Formulation And Evaluation of Fibre Composed Biodegradable Herbal Bandages to Increase Efficiency of Wound Healing

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***Abstract*—The present study focused on the formulation and evaluation of a biodegradable herbal wound bandage using coconut fiber, Aegle marmelos leaf extract, and aloe vera gel for improved wound healing. The objective was to develop a low-cost, eco-friendly, antimicrobial, and biocompatible dressing capable of maintaining a moist wound environment and enhancing tissue repair. Bel Patra leaves were shade-dried, powdered, and extracted using a hydroalcoholic solvent system. Sterilized coconut fiber sheets were impregnated with 5%, 10%, and 15% extract formulations mixed with aloe vera gel. The prepared bandages were evaluated for moisture retention, water vapor permeability, tensile strength, thickness, fold endurance, surface texture, and skin irritation. Results showed excellent moisture retention of 161%, water vapor permeability of 0.0167 g/cm²/h, tensile strength of 3 N/mm², thickness of 0.3 mm, and fold endurance of 34 folds. No redness, swelling, itching, or rash was observed during dermal testing, indicating good skin compatibility. These findings suggest that the formulated herbal bandage possesses promising wound-healing and antimicrobial potential.**

***Index Terms*—Herbal wound bandage, Aegle marmelos, Coconut fiber, Biodegradable dressing, Wound healing, Aloe vera, antimicrobial activity, Moisture retention.**

I. INTRODUCTION:

Wound healing is a complex and dynamic biological process that restores the integrity and function of damaged skin and underlying tissues following injury. It involves a coordinated sequence of cellular, molecular, and biochemical events that work together to prevent infection, repair damaged tissue, and re-establish the protective barrier of the skin. The healing process is influenced by several factors, including the type and extent of the wound, microbial contamination, blood circulation, nutritional status, age, and underlying diseases such as diabetes. Wound healing generally progresses through four overlapping phases: hemostasis, inflammation, proliferation, and remodeling. The hemostasis phase begins immediately after injury, where platelets aggregate at the wound site to form a clot and stop bleeding through the formation of a fibrin matrix. This is followed by the inflammatory phase, during which neutrophils and macrophages migrate to the wound site to remove bacteria, dead cells, and debris while releasing cytokines and growth factors that initiate tissue repair. The proliferative phase is characterized by the formation of granulation tissue, angiogenesis, collagen synthesis, and re-epithelialization. Fibroblasts produce type III collagen and extracellular matrix components that provide structural support, while new blood vessels develop to supply oxygen and nutrients essential for healing. Keratinocytes migrate across the wound surface to restore the epithelial layer. In the remodeling phase, type III collagen is gradually replaced by stronger type I collagen, improving the tensile strength and stability of the repaired tissue. This phase may continue for several weeks to years, with scar tissue eventually reaching nearly 80% of the strength of normal skin.

Wound healing may occur through primary, secondary, or tertiary intention depending on the nature and severity of the injury. Primary intention healing occurs when wound edges are closely approximated, such as in surgical incisions, resulting in rapid healing with minimal scarring and a lower risk of infection. Secondary intention healing is observed in large, deep, or open wounds where the tissue gap cannot be closed directly. In such cases, healing occurs through granulation tissue formation, wound contraction, and epithelialization, often resulting in a more visible scar. Tertiary intention, also known as delayed primary closure, involves initially leaving the wound open to control contamination or swelling and later closing it surgically after the risk of infection has decreased. Effective wound management plays a crucial role in accelerating healing and preventing complications, and wound dressings are an essential component of this process.

