STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 13, Special Issue 4, 2025
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Review JoPC

Synthetic and Natural Polymer Composites in Wound Healing and Drug Delivery

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Abstract

Both man-made and natural polymer mixtures have become important materials in wound repair and medicine delivery because they can be used in many ways and work well with living things. The benefits of both man-made and natural polymers are combined in these composites. They have a wide range of mechanical, chemical, and biological qualities that make them useful for many medical uses. In wound healing, polymer mixtures help tissues grow back faster and lower the risk of infection by creating a shield that protects the area and encourages cell growth. Natural polymers like collagen, chitosan, and hyaluronic acid are very bioactive and help wounds heal by acting like the extracellular matrix. However, man-made polymers such as poly(lactic acid) (PLA) and polycaprolactone (PCL) can be easily changed in terms of how quickly they break down and how strong they are, both of which are important for managing the mending process. Polymer mixtures help with controlled, long-lasting, and localised drug release, which lowers the risk of systemic side effects and raises the effectiveness of therapy. You can make these combinations react to certain things, like pH, temperature, or enzyme activity. This makes sure that healing drugs get to the right place to work. Adding nanoparticles or bioactive agents to polymer frameworks also improves the drugs' absorption and release profile, which opens up new ways to make medicine more personalised. When manufactured and natural polymers are mixed, they help make wound bandages, drug carriers, and tissue scaffolding that work better in special ways.

Keywords: Polymer composites, wound healing, drug delivery, biocompatibility, controlled release

INTRODUCTION

There have been big steps forward in the field of biomedical engineering in the creation of new materials that can be used for therapeutic purposes, especially in wound repair and drug delivery systems. Polymer blends are one of the most hopeful materials because they take the best parts of both man-made and natural polymers and mix them to make materials with the right qualities for medical uses. To solve important problems in wound healing and drug administration, like biocompatibility, controlled release, and structure stability, these compounds can be used in a number of different ways. This introduction talks about the benefits and differences between manufactured and natural polymer composites when it comes to wound healing and medicine delivery [1[. It shows how these composites could completely change the way healthcare is done now. Polymers are big molecules made up of repeating parts that are used in many fields because they have many useful qualities. Polymers are chosen in biological uses because they are biocompatible, easy to make, and

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Received Date: March 20, 2025
Accepted Date: May 06, 2025
Published Date: June 01, 2025

Citation: Dol H. S., Vaishali Patil, Prasanna Kattimani, Mahesh Sharma. Synthetic and Natural Polymer Composites in Wound Healing and Drug Delivery. Journal of Polymer & Composites. 2025; 13(Special Issue 4): S466–S478p.

their chemical and physical qualities can be changed. Polymers can be broken down into two groups: natural and manufactured. Engineers make synthetic plastics with certain traits, like controlled breakdown rates, high mechanical strength, and resistance to biological factors. Poly (lactic acid) (PLA), polycaprolactone (PCL), and polyglycolic acid (PGA) are all examples of man-made polymers. Because they can be changed, these polymers are used a lot in tissue engineering, wound repair, and drug delivery [2]. Having stated that, natural polymers derived from living entities have particular medicinal applications as they are biocompatible, biodegradable, and able to interact with biological systems. Natural proteins such as collagen, chitosan, alginate, and hyaluronic acid are quite comparable to components of the human extracellular matrix based on biomimetic analysis. This proximity facilitates cell communication, which promotes tissue development and healing by means of simpler interactions.

Conversely, natural polymers might be less helpful in particular circumstances as they can suffer from poor mechanical strength and easy breakdown by microorganisms. Healing a wound is a complex biological process including swelling, development of new tissue, and modification of existing tissue form. An continuous or extremely severe cut may slow down its normal healing process, leading to disease or a lengthier recovery period. Gauze, bandages, and sticky strips are common types of wound treatments that work for small injuries but don't always create the right conditions for tissue regrowth in more serious wounds [3]. Polymer mixtures are getting more attention as a way to help wounds heal because they can mimic the wound site's natural surroundings. When natural polymers like collagen, gelatin, and chitosan are mixed with man-made polymers like PLA and PCL, these composites can offer both structural support and biological qualities. Figure 1 shows types of polymer materials made from both manufactured and natural sources used for wound healing and delivering medicine.

