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Research Article

CHEMISTRY

## Chemically Crosslinked Polyvinyl Alcohol/ Gelatin Wound Dressing Loaded With Curcumin

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### KEY WORDS

PVA,  
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Hydrogel  
membranes,  
Wound  
dressings.

### ABSTRACT

Wound dressings are highly desired for treatment of chronic wound infections. This study aimed to prepare membranes composed of chemically crosslinked PVA and Gelatin polymers. Curcumin was added to improve the membrane biological properties. FTIR spectroscopy was used to investigate their chemical structures, while SEM and TGA analysis were applied to studies the morphology of the membrane and the thermal properties of the crosslinked membranes. In addition, the contact angle measurement was also performed to get more information about the physicochemical properties. In addition, the biodegradability studies were performed and the findings highlighted that the prepared biodegradable PVA/ Gelatin/ Curcumin membranes could be efficiently used as dressers for enhancing the wound healing.

## 1. Introduction

Polyvinyl alcohol (PVA) is a linear synthetic polymer produced via partial or full hydrolysis of polyvinyl acetate to convert the acetate groups to hydroxyl groups. The amount of hydroxylation determines the physical characteristics, chemical properties, and mechanical properties of the PVA [1]. The resulting PVA polymer is highly soluble in water but insoluble in organic solvents. The higher the degree of hydroxylation and polymerization of the PVA, the lower the solubility in water and the more difficult it is to crystallize [2]. Due to its water solubility, PVA needs to be crosslinked to form hydrogels for use in several applications. The crosslinks, either physical or chemical, provide the structural stability [3]. The degree of crosslinking dictates the amount of fluid uptake, and thus the physical, chemical, and diffusional properties of the polymer, and ultimately its biological properties.

Gelatin is a soluble protein compound made by partial hydrolysis of collagen, the major fibrous protein constituent in bones, cartilages and skins; therefore, age of the animal, the source, and type of collagen [4].

Gelatin quality for a particular application depends largely on its rheological properties

[5]. Apart from basic physico-chemical properties, such as composition parameters, colour, transparency, solubility, odour and taste, the main attributes that best define the overall commercial quality of gelatin are gel strength and thermal stability (gelling and melting temperatures). For 3 standardizing purposes, measurement of gel strength is determined using the so-called Bloom test, which consists of performing a well-defined protocol at a given gelatin concentration (6.67%), temperature (10°C) and maturation time (17h), thus allowing gel strength to be expressed in the normalized “bloom value” [6]. Both, gel strength and thermostability, are largely dependent on the molecular properties of gelatin, especially with respect to two main factors: (i) the amino acid composition, which is species specific, and (ii) the molecular weight distribution, which results mainly from processing conditions [7].

Curcumin is a hydrophobic polyphenol has antibacterial, antioxidant, antifungal, antiviral, anti-inflammatory, pro-apoptotic and anti-atherosclerotic effects, exerting medicinal benefits against neurodegenerative diseases, arthritis, allergy, inflammatory bowel disease, nephrotoxicity, AIDS, psoriasis, diabetes, multiple sclerosis, cardiovascular disease, and lung fibrosis [8].

Current work aims to produce membranes based on both PVA/ Gelatin and including

## 2. Experimental

### 2.1. Material

Polyvinyl alcohol PVA (Mw = 72,000 g/mol, 88% hydrolyzed) was bought from Bioc , Curcumin obtained from Germany, Gelatin from bovine (type B) and Glutaraldehyde (50%) were obtained from Sigma Aldrich, Germany. Bovine Serum Albumin (BSA, Fraction V).

### 2.2. Instruments

The FT-IR spectra were recorded by (EQUINOX 55 instrument (BRUKER, Germany), contact angle was measured using (advanced Gonimeter model 500-F1), TGA was measured using (Shimadzu TGA – 50, Japan), SEM was measured using (FE-SEM; Zeiss Leo Supra 50 VP).

curcumin in these membranes to be used as wound dressing application.

### 2.3. Preparation of PVA/ Gelatin/ Curcumin crosslinked membranes

Polyvinyl alcohol was dissolved in distilled Water with 10% concentration and mixed with 3% gelatin solution in distilled water in ratios 5:0 , 4:1, 3:2, 2:3 and 1:4 **Table (1)** then the mixture was stirred at 50 °C for 2 hours. Then Curcumin solution was added to the mixtures to reach final concentration 20µg/mL followed by addition of 150 µl glutaraldehyde 2.8% was added to the blend of PVA and Gelatin by traditional casting method in petri dishes were need to produce the membranes of PVA/gelatin/ curcumin.

