10	4 : 1
C02	95 : 5	1 : 1
C03	95 : 5	2 : 1
C04	90 : 10	2 : 1
C05	80 : 20	2 : 1

Table 3.2 In-Vitro Test Plans

No.	Sample	FTIR	Mophology Observation	Immersion Test	Tensile Test
1	C01 (9010, 4.1)	✓	✓	✓	✓
2	C02 (955, 1.1)	✓	✓	✓	✓
3	C03 (955, 2.1)	✓	✓	✓	✓
4	C04 (9010, 2.1)	✓	✓	✓	✓
5	C05 (8020, 2.1)	✓	✓	✓	✓

Table 3.3 Research Schedule

No	Activities	November				December				January				February			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	Literature Study	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
2	Assistance to supervisor	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
3	Report Preparation	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
4	Preparation of Tools and Materials				■	■	■										
5	Suture Material Fabrication							■	■	■	■						
6	FTIR Testing											■	■				
7	Tensile Strength Testing												■	■			
8	SEM Testing														■	■	
9	Immersion Testing																■
10	Fibroblast Cell Testing																
11	In-Vivo Testing																
12	Data Analysis and Discussion																

No	Activities	March				April				May				June			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	Literature Study	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
2	Assistance to supervisor	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
3	Report Preparation	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
4	Preparation of Tools and Materials																
5	Suture Material Fabrication																
6	FTIR Testing																
7	Tensile Strength Testing																
8	SEM Testing																
9	Immersion Testing	■	■														
10	Fibroblast Cell Testing			■	■												
11	In-Vivo Testing					■	■	■	■	■	■	■					
12	Data Analysis and Discussion												■	■	■	■	■

(This page is intentionally blank)

CHAPTER IV RESULTS AND DISCUSSION

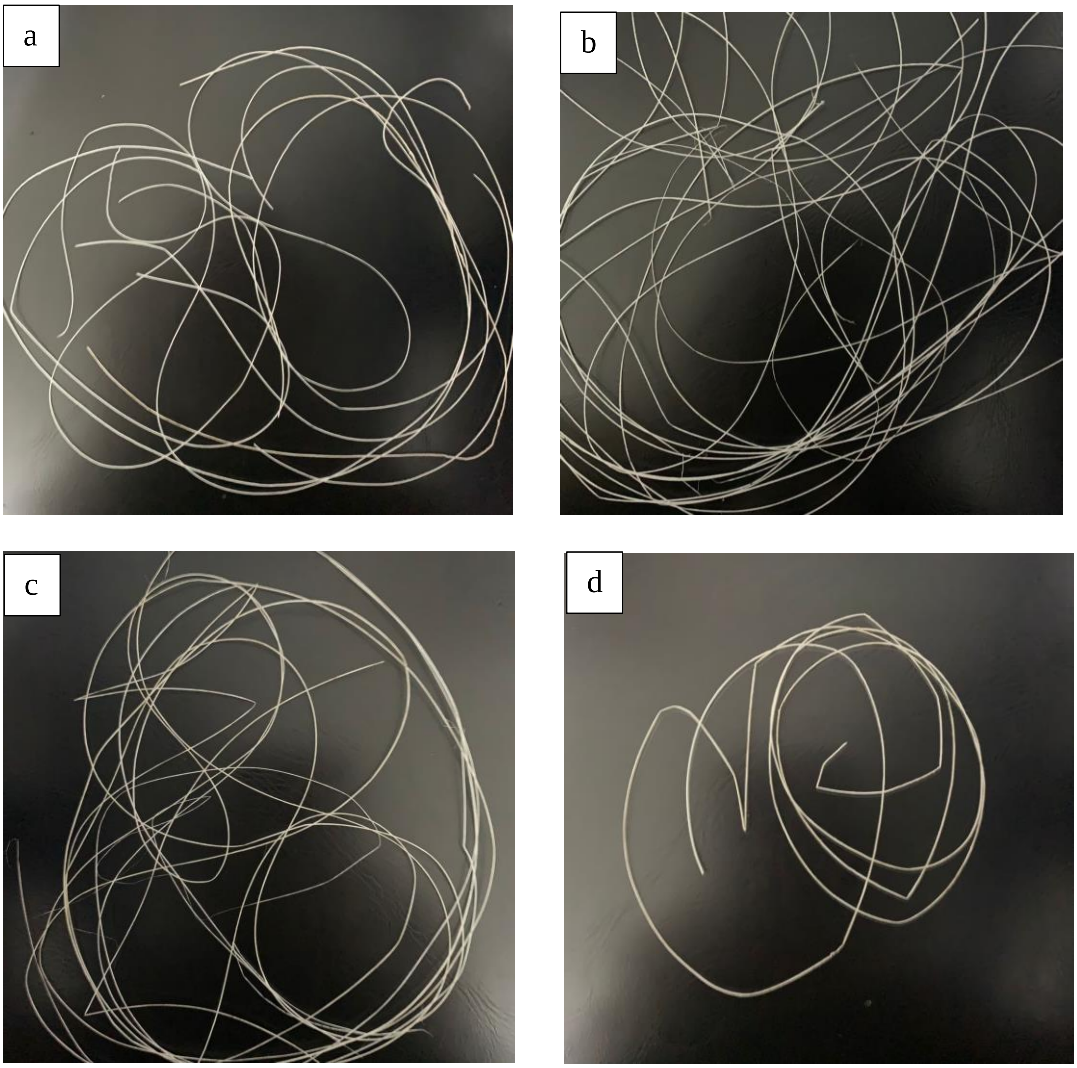
4.1 Research Results

This research uses Nano COS, PLA, and PCL as the basic materials for making surgical suture. The finished surgical suture was subjected to several tests in order to determine its properties and morphology. The tests carried out include Fourier Transform Infrared Spectroscopy (FTIR), Tensile Test, Immersion Test.

4.1.1 Fabrication Surgical Suture Results

The surgical thread is manufactured using an extrusion process that incorporates a blend of three polymers to form a composite thread. The nano chitosan oligosaccharide employed, derived from shrimp, is combined with varying ratios of PLA/PCL/Nano COS. The **Figure 4.1** below illustrate the final outcomes of the surgical thread production.

In the figures below, we can see the results of the surgical thread manufacturing process carried out using the extrusion technique. In this process, the material used is first melted to a certain temperature, and then shaped and drawn into threads with a very small diameter of around 0.4 mm. This extrusion technique enables the manufacture of surgical threads that have good mechanical properties and high consistency, making them suitable for use in various surgical procedures that require reliability and durability.



e

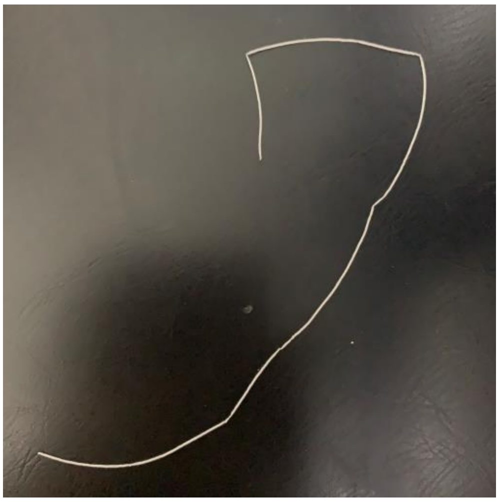


Figure 4.1 Visual Observation of suture results : a) Sample C01, b) Sample C02, c) Sample C03, d) Sample C04, e) Sample C05

The fabrication of surgical sutures using a combination of PLA (Polylactic Acid), PCL (Polycaprolactone), and Nano COS (Nano Chitosan Oligosaccharide) through the extrusion process has yielded highly satisfactory results. A detailed analysis of the **Figure 4.1 (a)** reveals that the suture appears remarkably smooth and consistent in both shape and size. The surface of the suture is notably free from significant defects or imperfections, which indicates that the extrusion process was meticulously conducted with optimal temperature and speed parameters. This smooth surface is of paramount importance as it significantly enhances the tensile strength of the surgical suture, a crucial property for its application in medical procedures where reliability and durability are essential.

In **Figure 4.1 (b)**, the suture demonstrates a remarkable degree of uniform distribution, with no visible signs of excessive rigidity or insufficient flexibility. The consistent diameter of the suture across its length suggests that the materials PLA, PCL, and Nano COS were thoroughly mixed, and that the subsequent cooling and winding processes were executed with precision. The good flexibility of the suture is evident from its ability to coil neatly without forming excessive knots or folds, which is a critical characteristic for ease of use during surgical procedures.

Furthermore, in **Figure 4.1 (c)** provides additional evidence of the suture's excellent mechanical properties. The suture's ability to coil effectively without forming sharp bends or breaking indicates the desired level of flexibility and resilience. The absence of cracks or fractures along the suture length underscores its robust mechanical stability, suggesting that the production process was carried out without imposing excessive mechanical stress that could potentially cause damage. This stability is crucial for ensuring that the suture can withstand the physical demands of surgical use without compromising its integrity.

Then, In **Figure 4.1 (d)** shows that the threads have varying thicknesses, which is caused by changes in pressure or temperature during the extrusion process. However, the suture in the fifth figure looks more uniform, although it still shows some slight curvature which may be caused by variations in extrusion speed or uneven cooling. The surface of the yarns in both images appears smooth, indicating that the PLA/PCL/Nano Chitosan material has been extruded well without any air bubbles or significant surface defects. The circular shape of the thread in the fourth image shows good flexibility, which is important for surgical threads to follow the contours of the human body. In **Figure 4.1 (e)**, which shows the thread in a more brittle state and breaking easily, indicates that the thread has weak tensile strength. The PLA/PCL/Nano Chitosan material was chosen for its biocompatibility and ability to biodegrade, which is important for surgical threads to not cause negative reactions in the body and to be absorbed after healing. Overall, the figures above show quite good results for surgical threads in terms of flexibility, smooth surface, and possibly adequate tensile strength, as well as homogeneity in thread diameter and distribution. This material combination provides the desired biodegradability, biocompatibility, flexibility and antimicrobial properties, making this surgical thread highly suitable for medical applications.

4.1.2 FTIR Results

In this research, (Fourier Transform Infrared Spectroscopy) FTIR testing was carried out using a Nicolet IS10 machine with a wavelength range of 500 - 4000 nm^{-1} which aims to determine the functional groups of molecules formed in the fabrication process. Testing of surgical suture samples can be seen in **Figure 4.2** and **Table 4.1.**

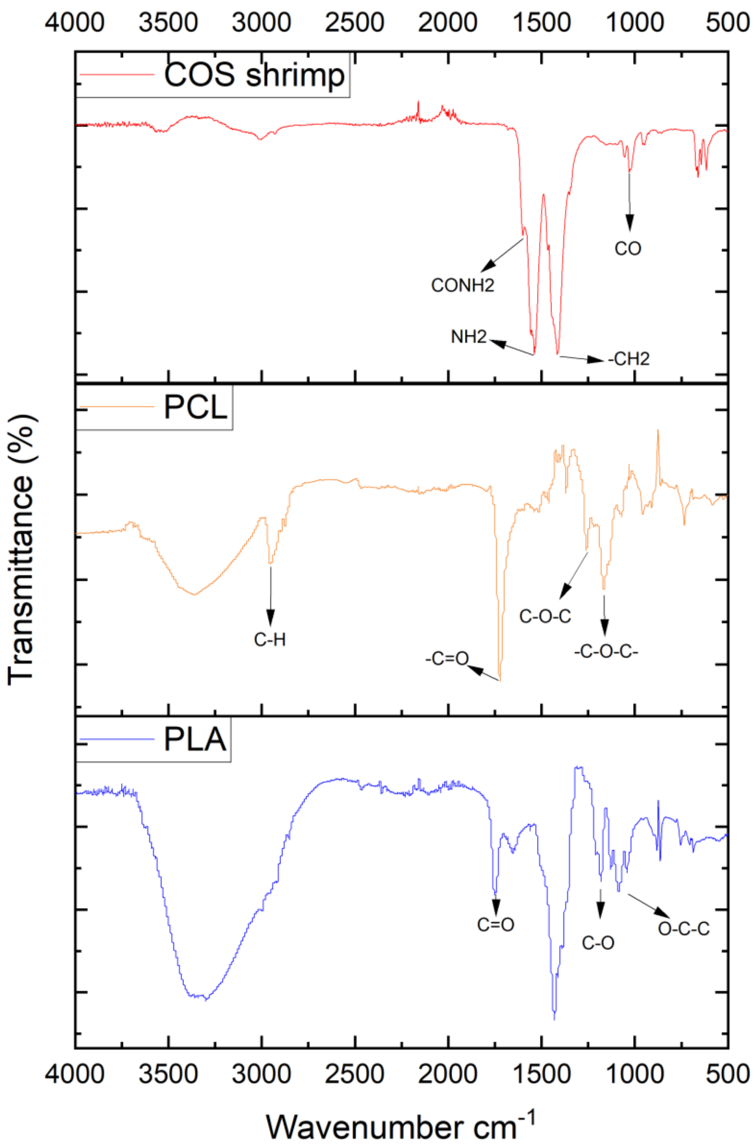


Figure 4.2 FTIR ingredient surgical suture

Fourier Transform Infrared Spectroscopy (FTIR) on surgical thread raw materials is an important step in material characterization for surgical thread applications. FTIR is used to analyze the chemical structure and composition of membranes by detecting characteristic molecular vibrations at infrared wavelengths. With FTIR, it is possible to identify the chemical functional groups and molecular interactions in surgical threads, which greatly affect their performance. The process involves taking the infrared spectrum of a surgical thread sample and comparing it to a reference spectrum to determine changes in chemical composition due to use or modification. The results from FTIR testing can provide in-depth information on the material degradation, presence of contaminants, and effectiveness of the surgical thread, which can help in the development and optimization of better and degradable thread results. Based on the FTIR spectra in Figure 4.1 nano COS shrimp there is a peak at wavenumber 1535.5 cm^{-1} which is a group of NH_2 bending.

At peak wavenumber 1033 cm^{-1} is a CO stretching group. Peak at wavenumber 1415.5 cm^{-1} is the $-CH_2$ stretching group. Then, the peak at wavenumber 1067 cm-1 is $CONH_2$ group (Drabczyk et al., 2020). For PCL material, there is a peak at wavenumber 2956.5 cm^{-1} for C-H stretching group. At peak wavenumber 1722 cm^{-1} there is a -C=O stretching group. Then, peaks at wavenumbers 1255 and 1163 cm^{-1} are functional groups of C-O-C stretching and -C-O-C- stretching. Furthermore, for PLA material there is a peak at wavemumber 1039.13 cm^{-1} which is the O-C-C stretching functional group. At peak wavenumber 1742 cm^{-1} is a functional group of C=O stretching. Finally, at peak wavenumber 1183 cm^{-1} there is a C-O stretching functional group.