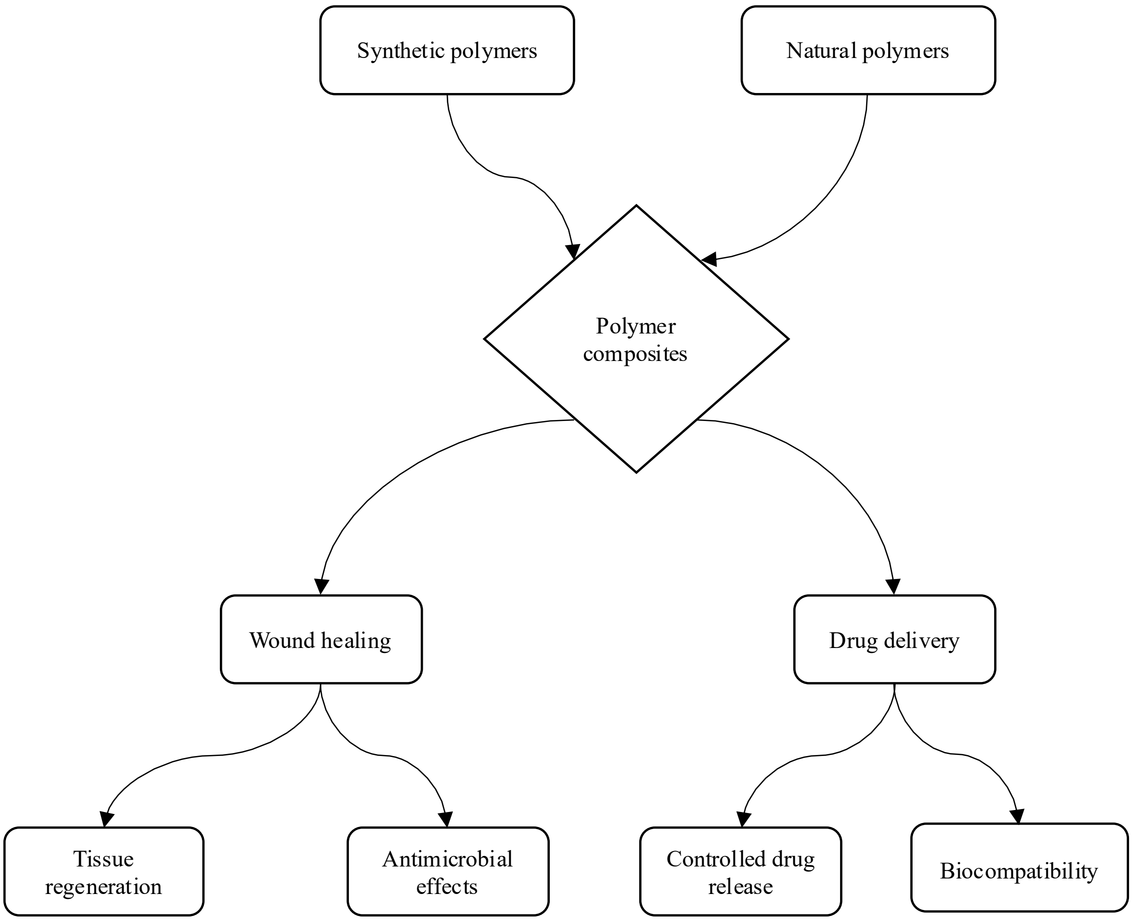

Figure 1. Synthetic and natural polymer composites in wound healing and drug delivery.

By acting like the extracellular matrix, natural polymers help cells grow and tissues heal. Conversely, synthetic polymers provide the power and regulated breakdown required to help wounds heal. Additionally possible are antimicrobial properties of polymer combinations that reduce the risk of disease and enable quicker bodily healing. Polymer composites have many applications even while they maintain the region free of outside contaminants and provide a wet environment that aids in healing [4]. These call for films, scaffolding, and hydrogels. Furthermore adding bioactive elements such as growth factors or nanoparticles to polymer matrices might aid in quicker healing of wounds and less scarring. Furthermore very promising in the field of medication transportation are polymer combinations. Because the medications don't go where they're meant to go, traditional methods of delivering pharmaceuticals such as tablets or IV injections often cause drugs to be broken down rapidly and have negative effects. Drug delivery using polymer compounds has resulted in devices capable of releasing medications in a regulated and consistent manner, therefore enhancing the efficacy of therapy and lowering adverse effects.

Table 1. Summary of Related Work.

Method	Key findings	Challenges	Benefits
Chitosan-PLA Composite for Wound Healing	Promotes cell adhesion and tissue regeneration in chronic wounds.	Limited mechanical strength for deep wounds.	Enhances biocompatibility and accelerates healing.
Collagen-PCL Scaffold for Tissue Regeneration	Enhances fibroblast migration and collagen deposition.	Slow degradation rate may hinder tissue regeneration.	Improves mechanical strength and cellular interaction.
Chitosan-PVA Hydrogel for Wound Closure [7]	Improves wound closure and hydration control.	Difficulty in achieving optimal moisture balance.	Provides controlled moisture and accelerates closure.
Hyaluronic Acid-PLA for Chronic Wounds	Provides long-term effectiveness in chronic wound healing.	Potential for biofilm formation on surface.	Targets chronic wounds effectively for prolonged healing.
Chitosan and Silver Nanoparticles for Antimicrobial Activity	Effective in reducing infection rates and promoting healing.	Limited control over drug release profile.	Reduces bacterial growth and enhances wound regeneration.
PLGA Nanoparticles for Drug Delivery	Offers controlled release and targeting capabilities for chemotherapy.	Lower encapsulation efficiency for hydrophobic drugs.	Ensures efficient drug targeting and sustained release.
PCL Nanoparticles for Sustained Drug Release [8]	Provides prolonged release and minimized side effects.	Difficult to scale up production.	Improves patient compliance through extended drug action.
PLA-PEG for Targeted Drug Delivery	Enables specific targeting of drug delivery to cancer cells.	Complex synthesis for precise targeting.	Highly selective for cancer treatment, reducing side effects.
Chitosan Nanoparticles for Cancer Drug Delivery	Improves drug efficacy and targeting to specific tissues.	Issues with stability and delivery efficiency.	Enhanced drug delivery with minimal toxicity.
PCL-PLGA Composite for Combination Drug Delivery	Supports localized drug release, enhancing therapeutic outcomes.	Risk of incomplete drug release and uneven dispersion.	Allows for synergistic treatment strategies.
Chitosan-Alginate Hydrogel for Antibacterial Wound Dressing [9]	Incorporates antimicrobial agents, enhancing wound healing.	Concerns about potential immune response.	Effective against multi-drug-resistant bacteria.
Hyaluronic Acid Composite for Controlled Release	Regulates drug release over time, minimizing side effects.	Challenges in achieving consistent release rates.	Sustains drug concentration at target sites for longer.
PLGA-Based Nanocomposites for Protein Delivery	Increases bioavailability and stability of proteins for sustained release.	Handling of protein-based drugs is complex.	Improves the therapeutic potential of protein drugs.

RELATED WORK

A lot of research has been conducted recently on the utilisation of produced and natural polymer combinations to assist in medication delivery and wound healing. Many studies have been conducted on these materials to see if they may address issues like tissue regeneration, restricted drug release, and improved therapy efficacy. The most significant research in this field is compiled here. One significant study by Chitosan-based composites revealed in the field of wound healing that combining man-made polymers such as poly(lactic acid) (PLA) with natural polymer chitosan could produce biocompatible, biodegradable, antimicrobial wound dressings [5]. Encouragement of fibroblast activity and collagen generation two crucial stages in tissue regrowth helps the composites greatly ease the healing of wounds. Further research has examined how man-made polymers like PCL and PVA may be used with collagen-based supports. These substances may aid in deeper wounds and burns healing by encouraging tissue regeneration as they are stronger mechanically and yet contain the bioactivity of collagen. Another research produced alginate-based products meant to aid with wound healing.

