Preparation of Wound-Dressings Based on Prepared Hydrogel and Studying Its Physical Properties

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Abstract

In this research, a wound-dressing sample based on PVA/CS hydrogel is prepared. Thus, Synthesizing PVA/CS is fundamental and achieved using a three-step protocol. We have performed physical properties tests aiming to study and determine the ideal tensile strength, Young's modulus and water absorption (WA) to prepare a physically qualified wound-dressing. First, tensile strength and Young's modulus are determined by applying force on the samples measured by a gauge, and then doing the required calculations depending on certain equations. Second, water absorption (WA) values are determined using a simple measurement method which has also been explained. The suggested design of the wound-dressing consists of three layers; Effective Bacterial Barrier, Self-adhesion and Gentle on Wound. Thus, the design satisfies the global considered criteria. We could locally produce a wound-dressing that is robust, well blood-absorbing and has the ability to reduce pain via a cooling effect and low adherence to tissue.

Keywords: tensile strength, young's modulus, swelling ratio, hydrogel, wound-dressing.

Introduction

The word "hydrogel", according to Lee, Kwon and Park, dates back to an article published in 1894. Anyway, the material described there was not a hydrogel as we describe it today; it was indeed a colloidal gel made with inorganic salts. Is yet remarkable to notice how the history of the term itself is consistently long. **[5]** However, hydrogels, as described nowadays, are crosslinked hydrophilic polymeric matrixes that swell but do not dissolve in water. Hydrogels for wound dressing applications need to adhere firmly to cover the open wound and to provide protective microenvironment for wound healing. **[6]** In order to produce a high-quality wound-dressing based on hydrogel, chemical and physical properties should be studied and determined including water absorption and tensile strength as a first step in an integrated process.

Materials

Poly vinyl alcohol (PVA), deionized water, DMAP, succine anhydride, acetone, Potassium bromide, Chitosan (CS), EDC, NHS, Carboxylic acid and NaOH.

Preparation of Hydrogel

Synthesis and Characterization of PVA-COOH:

10.00 g of (PVA) powder is added into 100 mL deionized water and heated to be $90°C$ with constant stirring. The temperature of the solution is cooled down to $65°C$, and 2.77 g of DMAP is added and stirred for 1 h. 22.715 g of succine anhydride is added to above solution, and reacted for 24 h at $65°C$. The reaction solution is cooled to room temperature, and added dropwise to stirred acetone. The precipitated product (PVA-COOH) is collected, washed twice with acetone, and dried in a vacuum oven at room temperature. The structure of PVA-COOH is examined by Fourier transform infrared spectroscopy. To obtain FTIR spectra, samples are milled with dry potassium bromide at weight ratio of 1/100 and then mounted on the sample holder and scanned from 4000 to 600 cm^{-1} for 32 times with 2 cm^{-1} resolutions to average signal. The $^{(1)}H$ NMR spectra are recorded on a Bruker Advance III 400 MHz Digital NMR spectrometer using D_2O as solvent. Chemical shifts are recorded in ppm and referenced against tetramethylsilane (TMS).

Preparation of the PVA-COOH and Chitosan Solutions:

2.50 g of PVA-COOH powder is added to 250 mL deionized water with continuous stirring at $90°C$ for 1 h, and the PVA-COOH solution (solution A) is cooled down to room temperature before using. CS solution (solution B) is prepared by adding chitosan powder to previously prepared 1% acetic acid at a concentration of 1% (w/v), with continuous stirring at room temperature overnight.