Table 4.1 Peak FTIR of the raw materials (Nandiyanto et al., 2019)

Sample	**Peak (cm^{-1})**	**References (cm^{-1})**	**Functional Group**
Nano COS	1033	1033,85	CO stretching
	1415,5	1417 and 1377	$-CH_2$ stretching
	1534,5	1557	NH_2
	1604	1639	$CONH_2$
PCL	2956,5	2940	C-H Stretching
	1722	1722	-C=O stretching
	1255,55	1255, 38	C-O-C stretching
	1163,9	1160	-C-O-C- Stretching
PLA	1039,19	1047	O-C-C stretching
	1742,36	1757.33	C=O stretching
	1183,09	1187.45	C-O stretching

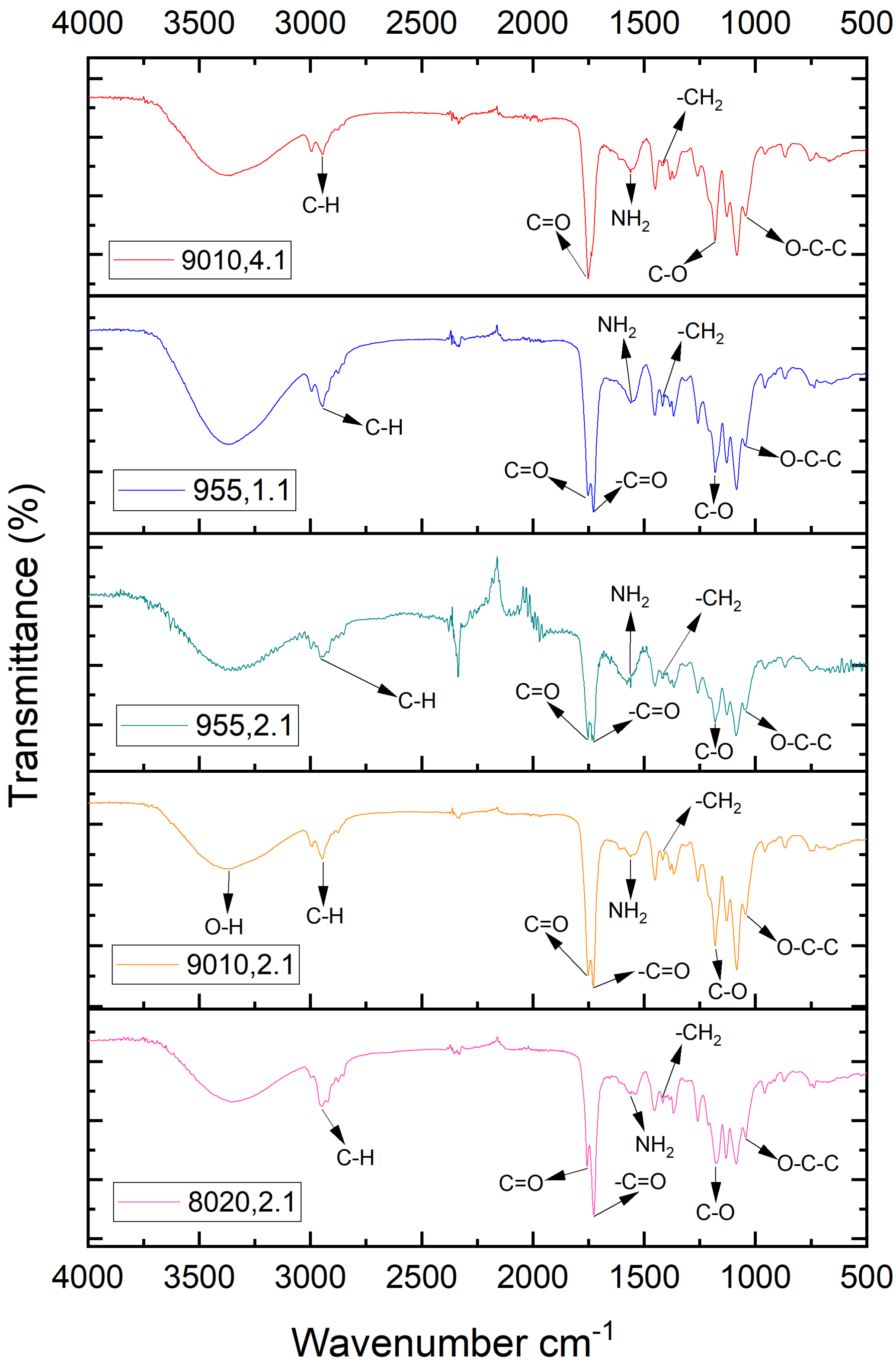


Figure 4.3 FTIR Surical suture from various parameter

Table 4.2 FTIR Absorption Region of Surgical Threads Sample

Sample	Peak	Peak from Reference	Functional Group
C01 (PLA/PCL:CS = 90:10) (PLA:PCL = 4:1)	1750	1757 (REf)	C=O stretching from PLA
	1181	1187	C-O stretching from PLA
	1416	1417 and 1377	$-CH_2$ stretching from COS
	1556	1557	NH_2 from COS
	2944	2940	C-H stretching from PCL
	1043	1047	O-C-C from PLA
C02 (PLA/PCL:CS = 95:5) (PLA:PCL = 1:1)	1753	1757	C=O stretching from PLA
	1726	1722	-C=O stretching from PCL
	1557	1557	NH2 from COS
	1417	1417	$-CH_2$ COS
	1044	1047	O-C-C from PLA
	1180	1187	C-O strecthing from PLA
	2945	2940	C-H stretching from PCL
C03 (PLA/PCL:CS = 95:5) (PLA:PCL = 2:1)	1047	1047	O-C-C from PLA
	1180	1187	C-O strecthing from PLA
	1558	1557	NH2 from COS
	1751	1757	C=O Strecthing from PLA
	1727	1722	-C=O stretching from PCL
	2952	2940	C-H from PCL
	1417	1417	$-CH_2$ from COS
C04 (PLA/PCL:CS = 90:10) (PLA:PCL = 2:1)	1044	1047	O-C-C from PLA
	1556	1557	NH2 from COS
	2945	2940	C-H stretching from PCL
	1727	1722	-C=O stretching from PCL
	1750	1757	C=O from PLA
	1181	1187	C-O from PLA
	1417	1417	$-CH_2$ from COS
C05	1043	1047	O-C-C from PLA

(PLA/PCL:CS = 80:20) (PLA:PCL = 2:1)	1560	1557	NH2 from COS
	2948	2940	C-H stretching from PCL
	1724	1722	-C=O stretching from PCL
	1755	1757	C=O from PLA
	1178	1187	C-O from PLA
	1417	1417	-CH_2 from COS

These surgical threads has a mixture of polylactic acid, polycaprolactone, and nano chitosan oligosaccharide polymers. Based on the FTIR pattern results, several peaks has been shown to appeared in various absorption region. In the C = O stretching region, several peaks were detected in all sample. Then, in the absorption area 1047 is known to be an O-C-C bond which is seen in the area peak wavenumber 1043, 1044, 1047, 1044, 1043 cm^{-1} in sample C01, C02, C03, C04, C05. Furthermore, the absorption area of 2940 shows the presence of C-H bonds which are seen in the areas peak wavenumber of 2944, 2945, 2952, 2945, 2948 cm^{-1} in sample C01, C02, C03, C04. In the absorption area 1417 shows the presence of -CH2 bonds found in the area peak wavenumber 1416, 1417, 1417, 1417, 1417 cm^{-1} in sample C01, C02, C03, C04, C05. Then, in the absorption area 1187 shows the C-O bond which is seen in the peak wavenumber 1181, 1180, 1180, 1181, 1178 cm^{-1} in sample C01, C02, C03, C04, C05. Finally, the absorption region 1722 shows the presence of -C=O bonds found in the regions peak wavenumber 1726, 1727, 1727, 1724 cm^{-1} in samples C02, C03, C04, C05 (Nandiyanto et al., 2019).

4.1.3 Tensile Strength Testing Results

Tensile testing is carried out to obtain information about the tensile strength of the suture in the form of tensile strength, Young's Modulus, and Elongation in accordance with ASTM D2256M standards. Tensile strength is defined by the US Pharmacopeia (USP) as the weight necessary to break a suture divided by the crosssectional area of the suture. The relationship between the weight necessary to break a suture and the suture’s diameter is not linear. Tensile strength can be measured using either dry or wet sutures. Tensile strength is indicative of the strength derived from factors such as fiber strength, fiber length, and bonding. It may be used to deduce information about these factors, especially when used as a tensile strength index. For quality control purposes, tensile strength has been used as an indication of the serviceability of many papers which are subjected to a simple and direct tensile stress. When evaluating the tensile strength, the stretch and the tensile energy absorption for these parameters can be of equal or greater importance in predicting the performance of suture (Bajpai, 2019). The tensile strength of wet sutures is more clinically relevant, given that sutures are implanted into tissue comprised of extracellular fluid. Effective tensile strength is an additional measurement that evaluates the tensile strength of a looped and knotted suture. Effective tensile strength will vary with suture material and knot type. A suture should have and maintain adequate tensile strength for its specified purpose. In the tests carried out, surgical thread samples were prepared and cut (Dart & Dart, 2020). Young's modulus is one of the elasticity values that expresses the resistance of a solid object to changes in length. The Young's Modulus value of a material in the industrial world is an important thing to know. One of them is related to the selection of the right material for its utilization as a product of technological development in daily life. Measurement to determine the Young's Modulus value of a material in learning is still lacking. Young's Modulus measurement is done by observing the increase in length of surgical thread when pulled with a force. The force is applied by putting a load on the end of the wire. The method used has the disadvantage of damaging the surgical thread if the added load is not controlled and exceeds the elasticity limit of the surgical thread (Tefa & Edi Santosa, 2021). Elongation at break, also known as fracture strain, is the ratio between changed length and initial length after breakage of the test specimen. It expresses the capability of natural plant fiber to resist changes of shape without crack formation. The elongation at break can be determined by tensile testing in accordance with EN ISO 527. To ascertain the percentage of elongation, first, determine the difference between the sample's final length post-fracture and its initial length. Then, divide this difference by the original length. Multiply the resulting ratio by 100 to express it as a percentage. Mathematically, this is articulated as:

$$\left(\frac{\text{Final Length} - \text{Original Length}}{\text{Original Length}}\right) \text{x } 100\%$$

This computation is essential as it quantifies the material's ductility, a vital attribute in various engineering applications where both flexibility and durability are paramount (Djafari Petroudy, 2021) The diameter of the surgical thread is fabricated using a 3D printing nozzle with a diameter of 4mm and measured again using a caliper. The results of surgical thread samples with a diameter of less than 4 mm are due to shrinkage caused by one of the preparation materials, namely dichloromethane (DCM). Tensile testing was carried out using an Autograph tensile machine. Measurements were taken with a withdrawal speed of 2 mm/second. The measurement results obtained are in the form of stress-strain graphs along with strength, ductility, and Young's Modulus values. The calculation of strength takes the ultimate tensile strength value, while ductility takes the maximum elongation value. The mechanical property values of the tensile testing results of nano COS-PLA-PCL surgical threads are presented in **Figure 4.4** and **Table 4.3** below.

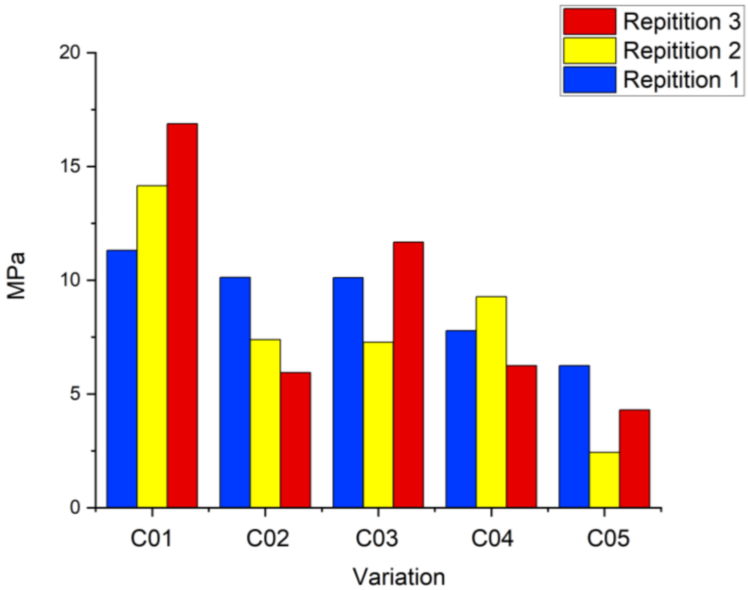


Figure 4.4 Tensile Testing of Surgical Threads Sample

Table 4.3 Tensile Testing of Surgical Threads Sample

Sample	Trial	Tensile Strength (MPa)	Modulus Young (MPa)	Elongation (%)
C01	1	11.31	510.41	2.77

(PLA/PCL:CS = 90:10) (PLA:PCL = 4:1)	2	14.46	491.83	3.86
	3	16.88	490.31	5.75
C02 (PLA/PCL:CS = 95:5) (PLA:PCL = 1:1)	1	10.13	307.25	13.67
	2	7.39	336.23	5.37
	3	5.94	300.43	4.84
C03 (PLA/PCL:CS = 95:5) (PLA:PCL = 2:1)	1	10.12	359.81	6.22
	2	7.28	386.82	4.61
	3	11.68	429.11	3.75
C04 (PLA/PCL:CS = 90:10) (PLA:PCL = 2:1)	1	7.78	353.20	3.67
	2	9.28	311.52	4.45
	3	6.27	297.53	2.88
C05 (PLA/PCL:CS = 80:20) (PLA:PCL = 2:1)	1	6.34	227.27	3.89
	2	2.43	64.58	8.12
	3	4.33	159.11	4.90

Based on **Table 4.4**, it can be seen that the addition of Nano COS, polylactic acid, and polycaprolactone affects the tensile strength, young modulus, and elongation. Nano COS that exceeds 10 percent causes the tensile strength to tend to decrease. This can be seen in variation C05 because the addition of more COS can make the surgical thread more brittle so that it also causes a decrease in the elongation value of the surgical thread sample (Ma et al., 2018). Meanwhile, the C01 variation has the greatest tensile strength because it is dominated by PLA (Farah et al., 2019). Not only tensile strength, surgical thread is very important to have flexibility because the material should have the ability to conform to the current stage of wound repair (Chu, 2021). Thus, PCL plays a role to provide flexibility and increased elongation results. The results of C02 variation with PLA:PCL ratio of 1:1, the mechanical properties of PLA proved the existence of elastic properties (Rojas-Rojas & Teodolíto Guillén-Girón, 2023)

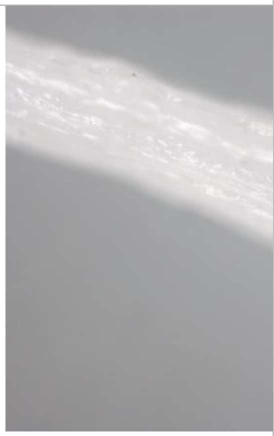
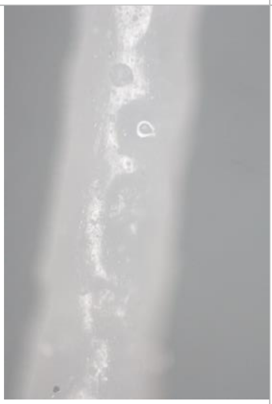
Table 4.4 Comparison of tensile test results

Surgical Suture Composite	Ratio	Tensile Strength (MPa)	Citation
PLA : PEG	70:30	10,573	(Asmeer & Roslan, 2020)
PLA : CS	60:40	17,8	(Kasirajan et al., 2019)
Neat PLA:CS	90:10	11,5	(Altuntas & Aydemir, 2019)
	95:5	34,3	

4.1.4 Immersion Test

In-vitro testing was carried out using the immersion test by immersing the fabricated bone substitute into saline solution (0.9% NaCl) at a temperature of 360C. This test was conducted to determine how the bone substitute performs when in contact with saline solution. This test was conducted on all bone substitute variations: a. C01, b. C02, c. C03, d. C04, d. C05, each of which uses a repetition of 3 times the sample. This test itself is carried out time monitoring every 5 days until day 16th. The average change in sample mass and surgical thread morphology is shown in **Table 4.5**. The trend shows that almost all samples experienced mass gain. This indicates that the surgical thread product experiences swelling or expansion in its structure by absorbing the saline solution.