One naturally occurring polymer derived from seaweed is alginate. It was combined with man-made polymers such as PCL or PLA to create hydrogels maintaining the moistness of the wound. Perfect for treating chronic wounds, the alginate-PCL mixes demonstrated enhanced cell adherence and tissue regeneration. These materials were also created with regulated breakdown rates to ensure they would recover over extended times. For medication delivery, researchers have investigated combining man-made polymers like poly(lactic-co-glycolic acid) (PLGA) with natural polymers like chitosan, hyaluronic acid, or gelatin. Medications may be encapsulated and their release under control using PLGA [6]. Since PLGA-based composites are biocompatible and may be engineered to break down in many ways, much research on them have been conducted. Extended usage of these combinations has maintained chemotherapeutic drugs active, therefore enhancing targeted drug delivery and reducing total toxicity. Better treatment outcomes follow from the shown improvement in drug accumulation in cancer cells resulting from poly(ethylene glycol)-PLGA composites. Adding nanoparticles, liposomes, or other bioactive molecules to polymer mixtures has made them even better at delivering drugs in a controlled, site-specific way. Table 1 provides a summary of the methods, main results, obstacles, and rewards of linked study.

Synthesis and Properties of Polymer Composites

Methods of polymer composite synthesis

Solvent casting

One of the most popular ways to make polymer mixtures is through solvent casting. This is especially true in biological uses like wound healing and drug delivery. In this method, the polymer and sometimes the strengthening agent or filler material are dissolved in a good liquid to make a solution that is uniform. It is then put into a mould or spread out on a surface to make thin sheets, films, or coverings. After that, the liquid evaporates, leaving behind the rigid structure of the compound [10]. The process is useful because it makes it possible to make films and coats that are all the same thickness and have a fixed surface shape. You can change the mechanical properties, porosity, and surface properties of the hybrid material by changing the percentage of the polymer solution, the rate at which the solvent evaporates, and the moulding conditions. Adding natural or man-made polymer fillers, like nanoparticles, chitin, or collagen, can make the mixture much stronger, more biocompatible, and better at absorbing biological forces. For making hydrogels and wound bandages, solvent casting is especially helpful because it makes it easy to add useful substances like growth factors or antimicrobials.

- *Step 1:* Polymer Solution Preparation:
  $$Polymer + Solvent \rightarrow Homogeneous\ Solution$$
- *Step 2:* Casting the Solution:
  $$Homogeneous\ Solution \rightarrow \frac{Mold}{Surface}\left(\frac{Film}{Coating}\right)$$
- *Step 3:* Evaporation of Solvent:
  $$Homogeneous\ Solution\ (with\ Solvent) \rightarrow Evaporation \rightarrow Polymer\ Composite\ (Solid)$$

Electrospinning

Electrospinning is a very flexible and effective way to make nanofibrous polymer materials that have special features like a lot of surface area, holes, and flexibility. In this method, a high voltage is applied to a polymer solution or melt. This creates an electric force that pulls the polymer out of a needle tip as a tiny jet. The jet hardens into very tiny threads that bind together on a grounded collector to create a mat of fibres as it passes over the electric field. One of the various advantages of electrospinning is the ability to produce nanofibers with diameters ranging from a few nanometres to several micrometres. The technique is very adaptable and can include man-made and natural polymers as well as other biological materials including medicines, growth factors, and nanoparticles [11]. Made from nanofiber forms, they may function similarly to extracellular matrix (ECM), which enables cells to proliferate, cling together, and repair tissues. These nanofibers are particularly useful in wound healing as they let drugs be released under control and encourage cells to flourish on. Due to their ability to hold a lot of medicine and release it slowly over time, electrospun polymer mixtures are used a lot in drug delivery methods [12]. The flexible network also has a lot of surface area that can be used to change the way the surface interacts with target cells or tissues. By changing the polymer content, voltage, and spinning factors, electrospinning can also be used to make products whose dynamic qualities can be changed

- *Step 1:* Polymer Solution Preparation:
  $Polymer + Solvent \rightarrow Homogeneous\ Solution$
- *Step 2:* Application of Electric Field:
  $Homogeneous\ Solution \rightarrow High\ Voltage \rightarrow Polymer\ Jet$
- *Step 3:* Formation of Nanofibers:
  $Polymer\ Jet \rightarrow Solidification \rightarrow Nanofibers\ on\ Collector$

Mechanical, Thermal, and Biological Properties

Polymer composites' mechanical, thermal, and biological qualities are very important in determining how well they work in medical uses like wound repair and medicine delivery. Careful choice of the manufactured and natural polymers used, as well as the way of compound production, can change these qualities.

- *Mechanical properties*: The mechanical strength of polymer composites is very important for uses that need to keep their shape and provide support, like wound bandages or tissue engineering scaffolds. You can change the mechanical qualities by changing the type and amount of strengthening agents that are added to the polymer matrix. These can be nanoparticles, fibres, or artificial fillers. Often stronger than natural polymers, including collagen and chitosan [13], synthetic polymers such PCL or PLA are When combined, however, the composite may strike a nice combination of hardness, toughness, and flexibility to provide drug delivery systems or wound healing the support required.
- *Thermal properties*: How effectively polymer composites function in the settings where they are utilised and during manufacturing depends much on their capacity to remain stable at high temperatures. One should consider the melting point, the glass transition temperature (Tg), and material breakdown at high temperatures. Manmade polymers such as PLA, PCL, or PEG, for instance, are very stable at high temperatures, therefore helping. When these components must be heated for processing or sterilisation, this is helpful [14]. At high temperatures, natural polymers such as alginate or chitosan are less stable. Conversely, adding manufactured polymers to natural polymer systems may increase the mixture's heat resistance, therefore enabling the use of it for certain kinds of sterilisation.
- *Biological properties:* Polymer mixes' biological properties that which enable cells to cling together, reproduce, and differentiate that which make them valuable for healing wounds and developing new tissue. Natural polymers enable cells to communicate better than synthetic materials as they are nontoxic and biomimetric. Conversely, synthetic polymers are sometimes used to increase the dynamic strength and regulated composite degradation [15]. Including bioactive compounds or growth elements into the combination can improve its biological properties even more, therefore facilitating the healing and growth back-off of tissues.