**Table (1): Sample codes for different PVA/Gelatin/curcumin membranes**

Code	10% PVA content	Gelatin content
100% PVA/0% Gelatin	25 ml	0.0 ml
80% PVA/20% Gelatin	20 ml	5 ml
60% PVA/40% Gelatin	15 ml	10 ml
40% PVA/60% Gelatin	10 ml	15 ml
20% PVA/ 80% Gelatin	20 ml	5 ml

#### 2.4. Gel fraction

The obtained PVA/ Gelatin/ Curcumin membranes were dried first in a laminar airflow chamber under sterile conditions for 24 hrs, then dried again at 50 °C in vacuum oven for 24 hrs and weighted ( $W_0$ ). The dried membrane samples were soaked in distilled water for 24 hrs up to an equilibrium swelling weight ( $W_s$ ) for removing the leachable or soluble gelatin parts from membrane. The membrane then dried directly at 50 °C in vacuum oven and weighted again ( $W_e$ ). The gel fraction (GF %) was calculated by the following equation [9]

$$\text{Gel fraction GF \%} = (W_e/W_0) \times 100$$

#### 2.5. Swelling behavior

In order to measure the swelling degree of PVA/ Gelatin/ Curcumin membranes, the membrane samples were cut into 2x 2 cm pieces and dried at 50 °C in an oven for 24 h, the weight of dried sample was determined ( $W_e$ ). The dried samples were soaked in distilled water, maintained and incubated at 37 °C, then weighted ( $W_s$ ) at specific interval times. The water uptake of PVA/ Gelatin/ Curcumin membranes was determined using the following formula [9].

Water uptake or swelling ratio

$$\text{SR\%} = [(W_s - W_e) / W_e] \times 100$$

#### 2.6. Biodegradability

Biodegradability of the membrane was measured by the following method, PVA/ Gelatin/ Curcumin membranes have been dried under vacuum at 50 °C for 24 h. dried membrane samples with size of 15x8 mm, were weighted and immersed in 3 ml phosphate buffer saline (0.1 M, pH 7.4, at 37 °C). The samples were removed at timed intervals and then wiped gently with soft paper to remove surface water. The samples were dried again under the same mentioned drying conditions above and finally weighted. All experiments were done in triplicate.

#### 2.7. Wettability (Contact angle measurements)

Static water contact angle measurements were performed at room temperature using (advanced Gonimeter model 500-F1) in a sessile drop configuration (using ultrapure water as the liquid), coupled with a video camera and image analysis software. At least ten droplet images were obtained for each film [10].

#### 2.8. FT-IR

Vacuumed and dried samples of PVA, Gelatin, Curcumin and PVA/ Gelatin/ Curcumin membranes were analyzed by FTIR on an EQUINOX 55 instrument (BRUKER, Germany). Translucent KBr-disks were prepared by

grinding the dried sample materials together with infrared grade KBr and then pressing. The FTIR spectra were obtained by recording 64 scans between 4000 and 400  $\text{cm}^{-1}$  with a resolution of 2  $\text{cm}^{-1}$ . All samples were freeze-dried using liquid nitrogen, crushed to a fine powder (KBr: sample = 140 mg: 2 mg), and pressed by applying a force 105 N into a transparent disk (maximum disk weight = 145 mg) with a diameter of 13 mm. All samples were measured in absorbance mode.

## 2.9. Thermogravimetric analysis

### (TGA)

The samples were subjected to TGA instrument to determine their thermal stability and decomposition characteristics. Thermal stability of the polymer films was examined, using thermogravimetric analyzer (Shimadzu TGA -50, Japan).

## 2.10. Scanning electron microscope

The surface morphology of the dried Gelatin layers was investigated using field-emission scanning electron microscopy (FE-SEM; Zeiss Leo Supra 50 VP). Before characterization, the samples were sputtered with a thin (B5 nm) gold layer to avoid electron charging effects during FE-SEM characterization. The gold-coated

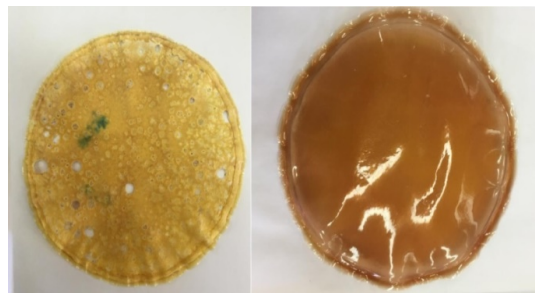
samples were then fixed on metallic stubs using a conductive carbon tape and placed into the vacuum chamber of the microscope for image capturing.