Bandages and wound dressings are protective materials applied directly to wounds to promote healing and prevent contamination. Traditionally, simple cotton gauze and fabric wraps were used as passive coverings; however, modern wound care has evolved significantly with the development of advanced and bioactive dressings designed to actively support the healing process. Wound dressings perform several important functions, including protecting the wound from dust, microorganisms, and mechanical injury, absorbing excess wound exudates, maintaining a moist environment favorable for healing, preventing infection, reducing pain, and providing physical support to the damaged tissue. An ideal wound dressing should be sterile, biocompatible, non-toxic, non-irritating, absorbent, permeable to gases, easy to apply and remove, comfortable for the patient, and cost-effective. Advanced wound dressings may also possess antimicrobial, biodegradable, and tissue-regenerative properties that further enhance healing outcomes.

Wound dressings are broadly classified into passive, interactive, and bioactive dressings based on their mechanism of action. Passive dressings, such as gauze and cotton bandages, mainly provide basic protection and absorb wound exudates without actively influencing the healing environment. Interactive dressings, including hydrogels, hydrocolloids, foams, alginates, and transparent films, maintain a moist wound environment that promotes cell proliferation, tissue regeneration, and faster healing while minimizing pain during removal. Bioactive or advanced dressings represent the latest development in wound care technology and are designed to actively interact with the wound bed by delivering antimicrobial agents, growth factors, or bioactive compounds that accelerate tissue repair and reduce the risk of infection. Examples include silver-impregnated and iodine-containing dressings, which exhibit strong antimicrobial activity. The continuous advancement in wound dressing technologies has significantly improved the management of acute and chronic wounds, enhanced patient comfort and promoting faster and more effective healing.

II. NEED & OBJECTIVE:

- Wound healing requires a moist, antimicrobial, and biocompatible environment for effective tissue repair and infection prevention.
- Traditional wound dressings like synthetic gauze and non-biodegradable polymers need frequent. replacement, often lack antimicrobial properties, and contribute to biomedical waste
- There is increasing interest in biodegradable, plant-derived dressings that combine structural. support with natural antimicrobial and antioxidant effects
- Aegle marmelos (bel or bael) leaf extracts are rich in flavonoids, phenolic compounds, and bio actives with antimicrobial, antioxidant, and wound-healing benefits, making them suitable for. herbal bandages. Coconut coir fibers are an abundant agricultural byproduct offering mechanical strength, porosity, biodegradability, and biocompatibility, ideal as scaf fold or dressing material.
- Combining bel leaf extract with coconut coir fiber scan create an eco-friendly wound dressing that:
- Such dressings address clinical needs for infection control and enhanced healing while promoting environmental sustainability through biodegradable materials.

Objectives:

- Extraction and Standardization of Leaf Extract [8],[9]
- Fabrication of coir-based bandage sheets [8]
- Physicochemical & mechanical characterization [13]
- Invitro antimicrobial activity [13]
- Biocompatibility and Cytotoxicity Assessment [8]
- Optional In Vivo Wound Healing Study (subject to ethical approval) [9]

III. PLAN OF WORK:

- Selection of research topic
- Literature survey
- Selection of plant materials and excipients
- Extraction of Bel Patra

- Preparation and compatibility assessment of coconut fibre base with extract
- Formulation of herbal biodegradable bandages
- Evaluation Study
- Conclusion and results
- Reference

IV. LITERATURE REVIEW:

- Gautam, M. K., et al (2014).

This study investigated the wound-healing effects of a 50% ethanol extract derived from Aegle marmelos fruit pulp (AME) using three rat wound models: excision, incision, and dead space wounds. AME was administered orally at a dose of 200 mg/kg once daily over specific time frames tailored to each wound type. In the incision model, wound tensile strength was measured; in the excision model, wound contraction rate, duration of epithelization, and skin histological changes were assessed; and in the dead space model, granulation tissue was analyzed for oxidative stress markers, antioxidant levels, inflammatory indicators, connective tissue components, and histopathology. Rats treated with AME demonstrated full wound closure and epithelization by day 20, compared with day 24 in untreated controls. Additionally, AME treatment shortened the epithelization period, reduced scar area, and enhanced wound breaking strength. Granulation tissue from treated animals showed significant increases in collagen content (ranging from 33.7% to 64.4 %, $P < 0.001$) and antioxidant enzyme activity (increases between 13.0 % and 38.8%, P values from <0.05 to <0.001), alongside marked reductions in oxidative stress markers (55.0 % to 55.6 %, $P <0.001$) and my eloper oxidase activity (21.3%, $P <0.001$). These findings suggest that Aegle marmelos facilitates wound repair by promoting connective tissue synthesis and enhancing antioxidant defense mechanisms, thereby minimizing free radical–induced tissue damage [9].