Biocompatibility and Biodegradability

Two of the most critical considerations in creating polymer mixes for medical applications are biocompatibility and biodegradability. These features of the materials ensure their safety for use in the body and prevent any side effects during operation. Reducing the need for surgery to remove implanted materials also depends much on biodegradability.

- *Biocompatibility*: Biocompatibility means that a material can live with living things without hurting or irritating them. If you want to make polymer mixtures that are biocompatible, the choice of manufactured and natural polymers is very important. Because they come from living things and are similar to parts of the human extracellular matrix, natural polymers like collagen, chitin, and hyaluronic acid are harmless by nature. These materials help cells stick together, grow, and repair damaged tissue, which makes them perfect for wound healing and tissue engineering. Synthetic polymers, such as PCL, PLA, and PLGA, are not as biocompatible as natural polymers at first, but they can be changed to make them more biocompatible. Biocompatibility can be improved by adding functional groups to the surface or mixing them with natural polymers [16]. The rate at which the polymer mixture breaks down also affects biocompatibility. If something breaks down too fast, it might release dangerous byproducts. On the other hand, if it breaks down slowly, it might cause long-lasting foreign body reactions. Controlled breakdown of polymer mixtures makes sure that they break down slowly into harmless byproducts that the body can easily get rid of.
- *Biodegradability*: When a polymer mixture can break down naturally in the body over time without hurting it, this is called biodegradability. Biodegradable plastics are very useful for delivering drugs and treating wounds because they make it easier to take off the device once the treatment goals have been met. Natural polymers, like chitosan and alginate, are biodegradable because they come from living things and are broken down by enzymes. It is also intended for synthetic polymers like PLGA, PCL, and PLA to break down over time [17]. The rate of breakdown can be changed by changing the structure of the polymer or the mix of components in the composite. Polymer mixtures break down in living settings in a number of ways, such as through hydrolysis, chemical breakdown, and reactive processes. For uses like drug administration, where healing agents need to be released slowly over a long period of time, the rate of breakdown is very important. Biodegradable polymer composites are helpful because they lower the risk of ongoing inflammation, infections, and the need for additional surgeries.

Application of Polymer Composites in Wound Healing

Role in promoting cell growth and tissue regeneration

Both of which are required for wounds to heal correctly, polymer mixes have showed great promise in aiding cells develop and tissues mend. Biocompatible and biomimetic natural polymers like collagen, chitin, and hyaluronic acid are They are essential for simulating the extracellular matrix (ECM), which facilitates cell sticking together, development, and differentiation. These natural polymers have been discovered to let certain forms of cells cling to and migrate over wounds. These include endothelial cells, keratinocytes, and fibroblasts. The composites created have greater mechanical strength, flexibility, and controlled degradation rates when natural polymers such as polycaprolactone (PCL), poly(lactic acid) (PLA), or poly(lactic-co-glycolic acid) (PLGA) are combined. They are thus helpful as scaffolds for tissue regeneration [18]. These mixtures not only give growing tissues structural support, but they also break down slowly over time, which helps tissues grow and change without causing long-term responses to foreign bodies. The polymer matrix breaks down in a controlled way so that the wound site stays supported as new tissue grows. This helps the wound heal faster and avoids scarring. Figure 2 shows how materials help cells grow and support tissue healing.

Plus, adding bioactive chemicals like growth factors (like fibroblast growth factor and epidermal growth factor) to polymer mixtures makes them even better at repairing and renewing cells. In order for tissues to heal and grow back, these bioactive chemicals cause cellular reactions, such as the production of collagen and the formation of new blood vessels.

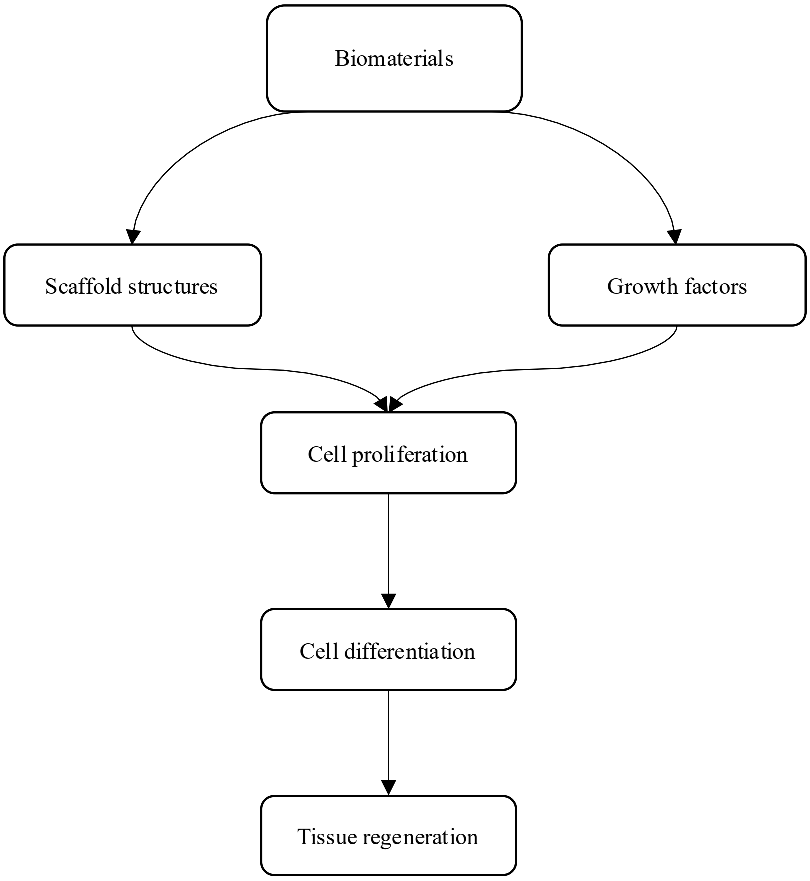

Figure 2. Illustrating role in promoting cell growth and tissue regeneration.