## 3. Results and discussion

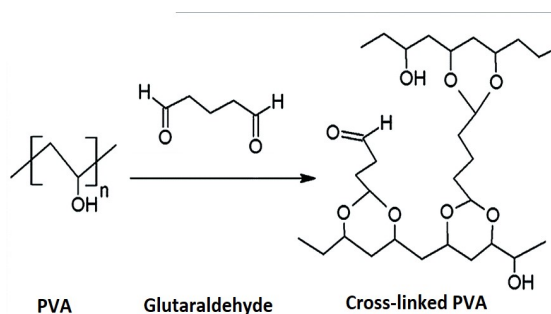
### 3.1. PVA stabilization forming hydrogel membranes

**Fig. (1)** represented photos of the formed chemically crosslinked films that formed after casting the PVA in Petri dishes with glutaraldehyde.

Addition of glutaraldehyde to PVA was made chemical crosslinking with PVA by forming chemical bonds as a bridge and convert membranes from soluble to be crosslinked insoluble membranes as shown in **Fig. (2)**.



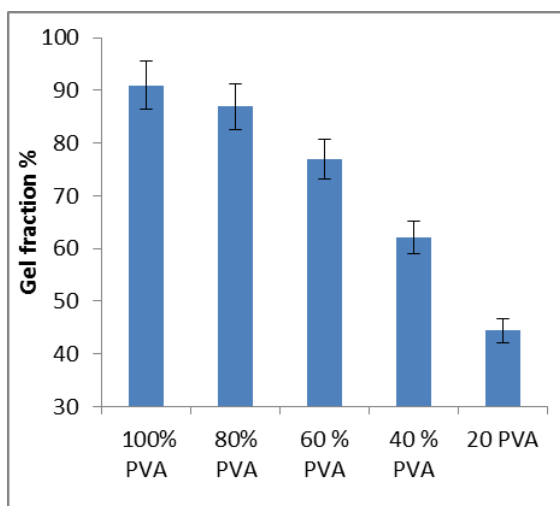
**Fig 1:** Photos of the prepared membranes



**Fig. (2):** Crosslinking between PVA and glutaraldehyde

### 3.2. Gel fraction

**Fig. (3)** represented gel fraction of crosslinked PVA/ Gelatin/ Curcumin membranes and it was appeared that the highest PVA content had the highest crosslinking degree and highest stability and incorporation of gelatin in content of membranes decreasing gel fraction percent and the highest gelatin content had the least crosslinking degree which confirm PVA crosslinking after glutaraldehyde addition.

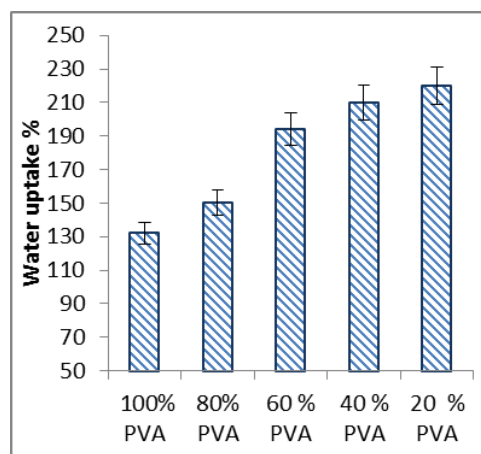


**Fig. (3):** Gel fraction of PVA/ Gelatin incorporated Curcumin crosslinked membranes graph.

### 3.3. Swelling behavior

**Fig. (4)** illustrated the water uptake for PVA/ Gelatin/ Curcumin crosslinked membranes, it was clear that membranes of only PVA containing Curcumin had the least water uptake and incorporation of gelatin in the content of PVA/ Curcumin membranes increased their swelling behavior and by increasing the