Table 4.5 The morphology structure

Sample	Initial suture before Immersion Test	After Immersion Test		
		6 days	**11 days**	**16 days**
C01				
C02				
C03				

C04				
C05				

From the picture in **Table 4.5**, it can be seen that there are changes in the surface morphology of the surgical thread in the sample with code C01, C02, C03, C04, C05 analyzed using a microscope with 10x magnification.

When before the immersion test is performed, the surface of the surgical thread is relatively smooth with an even texture. This indicates that the surgical thread still retains its structural integrity well.

On day 6, the degradation of PLA material was faster than that of PCL, indicating the beginning of a more intense biodegradation process. On day 11, the morphological changes became more pronounced with a rougher and more porous surgical thread surface. This indicates more advanced degradation, where PCL starts to show its effect by slowing down the overall degradation process but still contributing to the mechanical strength of the surgical thread. On day 16, the surgical thread showed a very uneven surface and started to fragment. This indicates an advanced stage of material degradation, where PLA has degraded considerably, and PCL although still present, cannot completely prevent further degradation.

Overall, immersion testing showed that different PLA/PCL/COS ratios can influence the speed and degradation characteristics of surgical threads. This ratio variation is important to ensure the optimal combination of mechanical and biodegradation properties desired in medical applications, particularly in surgical thread manufacturing.

4.1.5 Swelling Ratio Testing Results

Swelling ratio testing is used to measure the ability of surgical thread to absorb water. This test was conducted by looking at the rate of water absorption of PLA/PCL/Nano COS surgical thread with the water value calculated using the ASTM D570-98 standard. Swelling ratio is the swelling that occurs due to the volume of polymer expanding between molecules in solution. The swelling stability value can be calculated by comparing the membrane volume in wet condition (Swet) and in dry condition (Sdry**). Table 4.6** shows the presentation of water uptake and swelling ratio values on surgical thread with variations in the ratio of each sample.

Table 4.6 Water uptake dan swelling ratio of surgical suture after 16 days

Sample	*Swelling ratio* (%)
C01	25.80 ± 16.16
C02	16.97 ± 1.51
C03	20.83 ± 12.43
C04	22.76 ± 16.10
C05	23.33 ± 8.16

The results of in **Table 4.6** swelling ratio showed that the greatest ability to absorb occurred in sample variation C01 with a percentage of 25.80 ± 16.16%. Conversely, the smallest swelling ratio was found for sample variation C02 with a percentage of 16.97 ± 1.51%. Controlling the swelling ratio is effective in suture in because it is very important to ensure operational efficiency and longevity of surgical suture (Johnson et al., 2020). The addition of Chitosan (COS) in combination with PLA and PCL significantly improved the swelling ratio of the material. PLA and PCL, which tend to have low swelling ratios due to their hydrophobic properties, can be balanced by the hydrophilic properties of Chitosan, resulting in materials with higher swelling ratios and better functional properties for medical applications. Setting the proportions of PLA, PCL, and Chitosan allows customization of swelling characteristics to the specific needs of clinical applications. This combination offers an optimal balance between mechanical strength, flexibility, controlled biodegradation, and antimicrobial properties, making it a very attractive option for a wide range of biomaterial applications, including surgical threads and tissue scaffolds.

4.2 Discussion

In this study, nano COS-based surgical suture aims to improve the properties of the thread. The constituent materials are PLA, PCL, and nano COS shrimp with different mass ratio variations namely C01, C02, C03, C04, C05. In the manufacture of surgical threads with various variations to determine its ability and properties.

4.2.1 Effect of Nano COS on Surgical Suture

The incorporation of Nano Chitosan Oligosaccharide (Nano COS) into surgical sutures markedly influences their functional properties, particularly in terms of swelling ratio, biocompatibility, and antimicrobial activity. Nano COS, derived from chitosan, enhances the hydrophilic nature of the sutures, leading to an improved swelling behavior, which is crucial for wound healing applications. This enhanced hydrophilicity attracts water molecules, thereby facilitating a higher swelling ratio. A higher swelling ratio is beneficial for maintaining a moist wound environment, which is conducive to tissue regeneration and faster healing. Moreover, Nano COS exhibits inherent antimicrobial properties that can reduce the risk of infection, further supporting the healing process. These characteristics make Nano COS an invaluable addition to surgical sutures, improving their overall performance in clinical applications.

4.2.2 FTIR Analysis

Fourier Transform Infrared (FTIR) spectroscopy was employed to analyze the chemical structure and confirm the successful incorporation of Nano COS, PLA, and PCL into the sutures. The FTIR spectra revealed characteristic peaks corresponding to the functional groups of each component. The presence of peaks at specific wavenumbers confirmed the existence of C=O stretching from PLA, C-H stretching from PCL, and NH2 bending from chitosan. These results validate the successful fabrication of composite sutures and provide insights into the molecular interactions between the components. The detailed FTIR analysis underscores the chemical compatibility and the successful integration of Nano COS, PLA, and PCL, ensuring the composite material's functional integrity.

4.2.3 Effect of PLA/PCL on Tensile Strength

Tensile strength tests were conducted to evaluate the mechanical performance of the sutures. The results indicated that sutures with higher PLA content exhibited increased tensile strength, while those with higher PCL content showed enhanced flexibility but reduced strength. The optimal balance between PLA and PCL was achieved in samples with a 2:1 ratio, providing a suitable combination of strength and flexibility for surgical applications. The addition of Nano COS did not significantly compromise the tensile strength, indicating its potential as a reinforcing agent without degrading the mechanical properties of the sutures.

PLA has a relatively high tensile strength of around 50 MPa and a high modulus of around 3.4 GPa, but its elongation is low, less than 10%. PCL, on the other hand, has a relatively low tensile strength due to its fragile and brittle nature. (Rihayat al., 2018) However, adding fillers like chitosan can enhance its tensile strength. Combining PCL and PLA can result in a material with better mechanical properties than either polymer alone. Additionally, the extuder process making surgical suture using PLA can affect its tensile strength, with variations in parameters like infill pattern and nozzle temperature influencing the final product's strength. It can be seen from the variation of sample CO1 at a ratio of 4: 1 for PLA/PCL has a high average tensile strength of 14.11 Mpa.

4.2.4 Effect PLA/PCL/Nano COS on Immersion Test

The effect of PLA, PCL, and COS on the swelling ratio of surgical threads showed significant results. Swelling ratio is used to measure the ability of surgical thread to absorb water. Based on the test results, sample variation C01 showed the largest swelling ratio of 25.80 ± 16.16%, while sample variation C02 had the smallest swelling ratio of 16.97 ± 1.51%. The addition of Chitosan (COS) in combination with PLA and PCL significantly increased the swelling ratio of the material. The hydrophilic nature of Chitosan was able to compensate for the hydrophobic nature of PLA and PCL, resulting in a material with a higher swelling ratio and better functional properties for medical applications. The variation of PLA/PCL/COS ratio affects the speed and degradation characteristics of surgical threads, which is important to ensure the optimal combination of mechanical strength and biodegradation properties desired in medical applications. The combination of PLA, PCL, and Chitosan allows customization of swelling characteristics according to the needs of clinical applications. This combination offers an optimal balance between mechanical strength, flexibility, controlled degradation, and antimicrobial properties, making it a very attractive option for various biomaterial applications, including surgical threads and tissue scaffolds.

4.2.5 Tabulation of the Result

This research aims to find the suitable properties for the surgical suture using polymer materials such as PLA, PCL, and Nano COS. For the tabulation of the results of this study can be seen in **Table 4.7** which adjusts to the target application of surgical suture. **Table 4.7** shows that from the various variations of samples made, the variations that are close to the criteria for surgical suture are C01,C02, C04. It is shown that C01 is the optimum variation because it fulfilled the criteria required.

Table 4.7 Tabulation of Research Results

No	Sample	Tensile Strength	Elongation
1	C01	16.88	5.75
2	C02	10.13	13.67
3	C03	11.68	3.75
4	C04	9.28	4.45
5	C05	6.34	3.89

NOTE:

(yellow) = criteria fulfilled

CHAPTER V
CONCLUSIONS AND SUGGESTION

5.1 Conclusions

Based on the results of the data and discussion that has been carried out, the following conclusions can be drawn.

1. The manufacture of nano COS/PLA/PCL surgical suture has been successfully carried out with varying tensile strength and elongation performance from the tensile test results. The best strength value is best in the C01 variation with the results of 14.11 MPa and 7.96% for elongation.
2. Variations in the ratio of nano COS/PLA/PCL in surgical sutures affect the results of tensile and flexibility tests. In tensile strength testing, the addition of nano COS has an effect on decreasing the tensile strength of the membrane. This is in accordance with the results of the tensile test on the CO5 variation with 20% chitosan, which is 4.3 MPa. In the immersion test, although the results were not too significant, it was found that there were changes in the surface structure of the yarn in the phase before immersion and the 9th day after the immersion test. In the swelling ratio, the highest swelling results occurred in cr C02 and C03. This happens because PLA and PCL dominate in surgical threads so that it requires more dichloromethane when dissolving the surgical thread material. Dichloromethane affects the presence of pores in the surgical thread, so that NaCl is absorbed.

5.2 Suggestion

The suggestions that can be given regarding this Final Project are:

1. It is necessary to conduct additional tests that are not yet available such as In-Vivo tests and toxicity tests.
2. For further research can use a commercial extruder machine to get more perfect results.
3. Further research is needed to select biomaterials other than PLA that have more flexible material characteristics.

(This page is intentionally blank)

BIBLIOGRAPHY

Abrica-González, P., Zamora-Justo, J. A., Sotelo-López, A., Vázquez-Martínez, G. R., Balderas-López, J. A., Muñoz-Diosdado, A., & Ibáñez-Hernández, M. (2019). Gold nanoparticles with chitosan, N-acylated chitosan, and chitosan oligosaccharide as DNA carriers. *Nanoscale Research Letters*, *14*(1). https://doi.org/10.1186/s11671-019-3083-y

Altuntas, E., & Aydemir, D. (2019). Effects of wood flour on the mechanical, thermal and morphological properties of poly (L-lactic acid)-chitosan biopolymer composites. *Maderas: Ciencia y Tecnologia*, *21*(4). https://doi.org/10.4067/s0718-221x2019005000416

Asmeer, N., & Roslan, B. (2020). *BIODEGRADABLE FILMS FROM POLY (LACTIC ACID) (PLA)-CHITOSAN-POLYETHYLENE GLYCOL (PEG): FABRICATION AND EVALUATION OF MECHANICAL PROPERTIES CORE View metadata, citation and similar papers at core.ac.uk provided by UMP Institutional Repository*.

Atnurkar, V., Schuster, J., & Pasha Shaik, Y. (2023). Increased Elongation at Breaking Point with Improved Mechanical Characteristics in PLA. *Open Journal of Composite Materials*, *13*, 13–28. https://doi.org/10.4236/ojcm.2023.132002

Bajpai, P. (2019). Paper and Its Properties. In *Biermann's Handbook of Pulp and Paper* (pp. 35–63). Elsevier. https://doi.org/10.1016/b978-0-12-814238-7.00002-7

Baskara, R., Anandito, K., Nurhartadi, E., & Bukhori, A. (2019). PENGARUH GLISEROL TERHADAP KARAKTERISTIK EDIBLE FILM BERBAHAN DASAR TEPUNG JALI (Coix lacryma-jobi L.) EFFECT OF GLYCEROL ON THE CHARACTERISTICS OF EDIBLE FILM FROM JALI (Coix lacryma-jobi L.) FLOUR. In *Jurnal Teknologi Hasil Pertanian: Vol. V* (Issue 2).

Borchiellini, P., Rames, A., Roubertie, F., L'Heureux, N., & Kawecki, F. (2023). Development and characterization of biological sutures made of cell-assembled extracellular matrix. *Biofabrication*, *15*(4). https://doi.org/10.1088/1758-5090/acf1cf

Broughton, G., Janis, J. E., & Attinger, C. E. (2006). The basic science of wound healing. In *Plastic and Reconstructive Surgery* (Vol. 117, Issue 7 SUPPL.). https://doi.org/10.1097/01.prs.0000225430.42531.c2

Chu, C. C. (2019). Types and properties of surgical sutures. In *Biotextiles As Medical Implants* (pp. 231–273). Elsevier Inc. https://doi.org/10.1533/9780857095602.2.232

Chu, C. C. (2021). Types and properties of surgical sutures. In *Biotextiles As Medical Implants* (pp. 231–273). Elsevier Inc. https://doi.org/10.1533/9780857095602.2.232

Dart, A. J., & Dart, C. M. (2020). Suture material: Conventional and stimuli responsive. In *Comprehensive Biomaterials* (Vol. 6, pp. 573–587). Elsevier. https://doi.org/10.1016/b978-0-08-055294-1.00245-2

Djafari Petroudy, S. R. (2021). Physical and mechanical properties of natural fibers. In *Advanced High Strength Natural Fibre Composites in Construction* (pp. 59–83). Elsevier Inc. https://doi.org/10.1016/B978-0-08-100411-1.00003-0

Drabczyk, A., Kudłacik-Kramarczyk, S., Głab, M., Kedzierska, M., Jaromin, A., Mierzwiński, D., & Tyliszczak, B. (2020). Physicochemical investigations of chitosan-based hydrogels containing Aloe vera designed for biomedical use. *Materials*, *13*(14). https://doi.org/10.3390/ma13143073

Fadliyani, N., & Atun, S. (2021). THE UTILIZATION OF GLYCEROL, BIODIESEL SIDE PRODUCT OF USED COOKING OIL AS GLYCEROL ACETATE MATERIAL SYNTHESIS. *Jurnal Penelitian Saintek*, *20*(2). https://doi.org/10.21831/jps.v20i2.9601

Farah, S., Anderson, D. G., & Langer, R. (2019). Physical and mechanical properties of PLA, and their functions in widespread applications — A comprehensive review. In *Advanced*

Drug Delivery Reviews (Vol. 107, pp. 367–392). Elsevier B.V. https://doi.org/10.1016/j.addr.2016.06.012

Gaspar-Cunha, A., Monaco, F., Sikora, J., & Delbem, A. (2022). Artificial intelligence in single screw polymer extrusion: Learning from computational data. *Engineering Applications of Artificial Intelligence*, *116*. https://doi.org/10.1016/j.engappai.2022.105397

Grada, A., Mervis, J., & Falanga, V. (2019). *Research Techniques Made Simple : Animal Models of Wound Healing*. https://doi.org/10.1016/j.jid.2018.08.005

Greenhalgh, D. G. (2019). *The role of apoptosis in wound healing*.

Guerrero-Pérez, M. O., & Patience, G. S. (2020). Experimental methods in chemical engineering: Fourier transform infrared spectroscopy—FTIR. In *Canadian Journal of Chemical Engineering* (Vol. 98, Issue 1, pp. 25–33). Wiley-Liss Inc. https://doi.org/10.1002/cjce.23664

Guo, S., & DiPietro, L. A. (2019). Critical review in oral biology & medicine: Factors affecting wound healing. *Journal of Dental Research*, *89*(3), 219–229. https://doi.org/10.1177/0022034509359125

Hani, Y., Yousef, H., & Sharma, S. (2019). *Anatomy, Skin (Integument), Epidermis*. https://www.researchgate.net/publication/322063118

Hanum Hamzah, F., Fatthoni Sitompul, F., Fortuna Ayu, D., & Pramana, A. (2021). Effect of the Glycerol Addition on the Physical Characteristics of Biodegradable Plastic Made from Oil Palm Empty Fruit Bunch Pengaruh Penambahan Gliserol terhadap Sifat Fisik Plastik Biodegradable Berbahan Dasar Tandan Kosong Kelapa Sawit. *Jurnal Teknologi Dan Manajemen Agroindustri*, *10*, 239–248. https://doi.org/10.21776/ub.industria.2021.010.03.5

Hart, J. (n.d.). *education J O U R N A L O F WO U N D C A R E VO L 1 1 , N O 6 , J U N E 2 0 0 2 2 0 5*.