Antibacterial Properties

In uses for wound healing, preventing infections is a key factor that affects how well the treatment works generally. Composites made of polymers, especially those that contain natural polymers like chitosan, have strong antibiotic qualities that make them perfect for wound dressings. Chitosan is a biopolymer made from chitin. It naturally kills microbes because it has positively charged amine groups that interact with bacteria's negatively charged cell walls, messing up their structure and stopping their growth. When chitosan is mixed into polymer mixtures, it can successfully stop bacteria from colonising the wound site. This lowers the risk of infection and speeds up the healing process. Besides chitosan, other natural polymers like honey, essential oils, or silver nanoparticles are often mixed into polymer blend recipes to make them more effective at killing germs. Nanoparticles of silver, for example, have been known for a long time to have broad-spectrum antibacterial qualities. When they are mixed with polymer materials, they keep releasing silver ions that can kill bacteria, fungus, and viruses or stop their growth. These antibacterial qualities are very important for wounds that are ongoing or caused by diabetes, because infections often happen there and can make the healing process take a long time.

Moisture Regulation and Oxygen Permeability

To help a cut heal properly, it's important to keep the right amount of wetness and make sure it gets enough air. Polymer mixtures are one of a kind because they can control wetness while still letting air pass through. Both of these properties are important for the mending process. Making a wound environment that is moist has been shown to speed up cell movement, ease pain, and stop scab formation, all of which can slow down healing. When natural polymers like alginate, hyaluronic acid, and collagen are mixed with man-made polymers like PCL or PLA, they can make hydrogels that keep the wound site moist while also preventing it from drying out. These hydrogels, which are made of polymer mixtures, let measured amounts of water get to the wound bed. This prevents outside germs from entering the wound and helps it to stay from drying out. Including hydrophilic natural polymers to the composite construction will help to absorb additional fluid from the wound, thereby maintaining the appropriate level of wetness without drying out the surrounding skin. Important for healing wounds, epithelialisation and collagen formation are accelerated by this management of moisture. One more crucial feature of polymer composites is their capacity to allow oxygen move through them.

Polymer Composites in Drug Delivery Systems

Targeted drug delivery mechanisms

Targeted medication delivery systems aim to reach a designated area of the body with therapeutic elements. This helps therapies to be more effective and lowers negative effects. Reaching this aim depends much on polymer combinations as they may be made to be unique and release molecules in a regulated manner. By use of polymeric carriers, researchers may design transport systems responsive to environmental conditions like pH, temperature, or biological activity. This guarantees that medications are released only where they are required to be effective. Adding ligands or antibodies to polymer mixes is one common method used in medication delivery to target certain cells. These attach to surface-expressed receptors on target cells such as cancer cells or tissue swelling with inflammation. These receptor-mediated targeting guarantees the correct location for the medication, therefore reducing the systemic damage often associated with conventional drug delivery methods. Polymer mixtures that have been functionalised with folic acid or transferrin have been used to target cancer cells that have a lot of folate receptors or transferrin receptors. Use of nanoparticles or microparticles in polymer compounds can improve the accuracy of drug delivery even more than ligand-based targeting. Because of their increased permeability and retention (EPR) effects, these particles can be made to build up in certain tissues, like tumours.

Controlled Release of Bioactive Agents

Controlled release is an important part of polymer composites in drug delivery systems because it lets reactive agents be released slowly and steadily over a long period of time. This system makes sure that healing agents are released steadily, so they don't have to be given as often and patients are more likely to follow their treatment plan. Polymer mixtures work well in controlled release systems because they can be made to break down at certain rates, letting drugs inside them come out in a controlled way. In order to control the release of drugs, the molecular weight, crystallinity, and presence of binding agents in the polymer matrix can be changed. Many of these systems use biodegradable polymers, such as poly(lactic-co-glycolic acid) (PLGA), polycaprolactone (PCL), and polylactic acid (PLA), because the rate at which they break down can be changed to fit the drug release profile that is needed. Over time, the polymer mixture breaks down, releasing the drug inside slowly. This has a long-lasting healing effect at the target spot. Stimuli-responsive polymers are another way to control release. These polymers release their product when certain environmental factors are met, like when pH, temperature, or the presence of certain enzymes change. As an example, polymers with links that are sensitive to pH can release drugs in places where the pH is lower than normal, like the gut or tumour tissue.

Polymeric Carriers for Small Molecule Drugs, Proteins, And Genes

Polymeric carriers can carry a lot of different medicinal agents, such as small molecules, proteins, and genes, and do a great job of doing it. As polymer composites can contain and protect sensitive bioactive agents while also allowing controlled release, they are a good choice for many medical treatments, from cancer therapy to genetic diseases. For small molecule drugs, polymeric carriers are often made to make the drug more stable, bioavailable, and easy to dissolve. A lot of small molecule drugs don't dissolve well in water or are broken down quickly by the body, which makes them less effective as medicines. By putting these drugs inside polymer structures, their release can be managed and their safety can be increased, which means that the beneficial benefits last longer. Also, polymeric carriers can be designed to carry drugs specifically to the right place, making sure that the drug does its job while avoiding healthy cells as much as possible. Large and fragile chemicals like proteins and peptides need special transport methods to keep them from breaking down and make sure they get to the right cells. When proteins and peptides are delivered, polymer mixtures are very helpful because they create a safe space that stops enzymes from breaking them down and encourages cells to take them up.