Preparation of CS Hydrogel Films Crosslinked with PVA-COOH:

Solution A and B are stirred to form a well-mixed blend solution. The amount of PVA-COOH and CS in the mixture was 1 wt%. The prepared EDC/NHS ethanolic solution is added to the above solution and stirred steadily. The molar ratio of EDC/NHS/carboxylic acid group in each specimen is 1:1:1. After stirring for 10 min, the mixture is poured onto a glass pane and placed in a fridge overnight at $4°C$ to remove air bubbles, followed by drying Subseq-uently, the dehydrated film is immersed in NaOH solution (1 mol/L), and then washed with distilled water until the pH is approximately 7.0. The obtained PVA-COOH-crosslinked CS hydrogel films containing various weight ratios of PVA-COOH to chitosan (75:25, 50:50, and 25:75) are prepared and denoted as

P70C30, P50C50, P20C80. As an example of the nom-enclature used herein, P70C30 indicates that the weight percent of PVA-COOH and chitosan in this specimen are 75% and 25%, respectively. The PVA/CS blend film (weight ratios of PVA-COOH to chitosan: 50:50) prepared by the same procedure without EDC/NHS added is denoted as blend, and used as a control. **[2][3]**

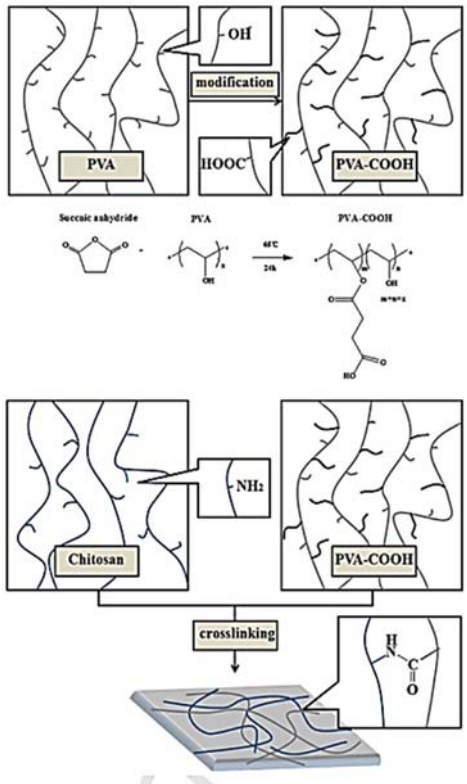

Figure (1): The synthetic route of PVA-COOH; The formation of crosslinked PVA-COOH/CS hydrogels. [1]

Preparation of Wound-Dressings Based on Hydrogel

A wide range of wound dressing categories and material compositions are currently available on the market. Traditional dressings like gauze and tulle mainly cover wounds while maintaining proper gaseous exchange. However, their strong adherence to the wound site causes pain and further lesions during dressing changes. In contrast, hydrogel-based dressings reduce pain for treated patients via a cooling effect and low adherence to tissue. Hydrogels consist of around 90 wt.% water and 10 wt.% natural or synthetic polymers; this high-water content makes hydrogel dressings suitable for treating dry and necrotic wounds. The moist environment is created by hydrogels enhances the cellular wound resolution process and enables effective debridement, i.e., the removal of necrotic tissue and foreign material, via the sorption capabilities of hydrogel materials. In fact, hydrogel-based dress-ings have been shown to absorb up to 1000 grams of wound exudate per gram of dressing, dependent on the hydrogel composition. Permeable hydrogel struc-tures further enable undisturbed exchange of gaseous CO2, O2 and H2O, allowing tissue to 'breath'. Intriguingly, hydrogel structures polymeric networks in an aqueous environment are often similar to that of ECM, allowing the incorporation of cells and biomolecules into dressings for next-generation, biologically enhanced wound treatments. Additional bioactivity may be engendered by combining natural and synthetic precursors to precisely architect the structure of the gel's polymer network, enabling wound dressings with novel wound healing features-controlled drug release, for example.

The wound-dressing is developed using a unique two-step protocol for fast wound recovery and minimal scar formation after skin injuries or surgery. It consists of three layers which are:

1. Effective Bacterial Barrier: The outer waterproof film is highly breathable and vapor permeable; yet it keeps out bacteria and other contaminants.