Harti, A. S. (2021). KAJIAN EFEK SINERGISTIK ANTARA CHITO-OLIGOSAKARIDA (COS) DAN PROBIOTIK (Lactobacillus acidophilus FNCC 0051) TERHADAP PENURUNAN KADAR KOLESTEROL SECARA in vivo THE SYNERGISTIC EFFECT OF CHITO-OLIGOSACCHARIDE (COS) AND PROBIOTIK (Lactobacillus acidophilus FNCC 0051) TO CHOLESTEROL REDUCTION by in vivo. In *Jurnal Teknologi Hasil Pertanian: Vol. IV* (Issue 1).

Hou, A. L., & Qu, J. P. (2019). Super-toughened poly(lactic Acid) with poly("-caprolactone) and ethylene-methyl acrylate-glycidyl methacrylate by reactive melt blending. *Polymers*, *11*(5). https://doi.org/10.3390/polym11050771

Kasirajan, S., Umapathy, D., Chandrasekar, C., Aafrin, V., Jenitapeter, M., Udhyasooriyan, L., Packirisamy, A. S. B., & Muthusamy, S. (2019). Preparation of poly(lactic acid) from Prosopis juliflora and incorporation of chitosan for packaging applications. *Journal of Bioscience and Bioengineering*, *128*(3), 323–331. https://doi.org/10.1016/j.jbiosc.2019.02.013

Katili, S., Harsunu, B. T., & Irawan, S. (2022). PENGARUH KONSENTRASI PLASTICIZER GLISEROL DAN KOMPOSISI KHITOSAN DALAM ZAT PELARUT TERHADAP SIFAT FISIK EDIBLE FILM DARI KHITOSAN. In *Jurnal Teknologi* (Vol. 6, Issue 1).

King, N. S., Luster-Teasley, S., & Clark, C. J. (2021). Preliminary Analyses of Controlled Release of Potassium Permanganate Encapsulated in Polycaprolactone. *Journal of Water Resource and Protection*, *13*(01), 32–43. https://doi.org/10.4236/jwarp.2021.131003

Kong, M., Chen, X. G., Xing, K., & Park, H. J. (2019). Antimicrobial properties of chitosan and mode of action: A state of the art review. In *International Journal of Food Microbiology* (Vol. 144, Issue 1, pp. 51–63). https://doi.org/10.1016/j.ijfoodmicro.2010.09.012

Konne, J. L. (2023). *Synthesis and Characterization of Chitosan-Copper complex using Shells of Fresh Water Shrimps and Salt Water Crabs in Rivers State as Raw Materials*. https://www.researchgate.net/publication/308693634

Kum Bora, K., & Mayur Choudhury, M. (2021). Suture Material-Its Importance in Wound Healing. *Journal of Evolution of Medical and Dental Sciences*, *4*, 48. https://doi.org/10.14260/jemds/2015/1204

Kumar Sharma, G., & Rachel James, N. (2023). Electrospinning: The Technique and Applications. In *Recent Developments in Nanofibers Research*. IntechOpen. https://doi.org/10.5772/intechopen.105804

Kuo, C. H., Chen, C. C., & Chiang, B. H. (2021). Process Characteristics of Hydrolysis of Chitosan in a Continuous Enzymatic Membrane Reactor. In *E332 JOURNAL OF FOOD SCIENCE* (Vol. 69, Issue 7). www.ift.org

Landén, N. X., Li, D., & Ståhle, M. (2016). Transition from inflammation to proliferation: a critical step during wound healing. In *Cellular and Molecular Life Sciences* (Vol. 73, Issue 20, pp. 3861–3885). Birkhauser Verlag AG. https://doi.org/10.1007/s00018-016-2268-0

Lazar, V. R. (2019). *Quantification of Bone Using a 3.0 Tesla Clinical Magnetic Resonance Scanner*. https://www.researchgate.net/publication/324819406

León-Sosa, A., Castañeda, V., Espinosa-Vallejo, R., Gómez, X., Díaz, R. F., Cabrera, F., & Caicedo, A. (2022). Key points for translating wound regenerative agents from in vivo assays in mice to clinical validation. *Cytotherapy*, *24*(11), 1074–1086. https://doi.org/10.1016/j.jcyt.2022.07.004

Li, L., Ding, S., & Zhou, C. (2020). *Preparation and Degradation of PLA/Chitosan Composite Materials*.

Liu, S., Yu, J., Li, H., Wang, K., Wu, G., Wang, B., Liu, M., Zhang, Y., Wang, P., Zhang, J., Wu, J., Jing, Y., Li, F., & Zhang, M. (2020). Controllable drug release behavior of polylactic acid (PLA) surgical suture coating with ciprofloxacin (CPFX)-polycaprolactone (PCL)/ polyglycolide (PGA). *Polymers*, *12*(2). https://doi.org/10.3390/polym12020288

Lu, Y., & Chen, S. C. (2020). Micro and nano-fabrication of biodegradable polymers for drug delivery. In *Advanced Drug Delivery Reviews* (Vol. 56, Issue 11, pp. 1621–1633). https://doi.org/10.1016/j.addr.2004.05.002

Łysik, D., Deptuła, P., Chmielewska, S., Bucki, R., & Mystkowska, J. (2022). Degradation of Polylactide and Polycaprolactone as a Result of Biofilm Formation Assessed under Experimental Conditions Simulating the Oral Cavity Environment. *Materials*, *15*(20). https://doi.org/10.3390/ma15207061

Ma, X., Qiao, C., Zhang, J., & Xu, J. (2018). Effect of sorbitol content on microstructure and thermal properties of chitosan films. *International Journal of Biological Macromolecules*, *119*, 1294–1297. https://doi.org/10.1016/j.ijbiomac.2018.08.060

Macedo, A. S., Mendes, F., Filipe, P., Reis, S., & Fonte, P. (2021). Nanocarrier-mediated topical insulin delivery for wound healing. In *Materials* (Vol. 14, Issue 15). MDPI AG. https://doi.org/10.3390/ma14154257

Mahatmanti, F. W., Kusumastuti, E., Jumaeri, J., Sulistyani, M., Susiyanti, A., Haryati, U., & Dirgantari, P. S. (2022). PEMBUATAN KITIN DAN KITOSAN DARI LIMBAH CANGKANG UDANG SEBAGAI UPAYA MEMANFAATKAN LIMBAH MENJADI MATERIAL MAJU. *Inovasi Kimia*, *1*, 1–38. https://doi.org/10.15294/ik.v1i1.60

Melani, A., Herawati, N., & Kurniawan, A. F. (2018). BIOPLASTIK PATI UMBI TALAS MELALUI PROSES MELT INTERCALATION. *Jurnal Distilasi*, *2*(2), 53. https://doi.org/10.32502/jd.v2i2.1204

Muanprasat, C., & Chatsudthipong, V. (2022). Chitosan oligosaccharide: Biological activities and potential therapeutic applications. In *Pharmacology and Therapeutics* (Vol. 170, pp. 80–97). Elsevier Inc. https://doi.org/10.1016/j.pharmthera.2016.10.013

Nandiyanto, A. B. D., Oktiani, R., & Ragadhita, R. (2019). How to read and interpret ftir spectroscope of organic material. *Indonesian Journal of Science and Technology*, *4*(1), 97–118. https://doi.org/10.17509/ijost.v4i1.15806

Naveed, M., Phil, L., Sohail, M., Hasnat, M., Baig, M. M. F. A., Ihsan, A. U., Shumzaid, M., Kakar, M. U., Mehmood Khan, T., Akabar, M. D., Hussain, M. I., & Zhou, Q. G. (2019). Chitosan oligosaccharide (COS): An overview. In *International Journal of Biological Macromolecules* (Vol. 129, pp. 827–843). Elsevier B.V. https://doi.org/10.1016/j.ijbiomac.2019.01.192

Niu, J., Lin, H. Z., Jiang, S. G., Chen, X., Wu, K. C., Liu, Y. J., Wang, S., & Tian, L. X. (2020). Comparison of effect of chitin, chitosan, chitosan oligosaccharide and N-acetyl-d-glucosamine on growth performance, antioxidant defenses and oxidative stress status of Penaeus monodon. *Aquaculture*, *372–375*, 1–8. https://doi.org/10.1016/j.aquaculture.2012.10.021

Paduan Pcl, K., DAN KITOSAN NANOKOMPOSIT Mukhsin, B., Sami, M., & Rihayat, T. (2018). *A-200* (Vol. 2, Issue 1).

Pillai, C. K. S., & Sharma, C. P. (2019). Review paper: Absorbable polymeric surgical sutures: Chemistry, production, properties, biodegradability, and performance. In *Journal of Biomaterials Applications* (Vol. 25, Issue 4, pp. 291–366). https://doi.org/10.1177/0885328210384890

Ramasastry, S. S. (2020). Acute wounds. In *Clinics in Plastic Surgery* (Vol. 32, Issue 2, pp. 195–208). W.B. Saunders. https://doi.org/10.1016/j.cps.2004.12.001

Razi, M. A. (2022). Chitosan Oligosaccharides as a Nanomaterial Platform: Biological Properties and Applications in the Biomedical and Pharmaceutical Fields. *Makara Journal of Science*, *26*(4), 238–254. https://doi.org/10.7454/mss.v26i4.1337

Rojas-Rojas, L., & Teodolíto Guillén-Girón. (2023). Mechanical properties of polycaprolactone microfilaments for muscular tissue engineering. *Revista Tecnología En Marcha*. https://doi.org/10.18845/tm.v36i2.6154

Saragih. (2019). KOMPOSIT NANOFIBER PVAc (POLYVINIYL ACETATE) DAN STYROFOAM UNTUK MENINGKATKAN KINERJA PENYARINGAN UDARA. *KOMPOSIT NANOFIBER PVAc (POLYVINIYL ACETATE) DAN STYROFOAM UNTUK MENINGKATKAN KINERJA PENYARINGAN UDARA*.

Shahbaz, U., Basharat, S., Javed, U., Bibi, A., & Yu, X. Bin. (2023). Chitosan: a multipurpose polymer in food industry. In *Polymer Bulletin* (Vol. 80, Issue 4, pp. 3547–3569). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/s00289-022-04269-0

Singh, B., Sharma, C., & Sharma, S. (2019). *Fundamentals of Extrusion processing*. https://www.researchgate.net/publication/326583547

Solekah, S., Sasria, N., Hizkia, D., & Dewanto, A. (2021). PENGARUH PENAMBAHAN GLISEROL DAN KITOSAN KULIT UDANG TERHADAP BIODEGRADASI DAN KETAHANAN AIR PLASTIK BIODEGRADABLE. In *Jurnal Ilmu Kimia dan Terapan* (Vol. 8, Issue 2).

Subbiah, T., Bhat, G. S., Tock, R. W., Parameswaran, S., & Ramkumar, S. S. (2023). Electrospinning of nanofibers. *Journal of Applied Polymer Science*, *96*(2), 557–569. https://doi.org/10.1002/app.21481

Sugiyana, D., Wahyudi, T., & Sugiyana Balai Besar Tekstil Jl Yani, D. A. (2019). *PEMBUATAN SERAT NANO MENGGUNAKAN METODE ELECTROSPINNING*.

Tefa, M., & Edi Santosa, I. (2021). Pengukuran Modulus Young dengan Analisis Keadaan Resonansi Batang Aluminium yang Bergetar Menggunakan ImageMeter. *Prosiding SNFA (Seminar Nasional Fisika Dan Aplikasinya)*, *2*, 346. https://doi.org/10.20961/prosidingsnfa.v2i0.21370

Trinh, X. T., Long, N. Van, Van Anh, L. T., Nga, P. T., Giang, N. N., Chien, P. N., Nam, S. Y., & Heo, C. Y. (2022). A Comprehensive Review of Natural Compounds for Wound Healing: Targeting Bioactivity Perspective. In *International Journal of Molecular Sciences* (Vol. 23, Issue 17). MDPI. https://doi.org/10.3390/ijms23179573

Vieira, A. C., Medeiros, R., Guedes, R. M., Marques, A. T., & Tita, V. (2021). Visco-elastic-plastic properties of suture fibers made of PLA-PCL. *Materials Science Forum*, *730–732*, 56–61. https://doi.org/10.4028/www.scientific.net/MSF.730-732.56

Wang, W., Meng, Q., Li, Q., Liu, J., Zhou, M., Jin, Z., & Zhao, K. (2020). Chitosan derivatives and their application in biomedicine. In *International Journal of Molecular Sciences* (Vol. 21, Issue 2). MDPI AG. https://doi.org/10.3390/ijms21020487

Xu, L., Liu, Y., Zhou, W., & Yu, D. (2022a). Electrospun Medical Sutures for Wound Healing: A Review. In *Polymers* (Vol. 14, Issue 9). MDPI. https://doi.org/10.3390/polym14091637

Xu, L., Liu, Y., Zhou, W., & Yu, D. (2022b). Electrospun Medical Sutures for Wound Healing: A Review. In *Polymers* (Vol. 14, Issue 9). MDPI. https://doi.org/10.3390/polym14091637

Yuan, X., Zheng, J., Jiao, S., Cheng, G., Feng, C., Du, Y., & Liu, H. (2019). A review on the preparation of chitosan oligosaccharides and application to human health, animal husbandry and agricultural production. In *Carbohydrate Polymers* (Vol. 220, pp. 60–70). Elsevier Ltd. https://doi.org/10.1016/j.carbpol.2019.05.050