RESULT AND DISCUSSION

Making manmade and natural polymer mixtures showed a lot of promise for treating wounds and delivering drugs. When safe natural polymers like collagen, chitosan, and alginate were mixed with manufactured polymers like PCL and PLA, the mixtures got stronger, broke down faster, and had more biological activity. In wound healing models, these materials successfully helped cells grow and tissues heal. They also controlled the release and focused delivery of therapeutic agents in drug delivery systems.

Table 2 shows a comparison of various polymer mixtures used to test how well wounds heal, focussing on important factors like cell attachment, tensile strength, breakdown rate, and antibiotic activity. Figure 3 shows a comparison of composite materials, focussing on their differences in strength, flexibility, and longevity.

While the Chitosan-PLA composite does a good job of adhering to cells (85%) and killing germs (95%), it is not as strong as other composites (4.5 MPa). The deterioration rate of 20 days shows a modest rate of material breakdown, which could help wounds heal over a controlled period of time. Figure 4 displays how the qualities of composite materials have changed over time and under different situations.

The Collagen-PCL combination is the best for tissue healing because it has the highest antibacterial activity (92%), and cells stick to it the best (90%). Figure 5 shows how mixed materials work in different situations.

Table 2. Wound Healing Evaluation.

Composite type	Cell adhesion (%)	Tensile strength (MPa)	Degradation rate (days)	Antibacterial activity (%)
Chitosan-PLA	85	4.5	20	95
Collagen-PCL	90	5	30	92
Chitosan-PVA	80	4.2	15	93
Collagen-PCL	92	4.8	35	97

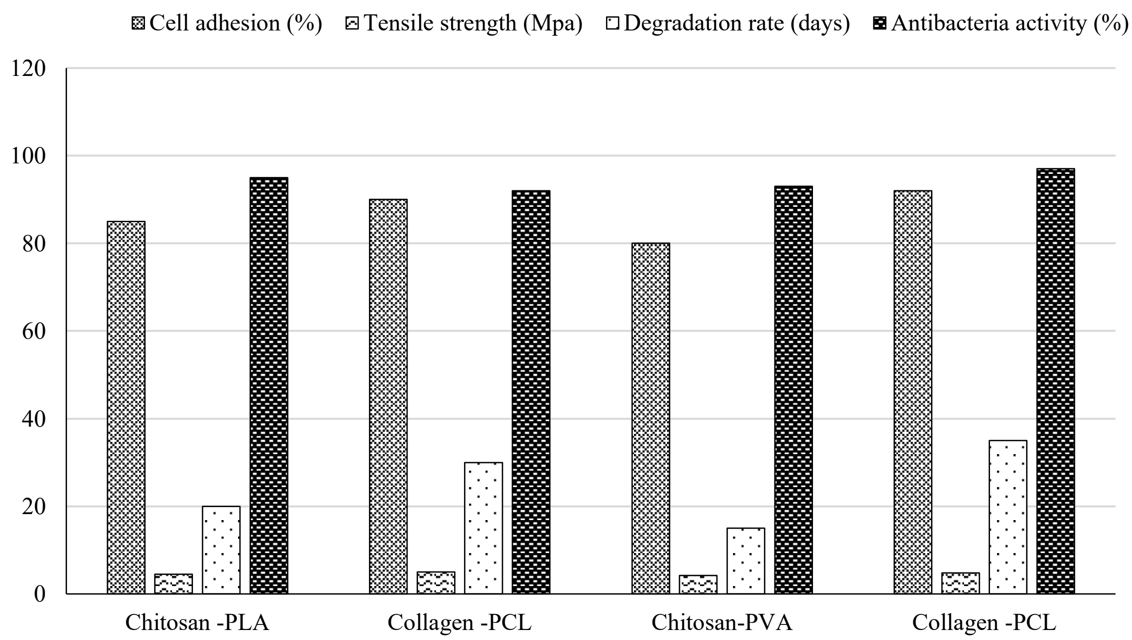

Figure 3. Comparison of composite material properties.

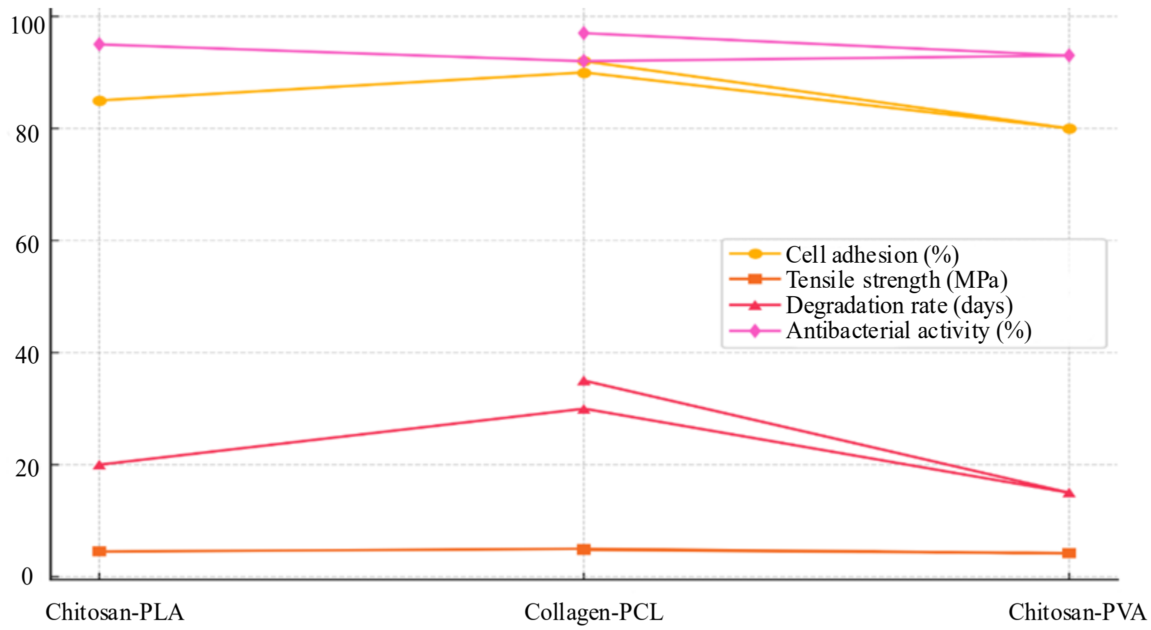

Figure 4. Trend of composite material properties.