- Monika, S., et al. (2011).

This literature review comprehensively examines the phytochemical constituents and biological activities associated with Aegle marmelos (bael). The authors conducted an extensive search of multiple data bases, including Google Scholar, PubMed, Science Direct, and Scopus, to gather and synthesize existing research on the plant's key secondary metabolites and their pharmacological potential. Findings reveal that different parts of A. marmelos are rich in bioactive compounds such as marmelos in and other coumarins, alkaloids, flavonoids, terpenoids, and phenolic compounds.

Preclinical evidence supports a broad spectrum of therapeutic effects attributed to the plant, including anti diarrheal, antimicrobial, antiviral, antioxidant, anticancer and chemo preventive, antipyretic, ulcer-healing, antigenotoxic, diuretic, antifertility, and anti-inflammatory properties [8]

- Jose, M., et al. (2014).

In rural regions of South India, people commonly use the fibrous husk of Cocos nucifera (coconut) for oral hygiene. Despite its widespread use, the antimicrobial potential of this plant material against typical oral pathogens has not been scientifically validated. This study aimed to assess the antimicrobial effects of an alcoholic extract derived from coconut husk on various oral pathogens.[6]

- Boateng, J. S., et al. (2015).

Advanced therapeutic dressings that actively contribute to the healing process are gaining significant attention for their potential to accelerate and enhance recovery, particularly in chronic wounds. Given the considerable economic impact worldwide, there is a pressing need for innovative wound healing strategies that promote faster and more complete repair. This review explores the current landscape of wound care products, highlighting the increasing demand for sophisticated wound therapy solutions. It synthesizes data primarily from peer-reviewed studies and credible sources such as the US Food and Drug Administration. Special focus is given to the management of chronic wounds—including diabetic ulcers, leg ulcers, pressure sores, amputations, as well as surgical and trauma- related wounds—where weakened immune defenses raise the risk of infection and complications. The review covers various dressing types such as medicated moist dressings, tissue-engineered grafts, biomaterial-based biological dressings, naturally derived dressings, medicated sutures, and their combinations. Additionally, it briefly examines emerging physical therapies like hyper baric oxygen treatment, negative pressure wound therapy, and laser-assisted healing, considering their future roles in standard clinical practice [2].

- Hamman, J. H., et al. (2008).

In his review article, Hamman explores the chemical makeup of the gel found inside the leaf parenchyma of Aloe vera and its diverse practical uses. The gel, which makes up most of the inner leaf, is primarily composed of about 99.5% water, along with a small percentage (0.5– 1%) of solid substances. These solids include polysaccharides like acetylated glucomannans (particularly "acemannan"), vitamins, minerals, enzymes, phenolic compounds, organic acids, and various other biologically active molecule [15].

- Guo, S, et al (2010).

This article delivers a detailed examination of key systemic and local elements that shape wound repair. They outline how healing unfolds in overlapping stages—clotting, inflammatory response, tissue growth, and maturation—yet these can falter due to multiple influences. Conditions like advanced age, chronic stress, hormone fluctuations, diabetes, excess weight, and inadequate diet hinder progress by weakening immunity, reducing collagen production, and limiting blood vessel formation. Drugs such as steroids and cancer treatments exacerbate delays in recovery. On the local level, factors including oxygen shortages, bacterial contamination, imbalanced moisture levels, and ongoing physical trauma impede cell movement and tissue regeneration. The paper stresses the need to optimize both overall health and the wound site for successful outcomes, providing a solid model for how physiological, biological, and external variables interplay in repair processes. This makes it a go-to resource for crafting targeted wound management approaches [1].