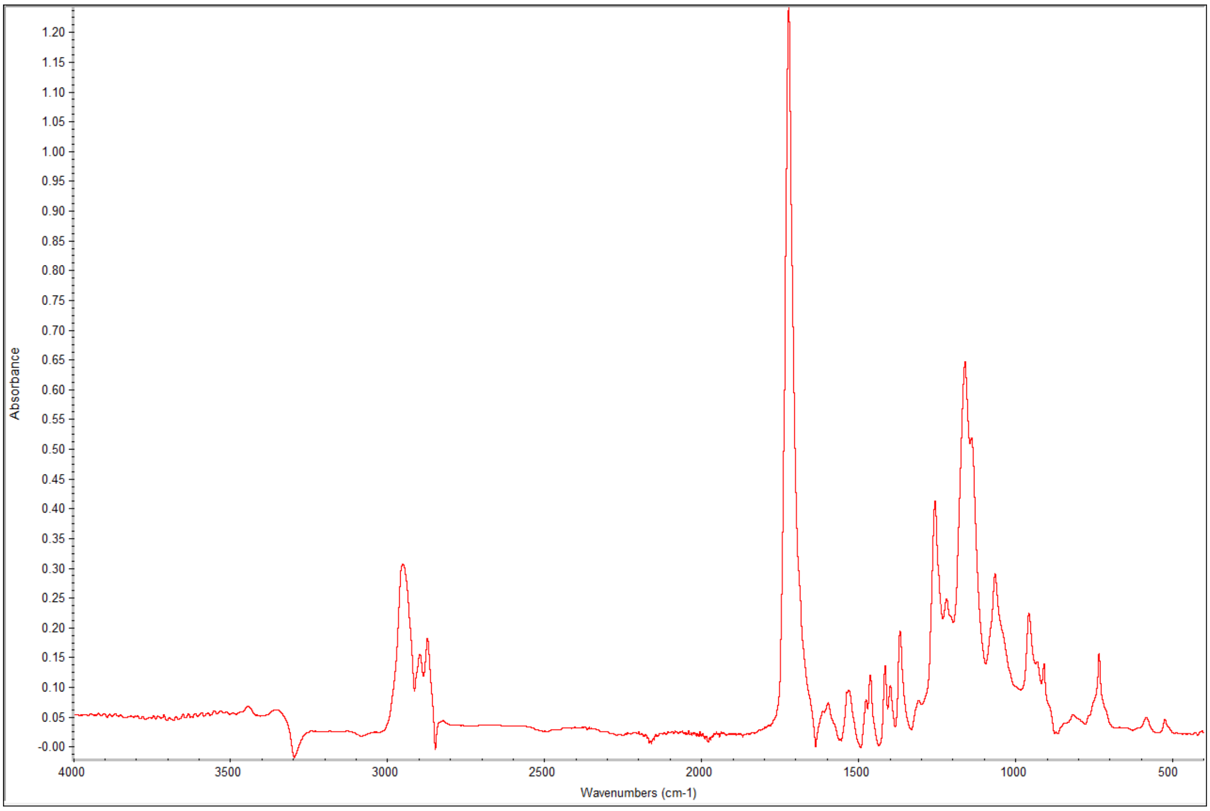
Zhang, Y., & Wang, Y. (2022). Electrospun Cellulose-Acetate/Chitosan Fibers for Humic-Acid Removal: Improved Efficiency and Robustness with a Core-Sheath Design. *Nanomaterials*, *12*(8). https://doi.org/10.3390/nano12081284

(This page is intentionally blank)

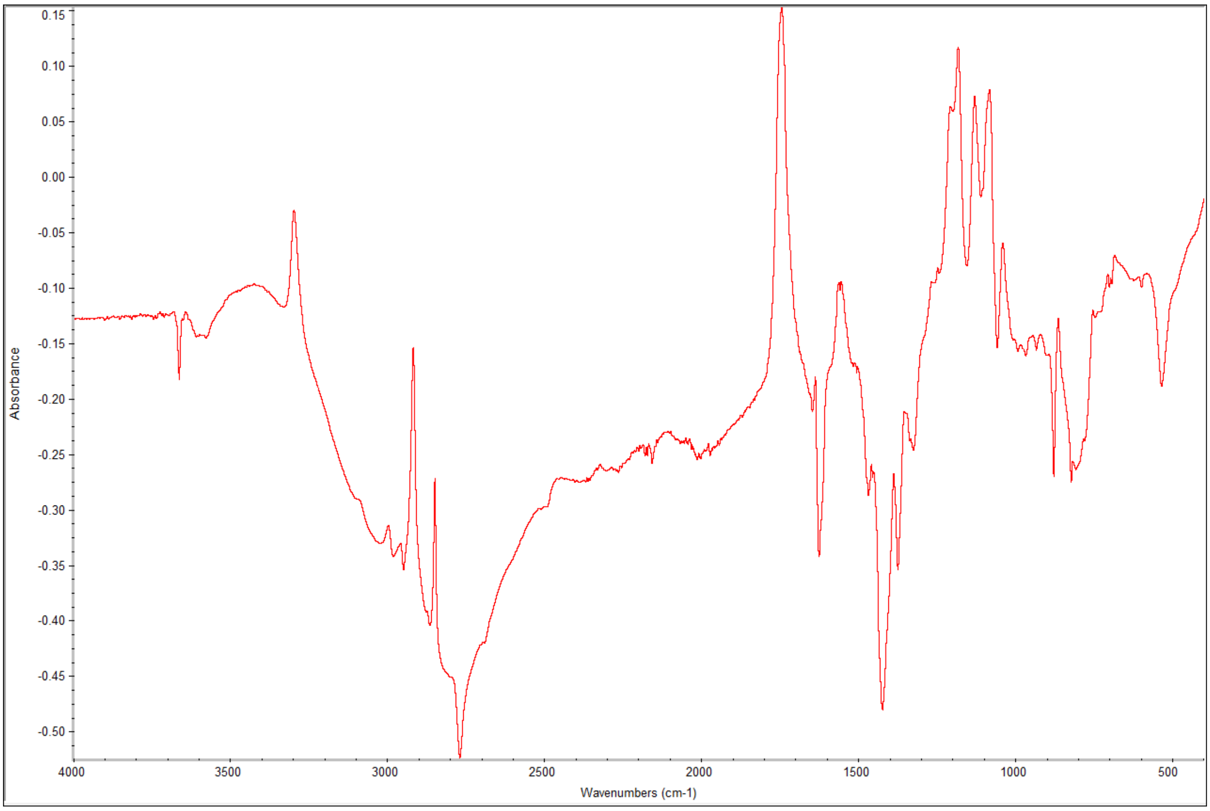
ATTACHMENTS

Attachment 1: FTIR Pattern Results

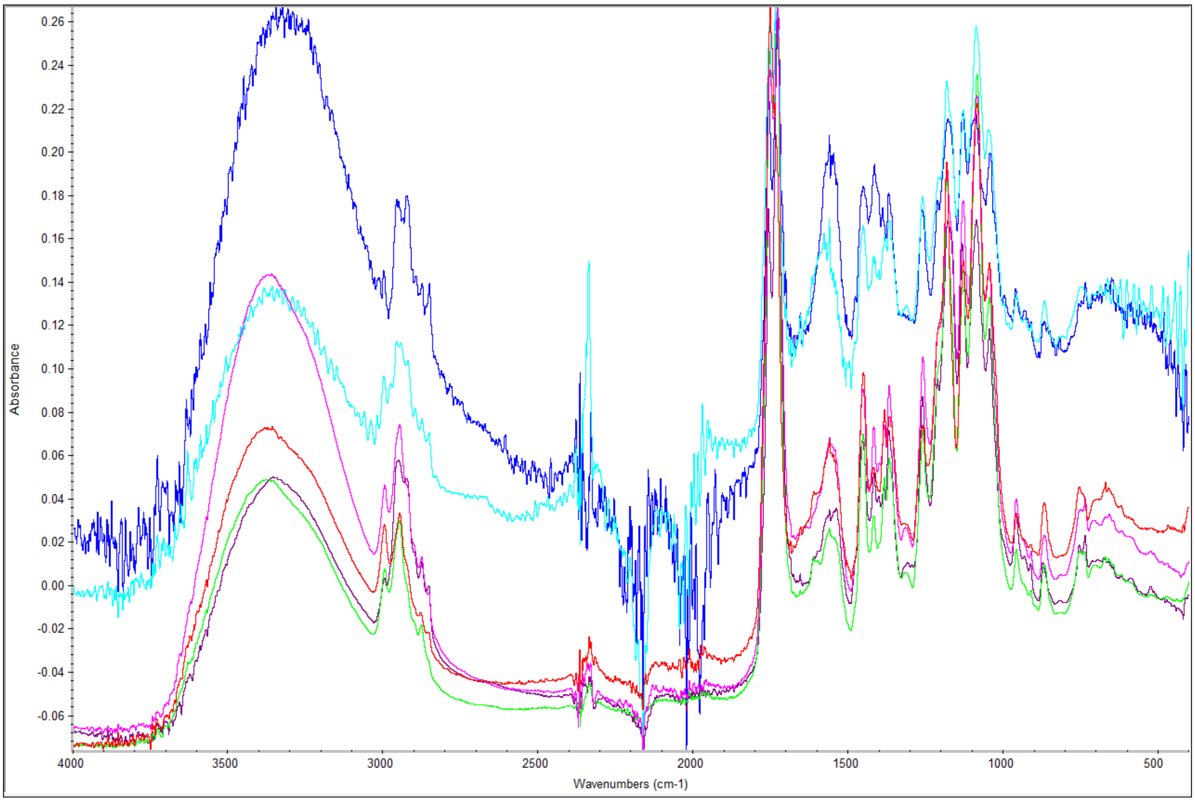
a. PCL



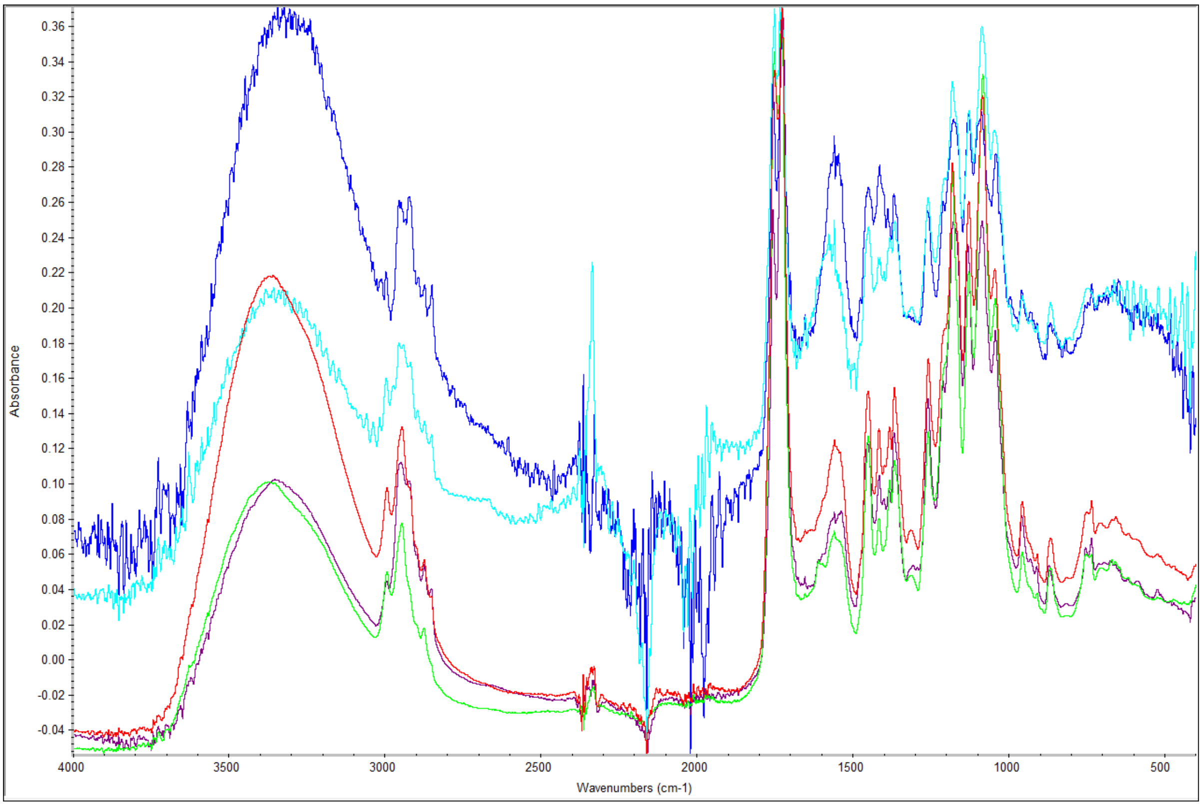
b. PLA



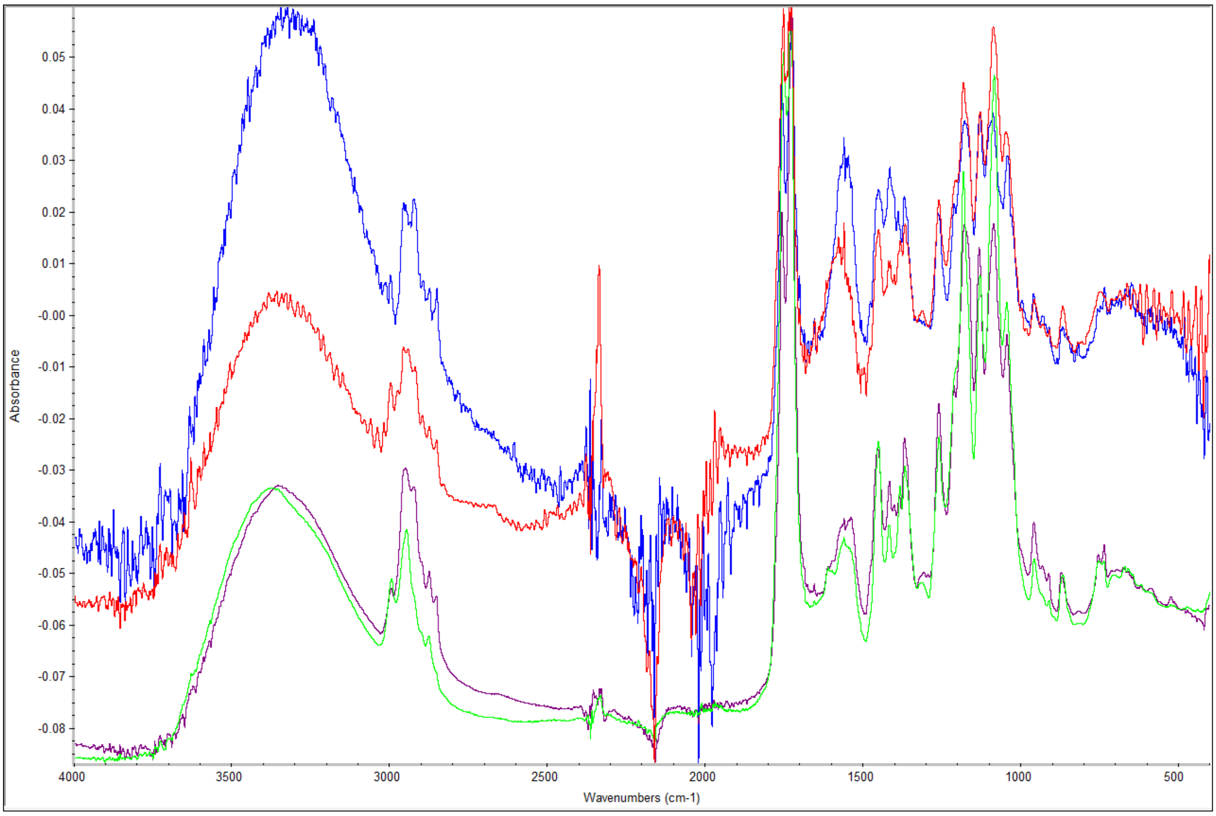
c. C01


Absorbance
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
4000
3500
3000
2500
2000
1500
1000
500
Wavenumbers (cm-1)