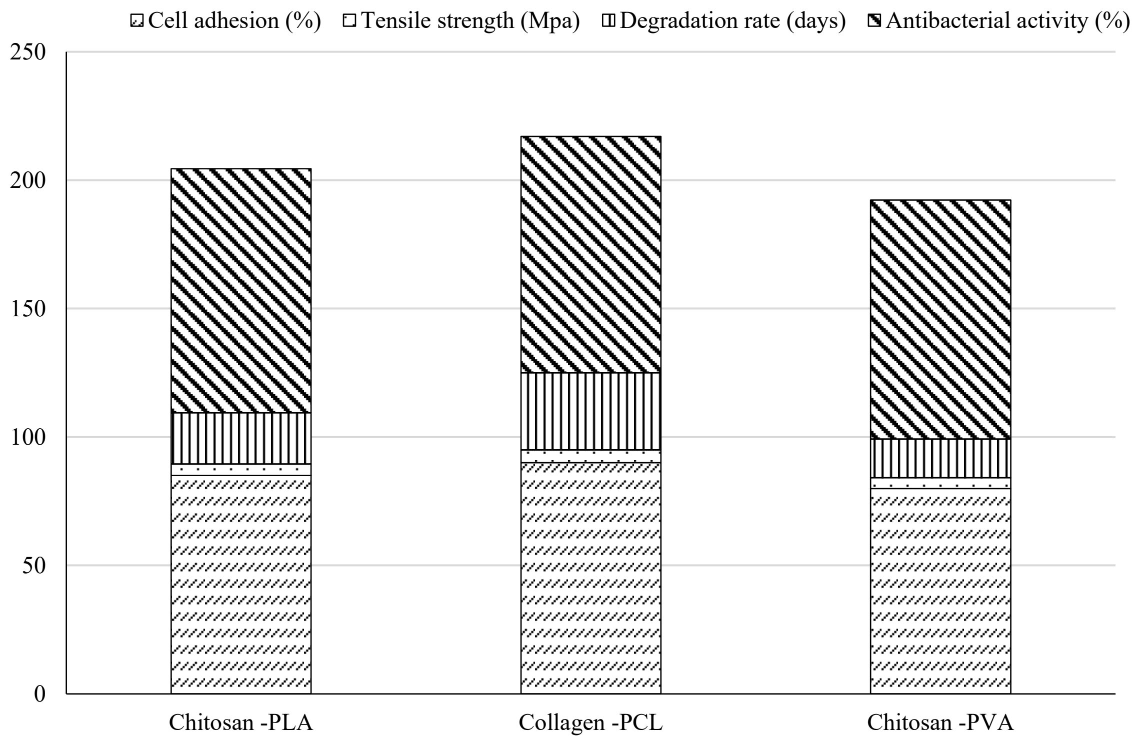

Figure 5. Cumulative properties of composite materials.

It also has a high tensile strength (5 MPa), which makes sure that the material gives enough muscular support while the wound heals. But the fact that it breaks down in 30 days says that it breaks down more slowly, which may be good for long-term support but could slow down tissue regrowth in the beginning. This is another Chitosan-PVA hybrid that has a cell binding rate of 80% and antibiotic activity of 93%. It breaks down relatively faster, in 15 days, which could help tissues heal faster, but it has a slightly lower mechanical strength (4.2 MPa).

Journal of Polymer & Composites
Volume 13, Special Issue 4
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

Table 3. Drug Delivery Evaluation.

Composite type	Drug release (%)	Targeted delivery efficiency (%)	Encapsulation efficiency (%)	Biodegradability (%)
PLGA-Nanoparticles	85	90	95	98
PCL-Nanoparticles	80	85	93	95
PLA-PEG	88	88	97	97
PCL-PLGA	87	87	94	96

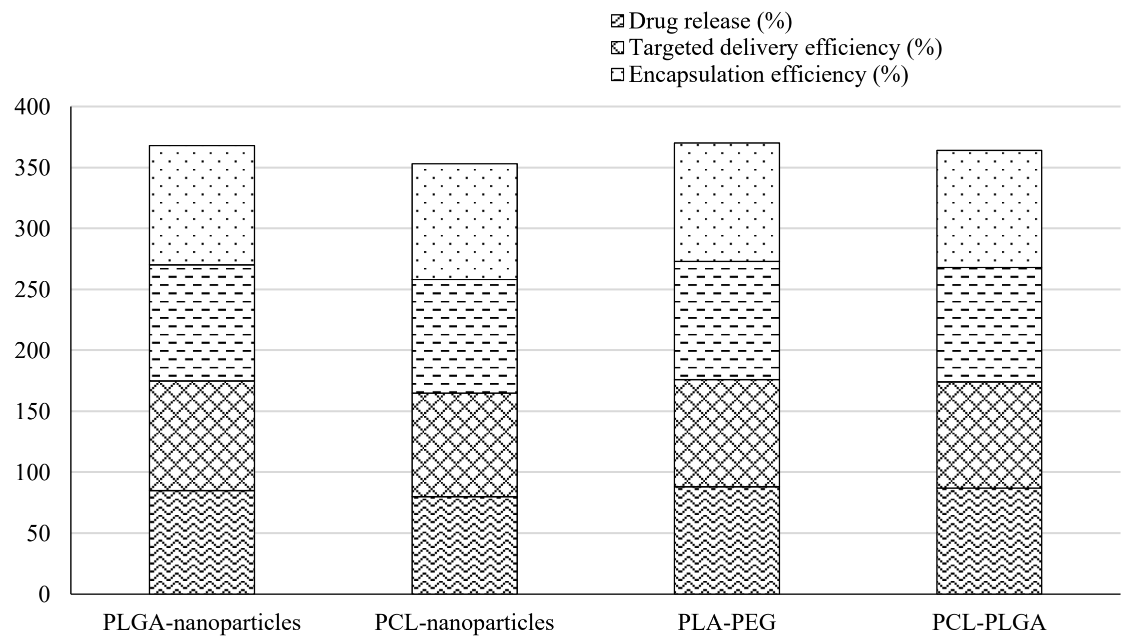

Figure 6. Cumulative performance of nanoparticle composites.