- Reddy, N, et al (2005).

This review explores how crop residues like corn husks, wheat straw, banana fibers, and similar agricultural waste can be transformed in to eco-friendly bio fibers. These fibers stand out for their renewability, biodegradability, and solid mechanical performance, positioning them well for uses in bio composites, packaging, textiles, and medical devices. By repurposing such waste, the approach cuts down on environmental harm and manufacturing expenses while turning low-value discards into high-potential resources. Overall, the study showcases biofibers as viable, green substitutes for conventional synthetic options, advancing sustainable manufacturing trend [5].

V. MATERIALS AND METHODS:

Fresh Aegle marmelos leaves:

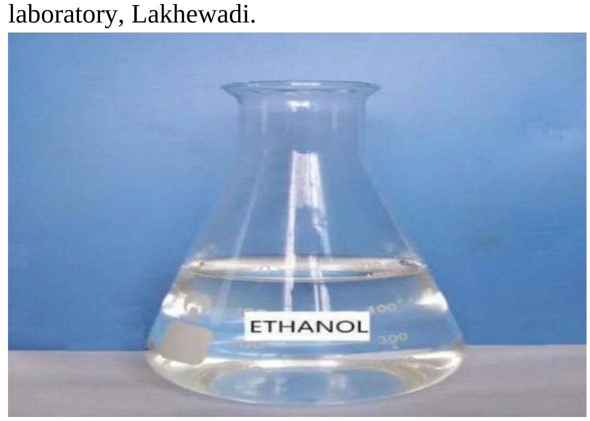
- Antimicrobial Properties:

Bel Patra leaves are rich in bioactive compounds such as alkaloids, phenolics, flavonoids, and tannins, which possess the ability to inhibit bacterial proliferation. When the se extracts are integrated into herbal bandages, they help reduce bacterial contamination at the wound site, thereby lowering the risk of infection. This antimicrobial effect supports a cleaner wound environment and promotes natural healing processes [18]. It obtained from the environment of Lakhewadi.

Fig.1 Bel Patra

- Solvent-Ethanol:

Ethanol in concentrations ranging from 70 % to 95% is commonly employed in the preparation of herbal bandages, primarily to facilitate extraction and enhance antimicrobial properties. It effectively isolates bioactive compounds such as phenols, flavonoids, alkaloids, tannins, and essential oils from medicinal plants like Aegle marmelos (Bel Patra). Extracts prepared with hydroalcoholic solutions exhibit potent antioxidant and antimicrobial effects, making them ideal for promoting wound healing in bandage applications [14]. It obtained from the VNCOP laboratory, Lakhewadi.



Fig; 2 Ethanol

- Coconut sheets /mats (food /medical grade if available)—pre-sterilizable:

Coir fibers provide essential structural reinforcement by enhancing tensile strength and durability in delicate plant-derived films or gauzes, preventing disintegration during application or patient activity [11]. It obtained from the Market of Lakhewadi.

Fig;3 Coconut Fibre sheets

- Aloe vera gel:

Aloe vera gel is rich in bioactive substances including anthraquinones, saponins, acemannan, salicylic acid, and phenolic compounds. These components possess antibacterial properties that help reduce microbial growth, making aloe vera effective in preventing infections when applied in wound dressings [15].

Fig 4 Aloe vera gel

Natural Preservatives:

- Neem Oil:

Neem oil is widely incorporated in herbal bandages because of its powerful antimicrobial, anti-inflammatory, and healing effects. Its antimicrobial action stems from bioactive compounds such as azadirachtin and nimb id in, which effectively suppress the growth of bacteria including Staphylococcus aureus, Escherichia coli, and Pseudo monas species, as well as various fungi, helping to protect wounds from infection [16]

Fig:5 Neem oil

- Honey:

Honey is a natural, bioactive substance widely used in wound-care applications. When incorporated into biodegradable herbal bandages, it enhances antimicrobial activity, moisture balance, healing rate, and shelf stability of the product [15] It obtained from the Market of Lakhewadi.