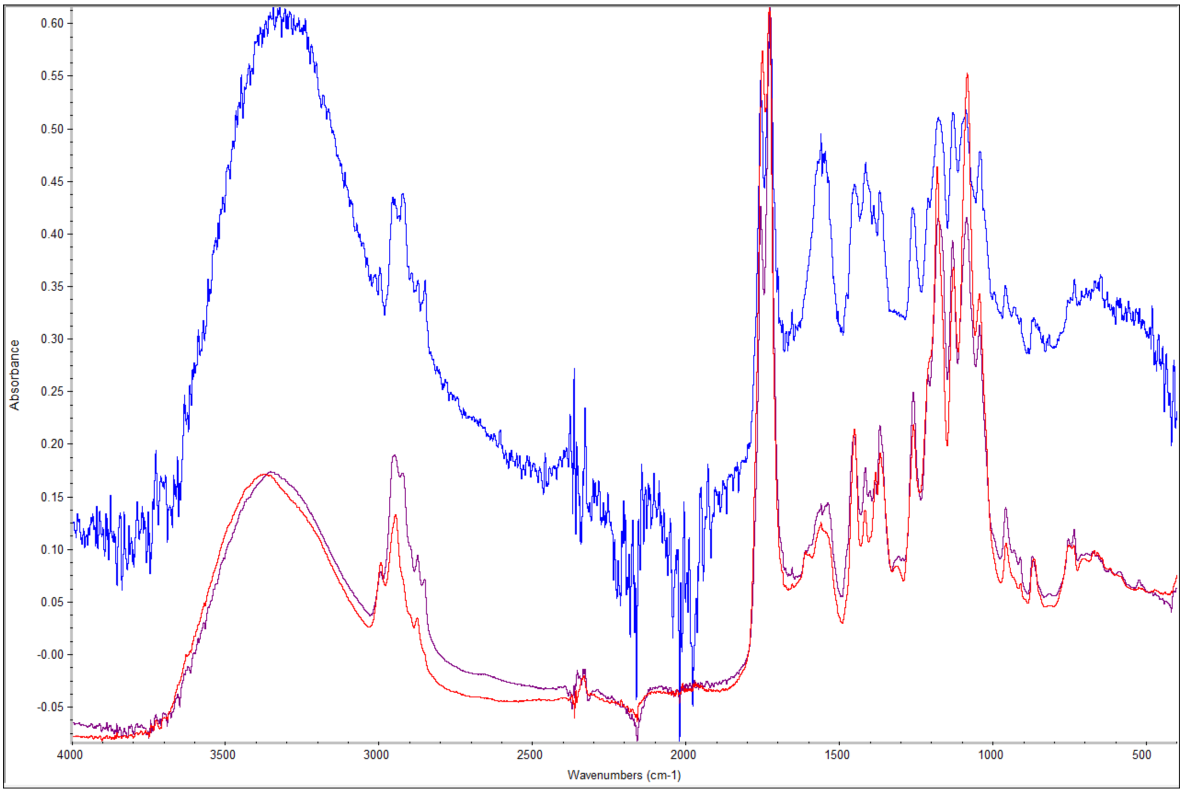
d. C02


Absorbance
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
4000
3500
3000
2500
2000
1500
1000
500
Wavenumbers (cm-1)

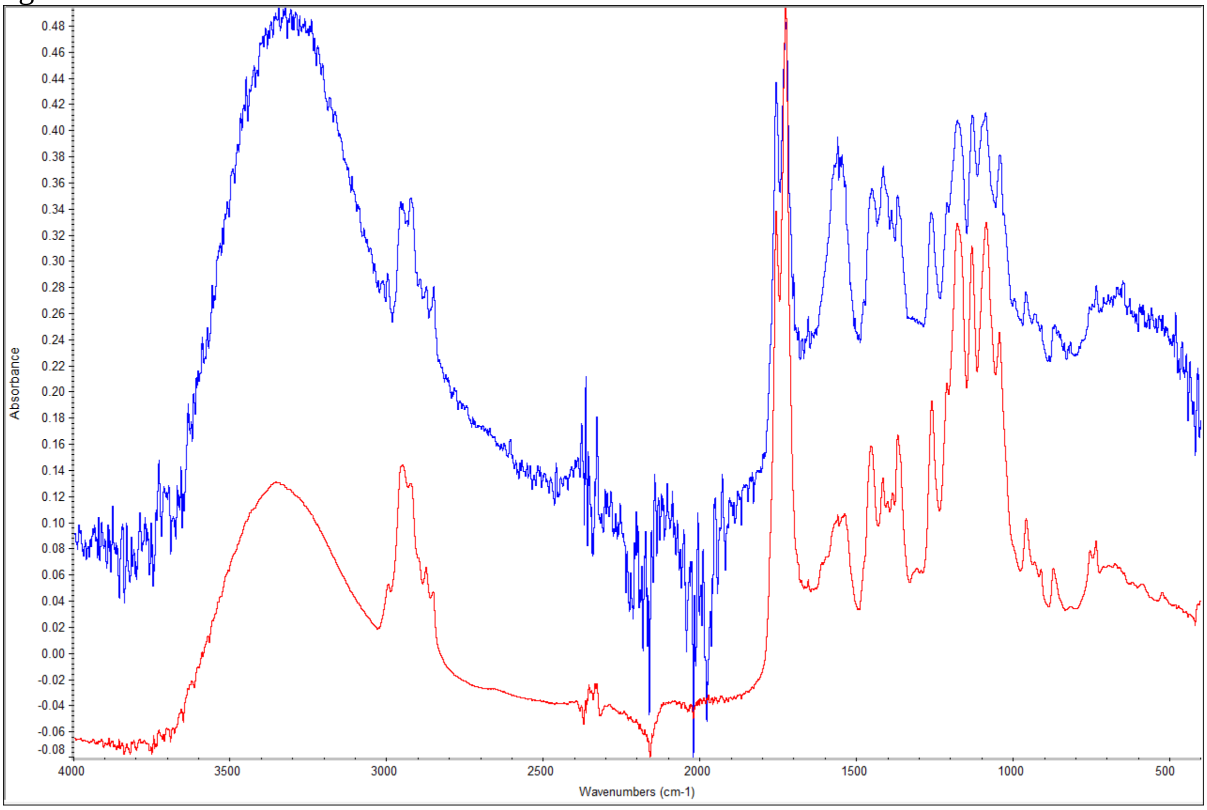
e. C03


Absorbance
0.05
0.04
0.03
0.02
0.01
-0.00
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
4000
3500
3000
2500
2000
1500
1000
500
Wavenumbers (cm-1)

f. C04


Absorbance
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
-0.00
-0.05
4000
3500
3000
2500
2000
1500
1000
500
Wavenumbers (cm-1)

g. C05



Attachment 2: Tensile Test Results

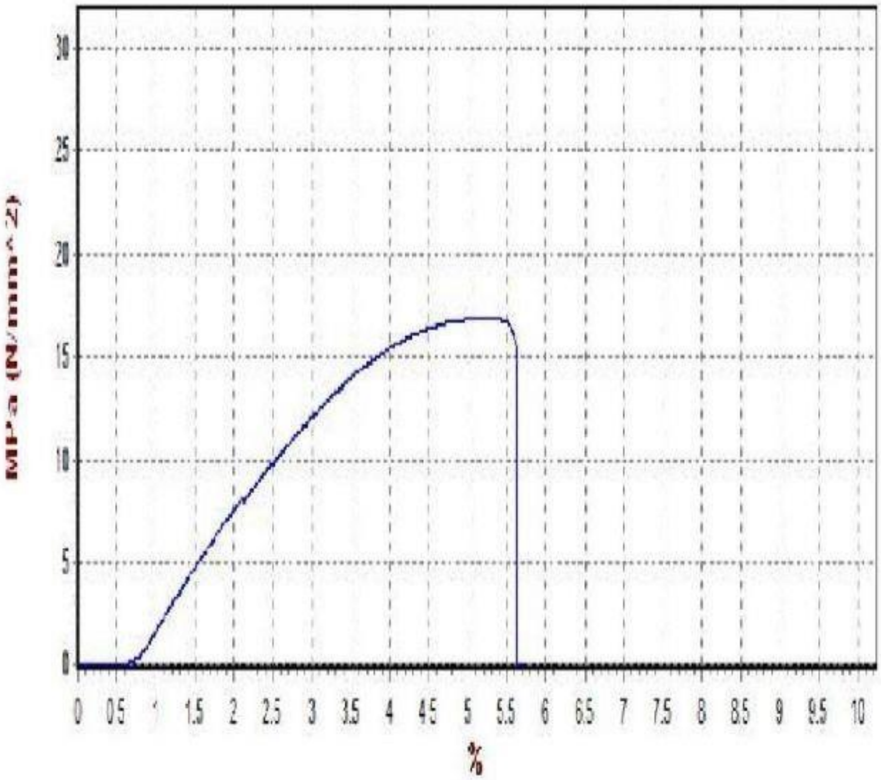
a. C01

LABORATORIUM INOVASI MATERIAL
JURUSAN TEKNIK MATERIAL DAN METALURGI
FAKULTAS TEKNOLOGI INDUSTRI
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
Kampus ITS Sukolilo, Surabaya 60111

TEST REPORT

Information : tasya tarik   Date :

Specimens	Area mm^2	Max Force N	Yield Strength N/mm^2	Tensile Strength N/mm^2	Young's Modulus (E) N/mm^2	Elongation %
90/10;4:1	0.126	2.1	15.13	16.88	490.31	5.74



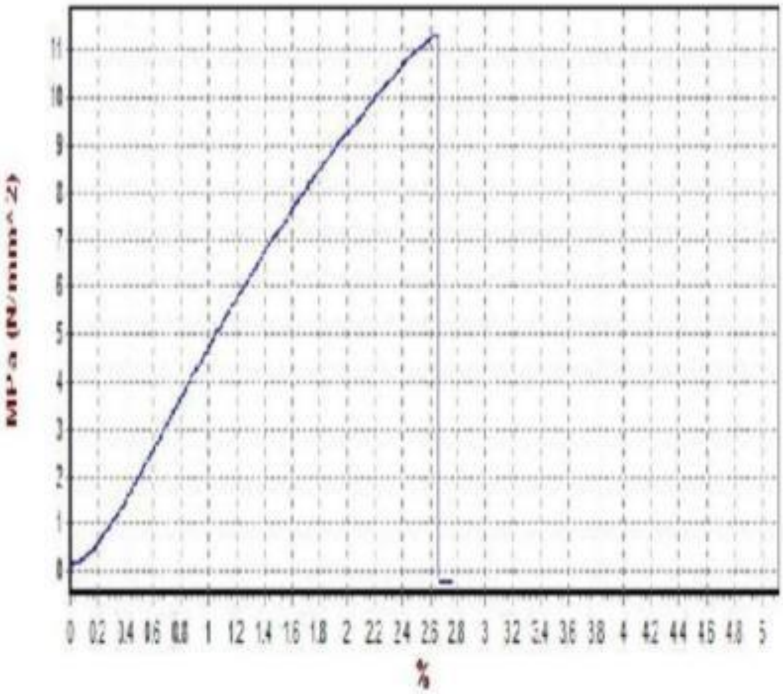
Tester. : ____________   *Customer :* ____________

LABORATORIUM INOVASI MATERIAL
JURUSAN TEKNIK MATERIAL DAN METALURGI
FAKULTAS TEKNOLOGI INDUSTRI
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
Kampus ITS Sukolilo, Surabaya 60111

TEST REPORT

Information : tasya tarik **Date :**

Specimens	Area mm^2	Max Force N	Yield Strength N/mm^2	Tensile Strength N/mm^2	Young's Modulus (E) N/mm^2	Elongation %
90/10;4:1	0.126	1.4	1.41	11.31	510.41	2.77



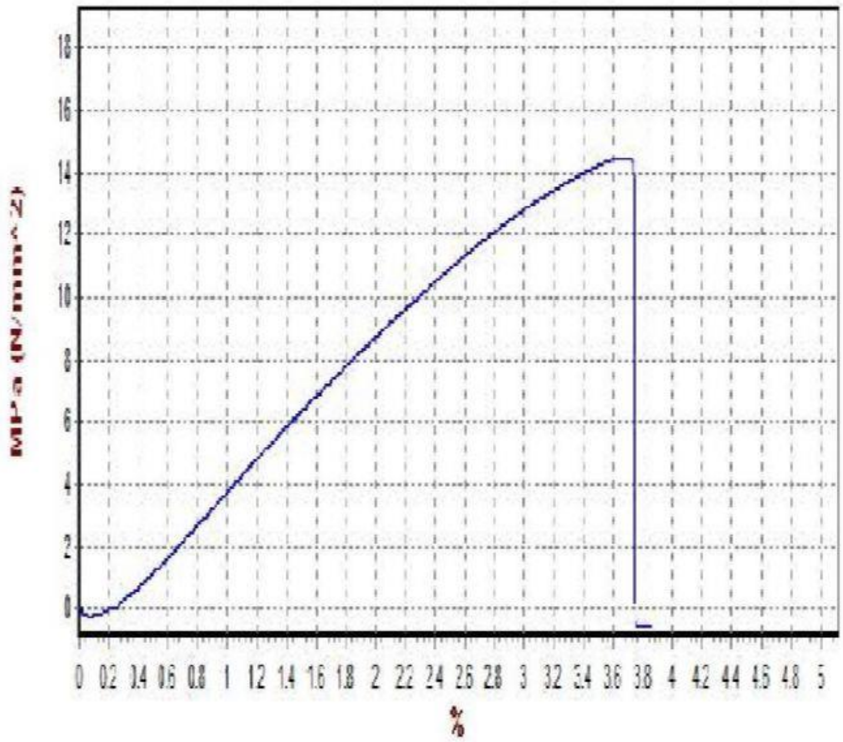
Tester. : ____________ *Customer :* ____________

LABORATORIUM INOVASI MATERIAL
JURUSAN TEKNIK MATERIAL DAN METALURGI
FAKULTAS TEKNOLOGI INDUSTRI
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
Kampus ITS Sukolilo, Surabaya 60111

TEST REPORT

Information : tasya tarik **Date :**

Specimens	Area mm^2	Max Force N	Yield Strength N/mm^2	Tensile Strength N/mm^2	Young's Modulus (E) N/mm^2	Elongation %
90/10;4:1	0.126	1.8	1.38	14.46	491.83	3.86



Tester. : ____________ *Customer :* ____________

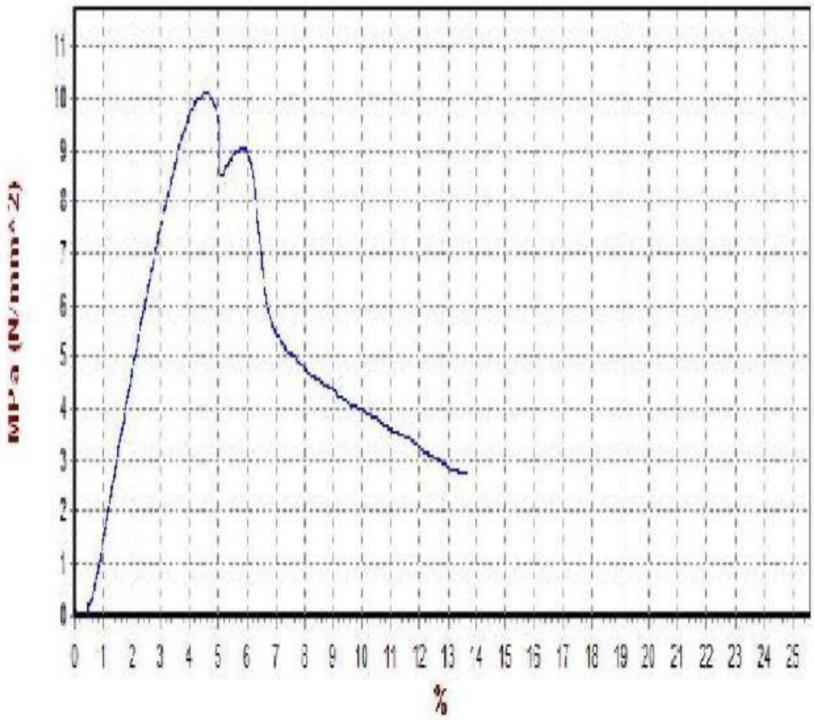
b. C02

LABORATORIUM INOVASI MATERIAL
JURUSAN TEKNIK MATERIAL DAN METALURGI
FAKULTAS TEKNOLOGI INDUSTRI
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
Kampus ITS Sukolilo, Surabaya 60111

TEST REPORT

Information : tasya tarik   Date :