content of gelatin increased the water absorbability of prepared membranes



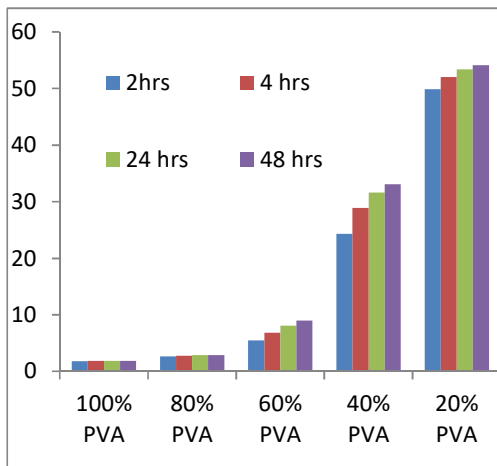
**Fig. (4):** water uptake of PVA/Gelatin incorporated Curcumin crosslinked membranes graph

### 3.4. Biodegradability

The hydrolytic degradation mechanism investigated in this study explained the degradation of native PVA and Gelatin and their contents in crosslinked membranes because the initial membranes had a smooth interface, allowed water to easily permeate to the inner side after immersion in PBS, resulting in rapid degradation from the outside to the inside and promoting weight loss. Membrane surface macromolecules preferentially hydrolyze into low molecules that were dissolved in PBS, and the degradation pattern is largely surface erosion [11].

It was appeared that from the following diagram in **Fig. (5)** that the prepared membranes from 100% PVA almost non degradable and the loss weight percent

around 1-1.2% and incorporation of Gelatin in PVA/ Curcumin membranes slightly increase the biodegradability until content of Gelatin reach 44% and more produce highly biodegradable membranes which confirm our results of Gel fraction degree and the samples with chemically crosslinking using glutaraldehyde.

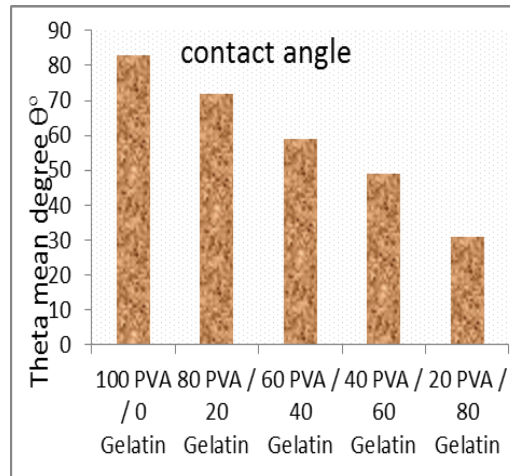


**Fig. (5):** Biodegradability of PVA/ Gelatin incorporated Curcumin stabilized hydrogel membranes.

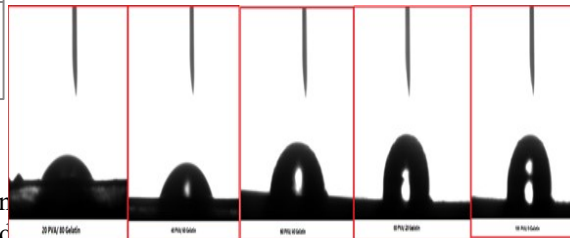
### 3.5. Wettability (contact angel)

Contact angel of PVA stabilized hydrogel membranes of 100% PVA content show highest contact angel value of electro spraying small droplets which was 81.2° which dramatically decreased to reach 31.7° for the lowest PVA content and highest 80% Gelatin extract content as represented in **Fig. (6)**. The results confirmed the data resulted from swelling experiment that the hydrophilicity increased with increasing

the content of Gelatin and decreasing PVA crystalized via glutaraldehyde. **Fig. (7)** showed the photos resulted from electro spraying small droplets.