Fig:6 Honey

- Vinegar:

Vinegar is used in herbal bandages as a natural preservative and antimicrobial agent. Its acetic acid content helps inhibit bacterial and fungal growth, maintains a slightly acidic environment favorable for wound healing, and preserves the bioactive compounds in herbal extracts, thereby enhancing the bandage’s shelf life and effectiveness [16]. It obtained from the Market of Lakhewadi.

Fig:7 Vinegar

Glassware and Cultural Media:

- Agar:

Agar is a gel-like material extracted from red algae, commonly utilized in microbiology to solidify culture media. Microbial culture It offers affirm and reliable surface for cultivating and assessing bacteria or fungi, enabling evaluation of the antimicrobial properties of herbal bandages [18]. It obtained from the VNCOP Pharmacognosy laboratory, Lakhewadi.

Fig:8 Agar

- Nutrient broth:

Nutrient broth is a liquid medium designed to supply vital nutrients necessary for bacterial prolife ration. Preparation of microbial inoculum involves cultivating bacterial cultures in this broth prior to evaluating their response to herbal bandages [18]. It obtained from the VNCOP laboratory, Lakhewadi.

Fig:9 Nutrient broth

- Petri Plates:

Petri plates, also known as Petri dishes, are shallow, round containers typically made from glass. They hold solid or semi-solid culture media such as agar [18]. It obtained from the VNCOP laboratory, Lakhewadi.

Fig:10 Petri Plate

METHODS:

Step 1: Preparation of Bel Patra Extract

- Collect fresh Bel Patra leaves and wash thoroughly to remove dust and impurities.
- Dry the leaves under shade and grind into a fine powder.
- Macerate the dried powder in ethanol/water solution for 48 hours.
- Filter the extract using muslin cloth or filter paper.
- Concentrate the filtrate using evaporation.
- Add suitable preservative to improve stability.

Step 2: Preparation of Coconut Fiber Base

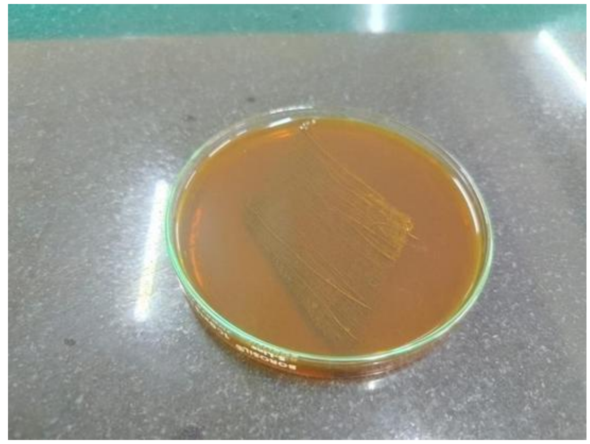
- Obtain coir (coconut fiber) mats.
- Cut into 5 × 5 cm uniform pieces.
- Sterilize the pieces by autoclaving.
- Dry the sterilized coir mats completely

Step 3: Preparation of Extract Solutions

- Prepare different concentrations of Bel Patra extract (5%, 10%, and 15%).
- Mix each concentration with aloe vera gel to enhance healing properties.

Step 4: Impregnation Process

- Dip the sterilized coir pieces into the prepared extract solutions.
- Ensure uniform soaking of the extract into the fiber.
- Remove and allow excess solution to drain.



Step 5: Drying

- Dry the impregnated coir pieces at 40–45°C in a hot air oven.
- Ensure complete drying to avoid microbial growth.

Step 6: Storage

- Store the prepared herbal bandages in sterile, airtight containers.
- Keep in a cool and dry place until further evaluation.