Specimens	Area mm²	Max Force N	Yield Strength N/mm²	Tensile Strength N/mm²	Young's Modulus (E) N/mm²	Elongation %
95/5;1:1	0.126	1.3	10.11	10.13	307.25	13.67



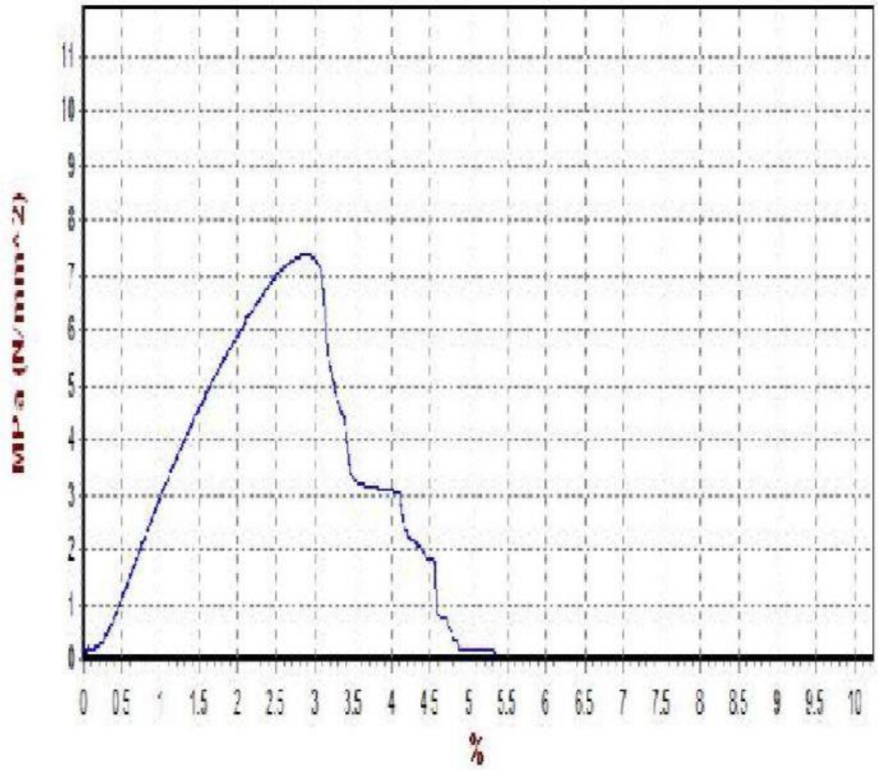
Tester. : ____________   Customer : ____________

LABORATORIUM INOVASI MATERIAL
JURUSAN TEKNIK MATERIAL DAN METALURGI
FAKULTAS TEKNOLOGI INDUSTRI
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
Kampus ITS Sukolilo, Surabaya 60111

TEST REPORT

Information : tasya tarik **Date :**

Specimens	Area mm^2	Max Force N	Yield Strength N/mm^2	Tensile Strength N/mm^2	Young's Modulus (E) N/mm^2	Elongation %
955; 11	0.126	0.9	0.65	7.39	336.23	5.37



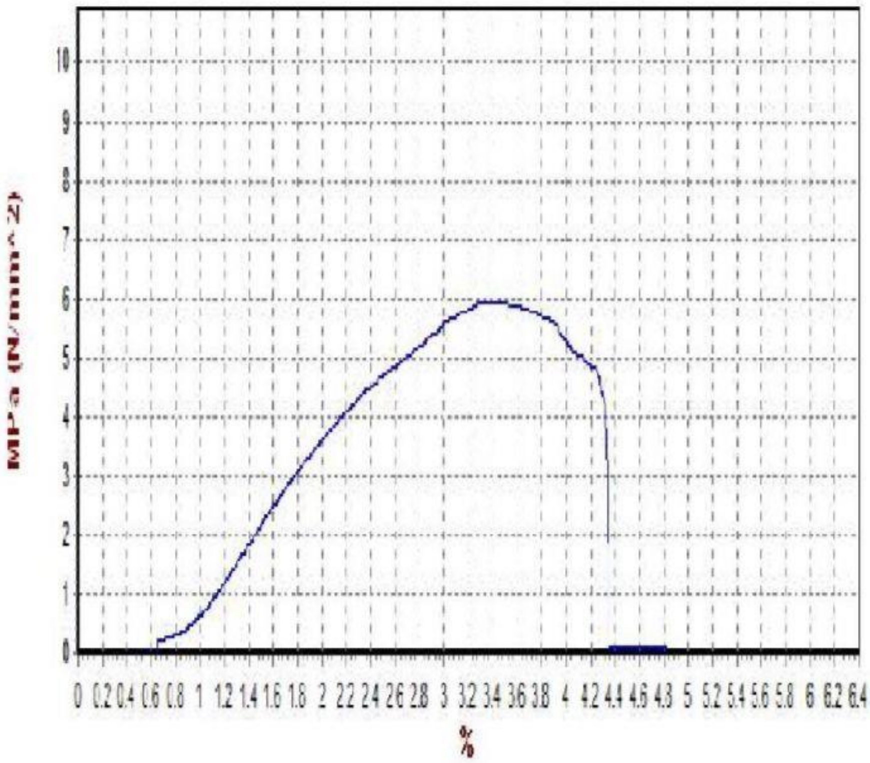
Tester. : ____________ *Customer :* ____________

LABORATORIUM INOVASI MATERIAL
JURUSAN TEKNIK MATERIAL DAN METALURGI
FAKULTAS TEKNOLOGI INDUSTRI
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
Kampus ITS Sukolilo, Surabaya 60111

TEST REPORT

Information : tasya tarik **Date :**

Specimens	Area mm^2	Max Force N	Yield Strength N/mm^2	Tensile Strength N/mm^2	Young's Modulus (E) N/mm^2	Elongation %
955; 11	0.126	0.7	5.94	5.94	300.43	4.84



Tester. : ____________   *Customer :* ____________

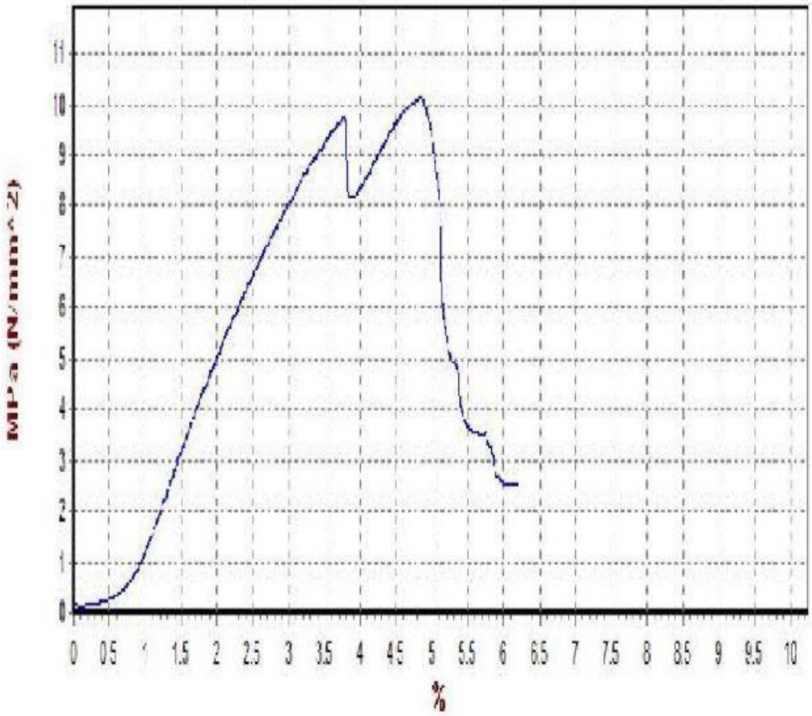
c. C03

LABORATORIUM INOVASI MATERIAL
JURUSAN TEKNIK MATERIAL DAN METALURGI
FAKULTAS TEKNOLOGI INDUSTRI
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
Kampus ITS Sukolilo, Surabaya 60111

TEST REPORT

Information : tasya tarik **Date :**

Specimens	Area mm ^{2}	Max Force N	Yield Strength N/mm ^{2}	Tensile Strength N/mm ^{2}	Young's Modulus (E) N/mm ^{2}	Elongation %
95/5;2:1	0.126	1.3	10.11	10.12	359.81	6.22



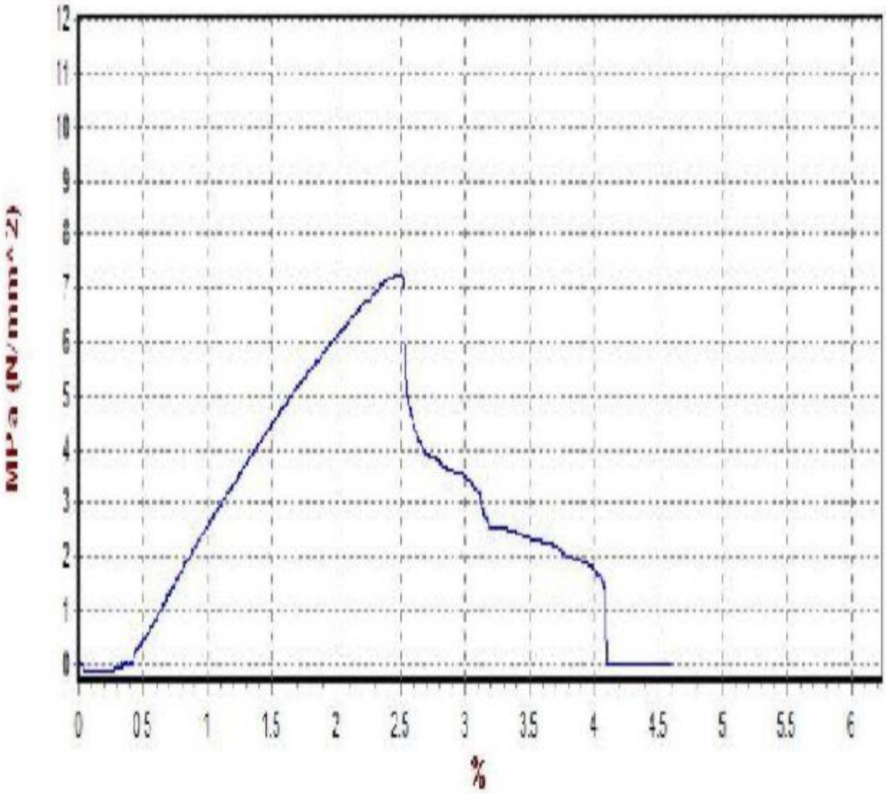
Tester. : __________ *Customer :* __________

LABORATORIUM INOVASI MATERIAL
JURUSAN TEKNIK MATERIAL DAN METALURGI
FAKULTAS TEKNOLOGI INDUSTRI
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
Kampus ITS Sukolilo, Surabaya 60111

TEST REPORT

Information : tasya tarik **Date :**

Specimens	Area mm^2	Max Force N	Yield Strength N/mm^2	Tensile Strength N/mm^2	Young's Modulus (E) N/mm^2	Elongation %
955; 21	0.126	0.9		7.28	386.82	4.61



Tester. : ____________ *Customer :* ____________

LABORATORIUM INOVASI MATERIAL
JURUSAN TEKNIK MATERIAL DAN METALURGI
FAKULTAS TEKNOLOGI INDUSTRI
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
Kampus ITS Sukolilo, Surabaya 60111

TEST REPORT

Information : tasya tarik **Date :**

Specimens	Area mm²	Max Force N	Yield Strength N/mm²	Tensile Strength N/mm²	Young's Modulus (E) N/mm²	Elongation %
95/5;2:1	0.126	1.5	1.56	11.68	429.11	3.75

Tester. : ____________ *Customer :* ____________

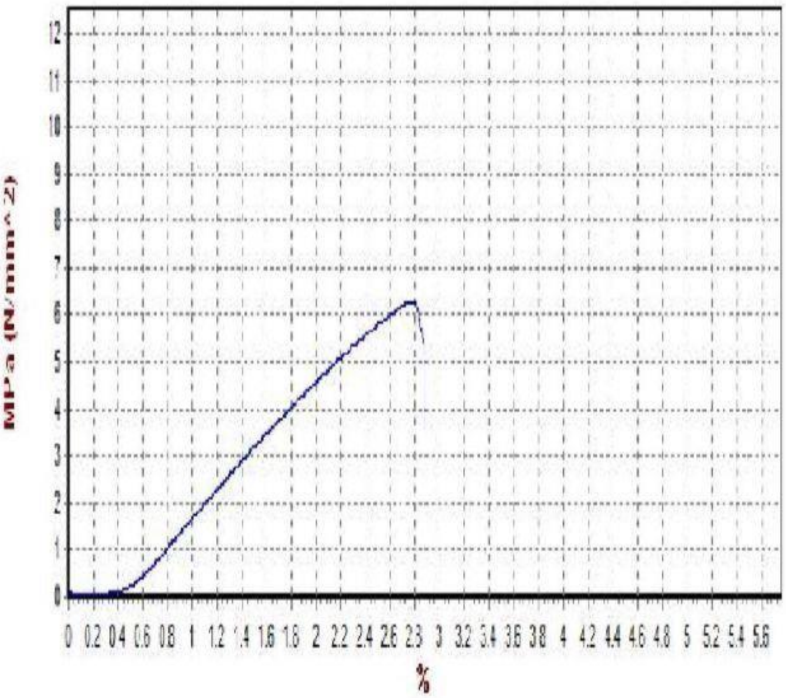
d. C04

LABORATORIUM INOVASI MATERIAL
JURUSAN TEKNIK MATERIAL DAN METALURGI
FAKULTAS TEKNOLOGI INDUSTRI
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
Kampus ITS Sukolilo, Surabaya 60111

TEST REPORT

Information : tasya tarik **Date :**

Specimens	Area mm^2	Max Force N	Yield Strength N/mm^2	Tensile Strength N/mm^2	Young's Modulus (E) N/mm^2	Elongation %
90/10;2:1	0.126	0.8	0.17	6.27	297.53	2.88



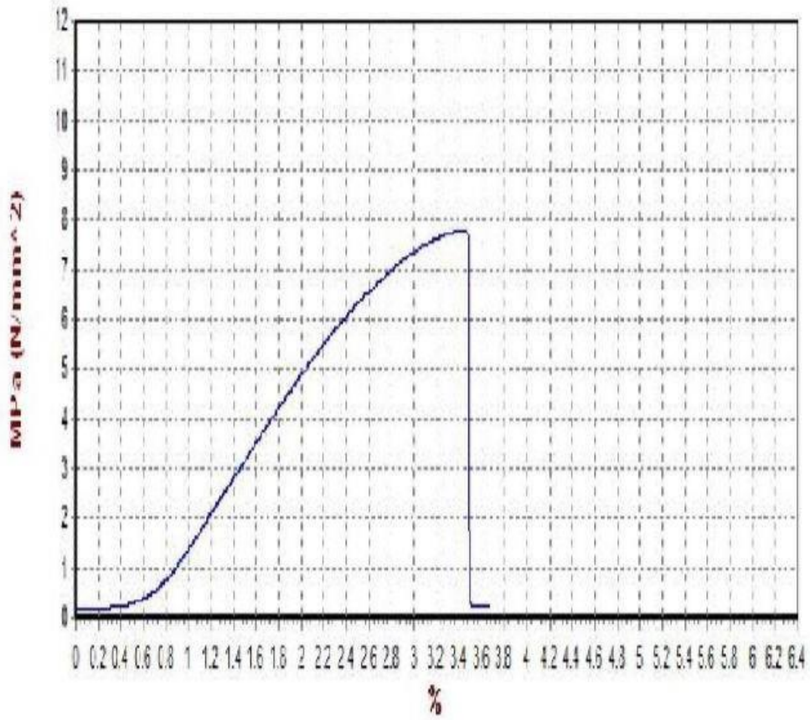
Tester. : ____________ *Customer :* ____________