**Fig. (6):** graph of contact angel results for PVA/ Gelatin incorporated Curcumin stabilized films

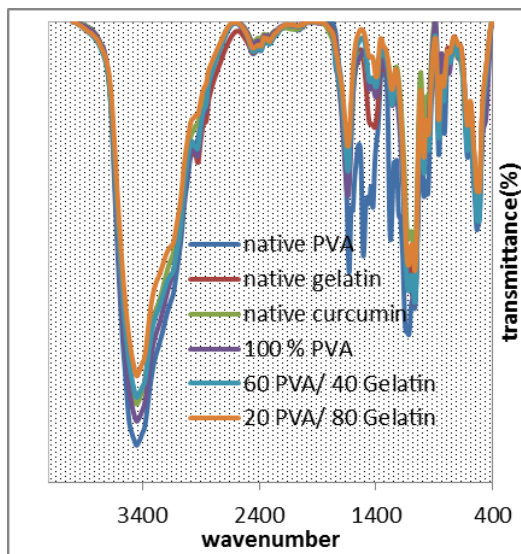


**Fig. (7):** photo of electro spraying small droplets on different membrane contents

### 3.6. FT-IR

**Fig. (8)**, pure PVA, The –OH stretching vibration was responsible for the band at 3301 cm<sup>-1</sup>, whereas the OH bending vibration of the hydroxyl group is responsible for the peak at 1425 cm<sup>-1</sup>. Asymmetric CH<sub>2</sub> group stretching vibration was shown by the vibrational band at 2925 cm<sup>-1</sup>. The C=C stretching vibration of PVA was responsible for the

peak at around 1633–1561  $\text{cm}^{-1}$ . The C–O stretching vibration had a peak at roughly 1089  $\text{cm}^{-1}$ , while the C–C stretching vibration had a band around 842  $\text{cm}^{-1}$  [12, 13].



**Fig. (8):** FT-IR graphs of PVA/Gelatin stabilized films with different contents

The IR spectra of Curcumin, shows stretching vibrations at 1628  $\text{cm}^{-1}$  attributed predominantly to the overlapping stretching vibrations of alkenes (C=C) and carbonyl (C=O) character. Infrared of Curcumin ligand showed stretching vibration at 3200–3500  $\text{cm}^{-1}$  due to O-H groups, C=C aromatic stretching vibration at 1427  $\text{cm}^{-1}$  and high intensity band at 1512  $\text{cm}^{-1}$  attributed to the mixed vibrations including stretching carbonyl bond vibrations  $\nu(\text{C}=\text{O})$ , in plane bending vibrations around aliphatic  $\delta \text{CC-C}$ ,  $\delta \text{CC}=\text{O}$  and in plane bending vibrations

around aromatic  $\delta \text{CC-H}$  of keto and enol configurations and stretching vibrations around aromatic  $\nu\text{CC}$  bonds of keto and enolic form of Curcumin [14]. Furthermore, significant intense band at 1277  $\text{cm}^{-1}$  attributed to the bending vibration of the  $\nu(\text{C-O})$  phenolic band.

The FTIR spectra of gelatin exhibited peaks at 3450  $\text{cm}^{-1}$  and 3423  $\text{cm}^{-1}$  due to secondary amide -NH stretching, C=O stretching at 1680  $\text{cm}^{-1}$  and 1640  $\text{cm}^{-1}$ , and C=O stretching at 1680  $\text{cm}^{-1}$  and 1640  $\text{cm}^{-1}$ . -NH bends between 1550 and 1500  $\text{cm}^{-1}$ . C-H stretching at 2922  $\text{cm}^{-1}$  and 2850  $\text{cm}^{-1}$  and -NH out-of-plane wagging at 670  $\text{cm}^{-1}$  [15].

### 3.7. Thermogravimetric analysis (TGA)

TGA thermograms various amounts of PVA/ Gelatin based membranes containing Curcumin showing changes in thermal degradation profile as loss weight percent and the concluded thermogram data have been compiled in **Table (2)**.

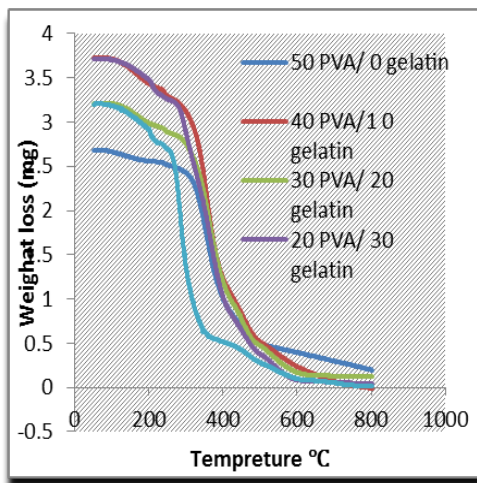
**Table (2):** Thermogravimetric results of PVA/ Gelatin/ Curcumin crosslinked membranes

	T25	T50	T75
20 PVA/ 80 Gelatin	342	375.37	454
40 PVA/ 60 Gelatin	338	377	447
60 PVA/ 40 Gelatin	331	367	438
80 PVA/ 20 Gelatin	307	359.8	410
100 PVA/ 0 Gelatin	275	293.55	332

The thermal decomposition temperature (T25, T50 and T75) have been studied.