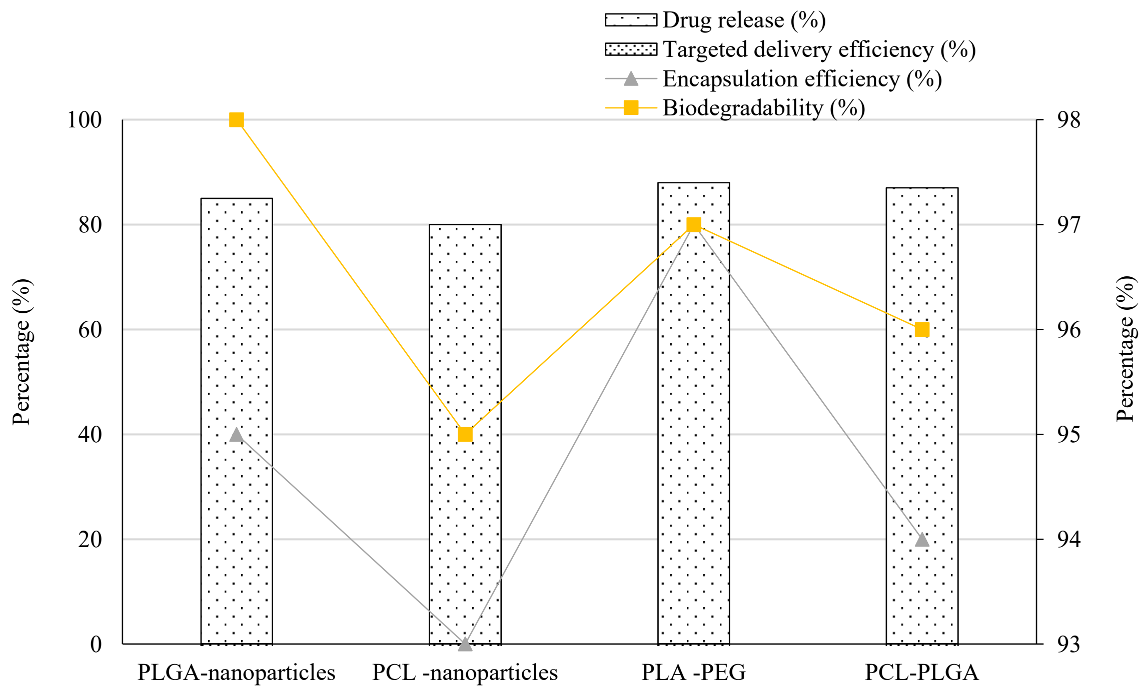

Figure 7. Comparative analysis of nanoparticle properties.

In Table 3, different polymer compounds for drug delivery are ranked by how well they release drugs, send drugs to specific areas, encapsulate drugs, and break down naturally. It looks like the PLGA-Nanoparticles combination can get drugs to the right place because it has high focused delivery efficiency (90%), which means it releases drugs well (85%). Figure 6 shows how well nanoparticle combinations work overall, emphasising their usefulness in different areas.

Its high encapsulation efficiency (95%) means that a lot of the drug is safely enclosed within the nanoparticles, which makes it more useful as a medicine. The biodegradability of 98% means that it breaks down quickly in the body, so it won't build up over time. The PCL-Nanoparticles combination also works well; it releases drugs 80% of the time and delivers them to the right place 85% of the time. Figure 7 shows a comparison of nanoparticle features, focussing on their size and functions.

Its 93% encapsulation rate is a little lower than PLGA's, but it's still good at getting medicinal agents to where they need to go. Biodegradability (95%) is also good, though a little lower than PLGA's, which means it breaks down more slowly. The PLA-PEG combination has the best drug release (88% of the drug is released) and packaging (97% of the drug is enclosed), so a lot of the drug is available for long-term release. It is a good choice for controlled and effective drug delivery because it biodegrades 97% of the time and has an 88% focused delivery efficiency.

CONCLUSION

When you mix manufactured and natural polymers, you get polymer blends, which show a lot of promise for both wound repair and drug delivery. It's better to combine natural polymers like collagen, chitosan, and hyaluronic acid with synthetic polymers like PLA, PCL, and PLGA. This is because the bioactivity and biocompatibility of natural polymers are combined with the mechanical strength and controlled degradation of synthetic materials. These mixtures are especially helpful for treating wounds because they help tissue grow back, speed up cell movement, and lower the risk of infection by killing germs naturally. These polymer compounds allow bioactive agents to be released in a controlled, prolonged, and focused way in drug delivery devices. Being able to change the rates of breakdown and add elements that respond to inputs makes it possible to create customised drug release patterns that reduce systemic side effects and boost treatment effectiveness. Polymer composites are also very flexible, which means they can hold a lot of different healing agents, like small molecules, proteins, and genes. This means they can be used in many different medical fields. Also, the way polymer materials control wetness and let air through makes the mending process better overall by keeping the right conditions for tissue growth while avoiding too much dryness or infection. Because of these features, as well as their biodegradability and dynamic strength, polymer composites are very appealing for making improved wound bandages and tissue scaffolds.

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