VI. EVALUATION PARAMETER

- Moisture retention and permeability [2]
- Moisture Retention Test-

The moisture retention test was carried out by cutting the bandage into equal-sized pieces. The initial dry weight of each sample was recorded accurately. The samples were then immersed in distilled water for 24 hours to allow complete swelling. After immersion, excess surface water was removed gently using filter paper, and the swollen weight was measured, and the percentage of moisture retention was calculated

- Moisture Permeability Test-

The moisture permeability test was performed by filling a vial with distilled water and covering its opening with the bandage sample, which was sealed properly to prevent leakage. The initial weight of the setup was recorded before incubation. The assembly was then kept at 37°C for 24 hours. After the incubation period, the final weight was measured, and the water vapor transmission rate (WVTR) was calculated.

- Skin irritation and allergy testing [28]:

The skin irritation and allergy test were performed by first cleaning and preparing the selected skin area properly. The bandage sample was then applied to the skin and covered with an adhesive dressing for 24–48 hours. After the specified period, the bandage was carefully removed, and the skin was examined for any signs of redness, swelling, itching, irritation, or allergic reaction. Observations were recorded at intervals of 24, 48, and 72 hours and compared with untreated skin. The absence of visible irritation or allergic response indicated that the bandage was safe and suitable for skin application.

Appearance and physical properties:

- Thickness Test Procedure [29]:

The thickness test was performed by cutting the bandage into uniform samples of suitable size. Each sample was placed carefully between the jaws of a vernier caliper or digital micrometer. The thickness of the bandage was measured at three different positions to ensure accuracy and uniformity. All readings were recorded, and the average thickness was calculated.

- Fold Endurance Test Procedure [29]:

The fold endurance test was carried out using a strip of the prepared bandage sample. The bandage was folded repeatedly at the same point either manually or with the help of a folding endurance tester. Folding was continued until the bandage developed visible cracks or broke completely. The number of folds required to break the bandage was counted and recorded as the fold endurance value. This test was used to determine the flexibility and mechanical resistance of the bandage during repeated handling and use.

- Surface Texture Test Procedure [29]:

The surface texture test was performed by placing the bandage sample on a clean and flat surface. The surface was visually examined under normal light conditions to observe its appearance and uniformity. The sample was gently touched to assess its smoothness or roughness. The bandage was also checked for stickiness, cracks, uneven texture, or any visible defects. For detailed analysis, the surface was further observed under a microscope whenever available. All observations related to the texture and physical appearance of the bandage were recorded.

- Tensile strength [13]:

The tensile strength test was carried out by cutting the bandage into uniform strips of suitable dimensions. Each strip was fixed firmly between the clamps of a tensile testing machine. A gradually increasing force was then applied to the sample until the bandage broke. The maximum force required to break the bandage was recorded as the breaking force. The tensile strength of the bandage was then calculated.

VII. RESULTS AND DISCUSSION:

Moisture Retention Capacity:

This test determines the ability of the bandage to retain moisture, which helps maintain a moist wound-healing environment.

Formula:

$$\text{Moisture Retention (\%)} = \frac{Wt - Wd}{Wd} \times 100$$

Where:

- Wt = Weight of hydrated/wet bandage after time
- Wd = Initial dry weight of bandage

Calculation:

- Initial dry weight (Wd) = 2.1 g
- Weight after hydration (Wt) = 5.5 g

$$\{\text{Moisture Retention (\%)}\} = \frac{5.5 - 2.1}{2.1} \times 100$$

=161%

Result

The herbal coconut fiber bandage exhibited a moisture retention capacity of 161%, indicating excellent water-holding ability and suitability for maintaining a moist wound environment.

- Water Vapor Permeability (WVP):

This test evaluates the ability of the bandage to allow oxygen and water vapor exchange while preventing excessive dehydration of the wound.