LABORATORIUM INOVASI MATERIAL
JURUSAN TEKNIK MATERIAL DAN METALURGI
FAKULTAS TEKNOLOGI INDUSTRI
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
Kampus ITS Sukolilo, Surabaya 60111

TEST REPORT

Information : tasya tarik **Date :**

Specimens	Area mm^2	Max Force N	Yield Strength N/mm^2	Tensile Strength N/mm^2	Young's Modulus (E) N/mm^2	Elongation %
90/10;2:1	0.126	1.0	7.77	7.78	353.20	3.67



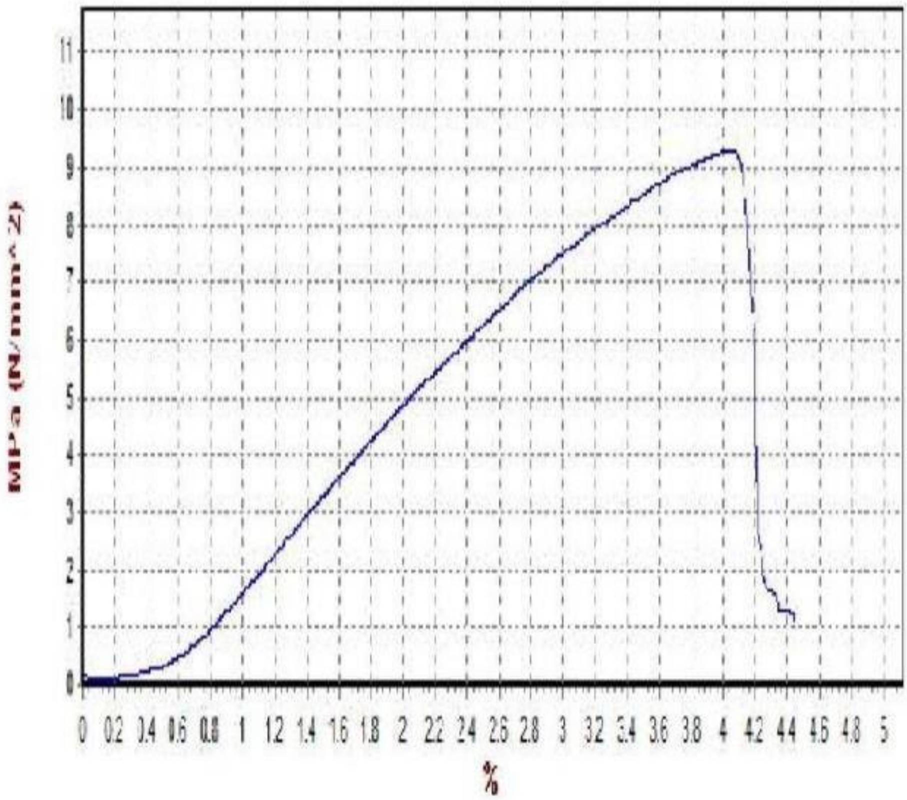
Tester. : ____________ *Customer :* ____________

LABORATORIUM INOVASI MATERIAL
JURUSAN TEKNIK MATERIAL DAN METALURGI
FAKULTAS TEKNOLOGI INDUSTRI
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
Kampus ITS Sukolilo, Surabaya 60111

TEST REPORT

Information : tasya tarik **Date :**

Specimens	Area mm^2	Max Force N	Yield Strength N/mm^2	Tensile Strength N/mm^2	Young's Modulus (E) N/mm^2	Elongation %
90/10;2:1	0.126	1.2	9.25	9.28	311.52	4.45



Tester. : ____________ *Customer :* ____________

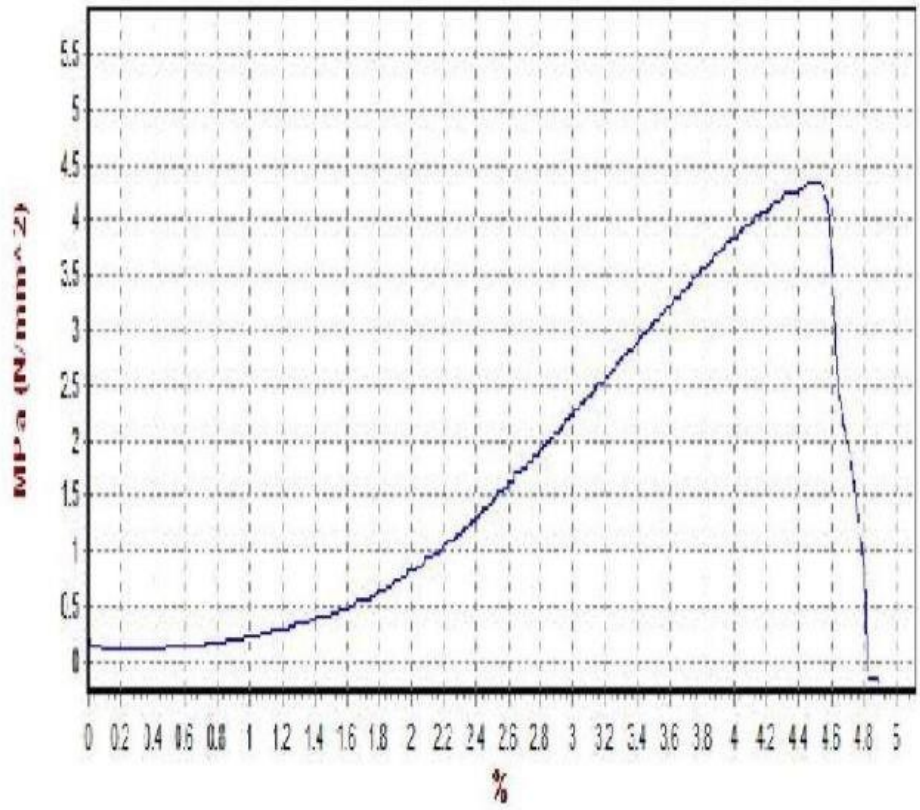
e. C05

LABORATORIUM INOVASI MATERIAL
JURUSAN TEKNIK MATERIAL DAN METALURGI
FAKULTAS TEKNOLOGI INDUSTRI
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
Kampus ITS Sukolilo, Surabaya 60111

TEST REPORT

Information : tasya tarik **Date :**

Specimens	Area mm ^{2}	Max Force N	Yield Strength N/mm ^{2}	Tensile Strength N/mm ^{2}	Young's Modulus (E) N/mm ^{2}	Elongation %
80/20;2:1	0.126	0.5	4.29	4.33	159.11	4.90



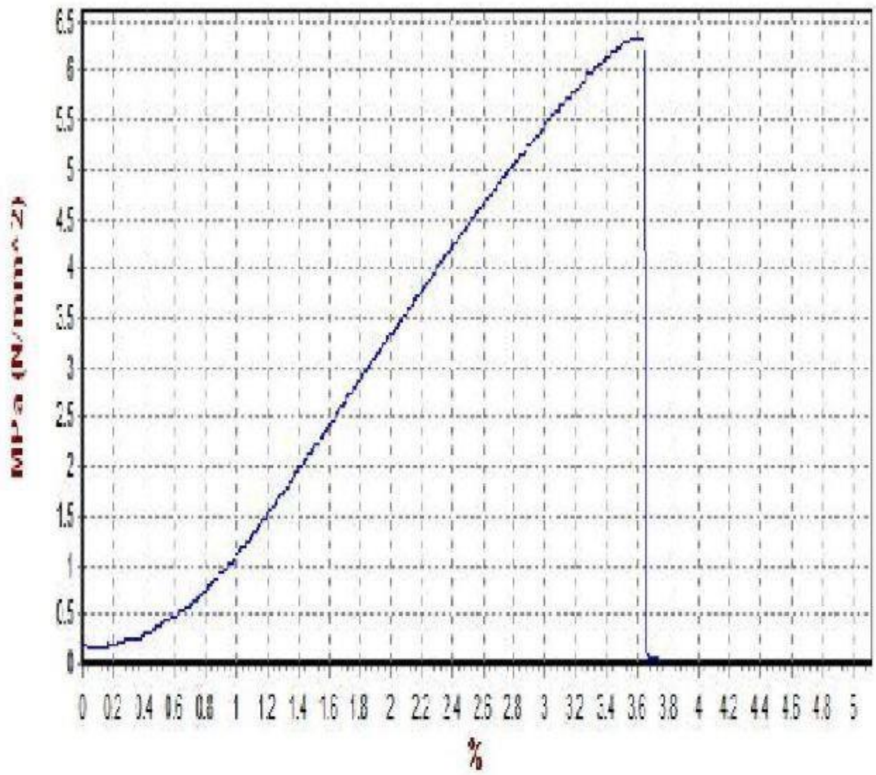
Tester. : ____________ *Customer :* ____________

LABORATORIUM INOVASI MATERIAL
JURUSAN TEKNIK MATERIAL DAN METALURGI
FAKULTAS TEKNOLOGI INDUSTRI
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
Kampus ITS Sukolilo, Surabaya 60111

TEST REPORT

Information : tasya tarik **Date :**

Specimens	Area mm^2	Max Force N	Yield Strength N/mm^2	Tensile Strength N/mm^2	Young's Modulus (E) N/mm^2	Elongation %
80/20;2:1	0.126	0.8	6.31	6.34	227.27	3.89



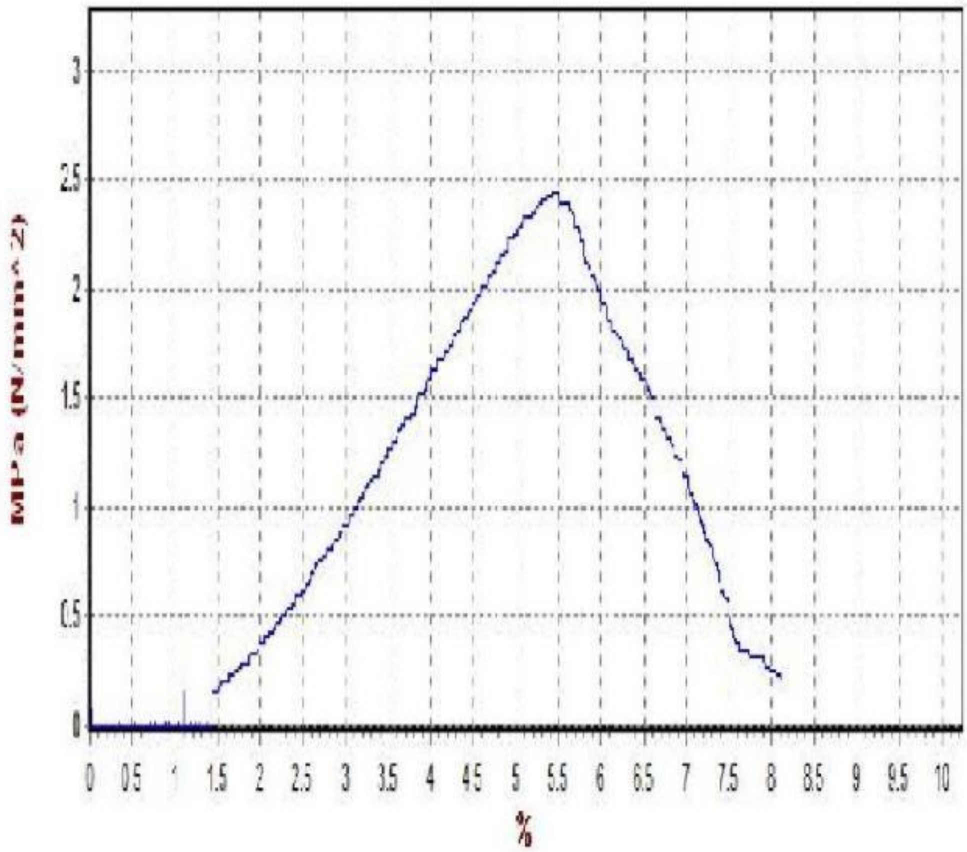
Tester. : ____________ *Customer :* ____________

LABORATORIUM INOVASI MATERIAL
JURUSAN TEKNIK MATERIAL DAN METALURGI
FAKULTAS TEKNOLOGI INDUSTRI
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
Kampus ITS Sukolilo, Surabaya 60111

TEST REPORT

Information : tasya tarik **Date :**

Specimens	Area mm^2	Max Force N	Yield Strength N/mm^2	Tensile Strength N/mm^2	Young's Modulus (E) N/mm^2	Elongation %
8020; 21	0.126	0.3	2.42	2.43	64.58	8.12



Tester. : ____________ *Customer :* ____________

(This page is intentionally blank)

ACKNOWLEDGEMENTS

The author expresses profound gratitude and appreciation to all parties who have contributed to the research and completion of this final project report. I extend my heartfelt thanks to:

1. God Almighty, for His blessings and guidance throughout the process of completing this Final Project, despite the numerous challenges faced.
2. My beloved parents, for their unwavering moral support and ceaseless prayers during this journey.
3. Mrs. Yuli Setiyorini, S.T., M.Phil., Ph.D.Eng., and Mrs. Azzah Dyah Pramata, S.T., M.T., M.Eng., Ph.D., my thesis advisors and co advisors, for their invaluable guidance, knowledge, and direction.
4. My colleagues in the extraction laboratory, for their constant support and companionship throughout the research process.
5. Diaz Fajar R., for being by my side through every joy and hardship during the execution of this Final Project.
6. My IUP peers, namely Ika, Mike, Hani, Dandy, Raphael, Fathan, Ivan, Wita, and Rora, for their camaraderie and support.
7. The late Izzan Widad, my best friend, who has always been a source of inspiration and motivation.
8. Mr. Ridha, Jennifer, Alamanda, Zidny, and other friends from the physics and materials science community, for their companionship and encouragement throughout the final project journey.
9. All friends who cannot be named individually, for their direct and indirect support and motivation.

Surabaya, 29 July 2024

Lidya Natasya

(This page is intentionally blank)

AUTHOR BIOGRAPHY

The author's name is Lidya Natasya, born in Jakarta, August 03, 2002. Currently the author is an 8th semester student at the Department of Materials Engineering and Metallurgy FTIRS, Sepuluh Nopember Institute of Technology Surabaya. The author has taken formal education, namely SD Marsudirini North Jakarta, SMPN 216 Jakarta, and SMAN 31 Jakarta, then continued her undergraduate studies at the Department of Materials Engineering and Metallurgy, Institut Teknologi Sepuluh Nopember Surabaya. During college, the author actively participated in several non-academic activities in the form of campus organizations and committees, such as Staff at HMMT FTI ITS, Kestari at Gerigi 2021, and Head of the Equipment Division at the 62nd ITS Anniversary. The author has practical work experience in the Drilling and Well Intervention section at PT Pertamina Hulu Energi South Jakarta. In addition, the author has international exposure experience, namely undergoing student exchange in Nantes, France for 5 months from January 2023 to June 2023 at École Supérieure du Bois (ESB). To complete his undergraduate education, the author conducted research in the field of Innovative Materials with a final project entitled "DEVELOPMENT OF BIOSUTURE BASED ON NANO CHITOSAN OLIGOSACCHARIDE-POLYLACTIC ACID-POLYCAPROLACTONE". The author can be contacted via email address: lidyanatasya3@gmail.com and cell phone number: 08119444346

(This page is intentionally blank)