As gelatin content increased, the residual weight loss after complete volatilization and the onset temperatures slightly increase **Fig. (9)**, and **Table (2)**. Thus, addition of gelatin improved the thermal stability of PVA/ Gelatin/ Curcumin membranes, because the hydroxyl groups of gelatin might form hydrogen bonding with those of PV



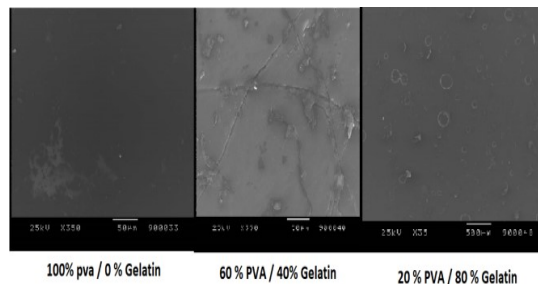
**Fig. (9):** TGA thermogram of PVA/ Gelatin stabilized hydrogel films.

The first degradation step at 50–150 °C could be ascribed to the removal of traces of water or solvent vapor. The second degradation step between 250 and 500 °C resulted in the highest residual weight loss and this was due to the decomposition and volatilization of organic components of polymer. The third decomposition step was after approximately 550 °C, the curves all become flat and mainly the organic residues are completely volatilized.

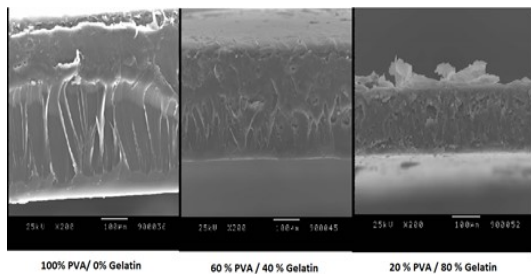
The presented data of thermal degradation in **Table 2** [9] who revealed that the addition of HES to PVA improved thermal properties of hydrogels.

### 3.7. Scanning electron microscope morphological study

Scanning electron micrographs revealed that the film morphology of highest Gelatin content had more destroying surface and more amorphous surface and cross-sectional shape but the higher PVA hydrogel membrane content gave more arranged surface and some vertical stacks like tubes or channels in cross-sectional shape as illustrated in **Figs. (10, 11)** from **Fig. (10)** also it was clear that the highest gelatin content sample had a highest porous surface that serve to increase hydrophilicity which confirmed from our results of contact angel and swelling at equilibrium.



**Fig. (10):** Surface SEM



**Fig. (11):** Cross Sectional SEM

#### 4. Conclusion

PVA/ Gelatin/ Curcumin membranes were chemically crosslinked by glutaraldehyde to wound dressing applications. FTIR, TGA and SEM analysis tools were used to describe the chemical structure of membranes and formation of bonds between PVA and glutaraldehyde, thermal properties and surface and cross section morphologies which was destroyed by addition of Gelatin made the membrane more hydrogel and increase swelling properties, respectively. Moreover, water-contact angle was also examined to describe the morphology. Addition of Gelatin increased hygroscopicity of membrane to save the wound wet which increase wound healing effect.

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### التشابك الكيميائي لكحول البولي فاينيل مع الجيلاتين في ضمادة الجروح المحملة بالكرميين

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ضمادات الجروح مرغوبة للغاية لعلاج التهابات الجروح المزمنة. هدفت هذه الدراسة إلى تحضير أغشية مكونة من بوليمرات PVA والجيلاتين المتشابكة كيميائياً. تمت إضافة الكرميين لتحسين الخواص البيولوجية للغشاء. تم استخدام التحليل الطيفي FTIR لإظهار الهياكل الكيميائية الخاصة بهم ، بينما تم تطبيق تحليل SEM و TGA لدراسة الشكل الخارجي للغشاء و الخواص الحرارية للأغشية المتشابكة. بالإضافة إلى ذلك ، تم إجراء قياس زاوية التلامس أيضاً للحصول على مزيد من المعلومات حول الخصائص الفيزيائية والكيميائية بالإضافة إلى ذلك ، تم إجراء دراسات التحلل البيولوجي وأوضحت النتائج أن أغشية PVA / الجيلاتين / الكرميين القابلة للتحلل الحيوي يمكن استخدامها بكفاءة كضمادة لتعزيز التئام الجروح.