Formula

$$\{WVP\} = \frac{Wi-Wf}{A \times t}$$

Where:

- Wi = Initial weight of assembly (g)Wf= Final weight after incubation (g)
- A = Exposed area of membrane ()
- t = Time (hours)

Calculation:

- Initial weight (Wi) = 50 g
- Final weight (Wf) = 46 g
- Area (A) = 10 cm^2
- Time (t) = 24 h

$$\{WVP\} = \frac{50-46}{10 \times 24}$$ = 0.0167\ g/cm^2/h Result

The bandage showed a water vapor permeability of 0.0167 g/cm²/h, demonstrating adequate gas exchange and controlled moisture transmission required for wound healing.

- Skin Irritation and Allergy Testing

Parameter	Observation	Results
Redness	No visible redness observed	Negative
Swelling	No swelling detected	Negative
Itching	Not observed	Negative
Rash formation	Absent	Negative

"The formulated herbal wound bandage exhibited no significant skin irritation or allergic reactions during dermal safety assessment. No redness, Sweling, rash, was observed, indicating that the bandage is dermatologically safe and suitable for topical wound healing applications."

Appearance and Physical Properties of Bandage:

Thickness Test:

Thickness was measured using a vernier caliper at three different points of the bandage.

Formula

$$\{Average\ Thickness\} = \frac{T1+T2+T3}{3}$$

Where:

T1, T2, T3 = Thickness values at different positions

Calculation:

$$\{Average\ Thickness\} = \frac{0.2+0.4+0.3}{3}$$

$$= \frac{0.9}{3} = 0.3$$

The average thickness of the bandage was found to be 0.3 mm, indicating uniform structure and good fabrication quality.

- Fold Endurance Test:

Fold endurance was determined by repeatedly folding the bandage at the same place until it broke.

Formula:

{Fold Endurance} = {Number of folds before breaking} Number of folds before breaking = 34 folds

The bandage exhibited a fold endurance of 34 folds, demonstrating good flexibility and mechanical durability.

- Surface Texture Evaluation:

Surface texture was evaluated visually and manually for smoothness and uniformity

Parameter	Observation
Surface appearance	Slightly smooth
Texture	Uniform
Cracks	Absent
Stickiness	Sticky

The bandage showed a slightly smooth surface texture with uniform fiber distribution, indicating good user comfort and acceptable physical properties Formula

- Tensile Strength:

$$\{\text{Tensile Strength}\} = \frac{F}{A}$$

Where:

- F = Maximum force applied at break (N)
- A = Cross-sectional area of bandage (mm^2)

Cross-sectional area:

A = Width × Thickness

Observed Data

- Width of bandage = 10 mm
- Thickness of bandage = 0.5 mm
- Breaking force = 15 N

Step 1: Calculate Area

$A = 10 \times 0.5 = 5\ mm^2$

Step 2: Calculate Tensile Strength

Tensile Strength = $\frac{15}{5}$

= $3\ N/mm^2$

Result

The tensile strength of the herbal bandage was found to be 3 N/mm^2, indicating adequate mechanical strength, flexibility, and suitability for skin application.

VIII. CONCLUSION:

The developed biodegradable herbal bandage containing Aegle marmelos extract and coconut fiber demonstrated effective wound dressing properties with good mechanical strength, flexibility, moisture retention, and skin compatibility. The herbal extract provided antimicrobial and antioxidant benefits, while the coconut fiber acted as a biodegradable and breathable scaffold supporting tissue repair. Evaluation studies confirmed satisfactory moisture retention (161%), controlled water vapor permeability (0.0167 $g/cm^2/h$), tensile strength (3 N/mm^2), and fold endurance (34 folds), indicating suitability for wound management applications. No signs of irritation or allergic reactions were observed during dermal testing, confirming safety for topical use. Overall, the study concludes that the formulated herbal coir-based bandage can serve as a cost-effective, eco-friendly, and natural alternative to conventional wound dressings with enhanced wound-healing potential.

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