2. Self-adhesion: Pressure-sensitive adhesive helps ensure good dressing retention with a secure border.
3. Gentle on Wound: The hydrogel layer does not stick to wound bed to avoid damage caused by replacing dressing.

Figure (2): the unique two-step protocol for fast wound recovery and minimal scar formation.

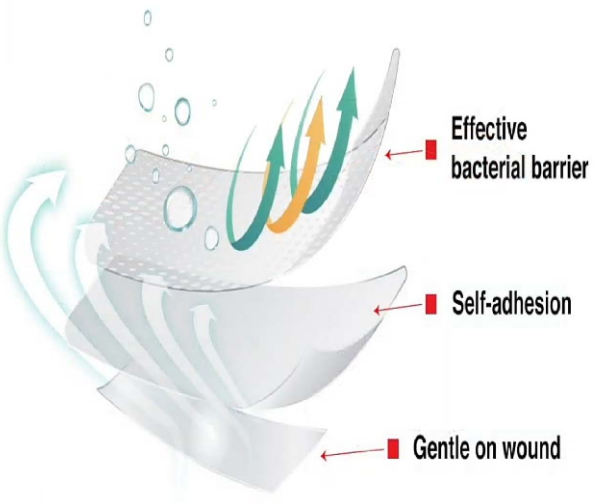

Figure (3): the three layers forming the hydrogel wound-dressing.

Studying Physical Properties of the Resulted Wound-dressings

Determination of the fluid uptake of PVA-COOH\CS dry and granulate:

A cylindrical plastic tube of 20 mm diam. closed at the bottom with a nylon net is filled with PVA-COOH\CS dry and granulate. This cup is dipped in a weighted beaker filled with IO ml fluid and placed on a balance. At appropriate intervals the cup is removed, the fluid loss in the beaker determined, and the fluid uptake per min by the granulate calculated. For determination of water uptake by the dry sheet the material is immersed in 100 ml of distilled water and its increase in water content measured by weighing out at different times.

The water absorption (WA) capacity of PVA/CS hydrogel is determined after 24h of incubation in a water bath at different temperatures, and the values for the three hydrogels and the cotton gauze are shown below in table (1):

Material	PVA/CS 75:25	PVA/CS 50:50	PVA/CS 25:75	Cotton Gauze
Swelling ratio (%)	83	80.5	78.8	11.8

Tensile strength:

To measure the ultimate tensile strength of test strips, 60 mm wide and 3.3 mm thick are used. Young's modulus is determined from the equation:

$$E = \frac{F}{A \times \Delta l};\ \Delta l = l - l_0 \qquad (1)$$

Where:

F: The applied force.

A: The square area.

l_0: The initial length.

l: The terminal length. **[4]**

Three different batches were measured, each one four times and according to three coordinates. The following values rep-resent the mean of the previous mea-surements. Thus, mechanical force gauge is used to measure different forces, which are applied then to the Hydrogel wounds.

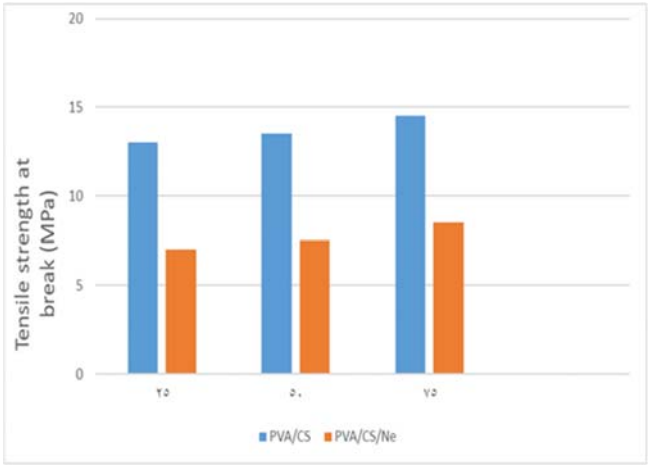

Figure (4): tensile strength at break.

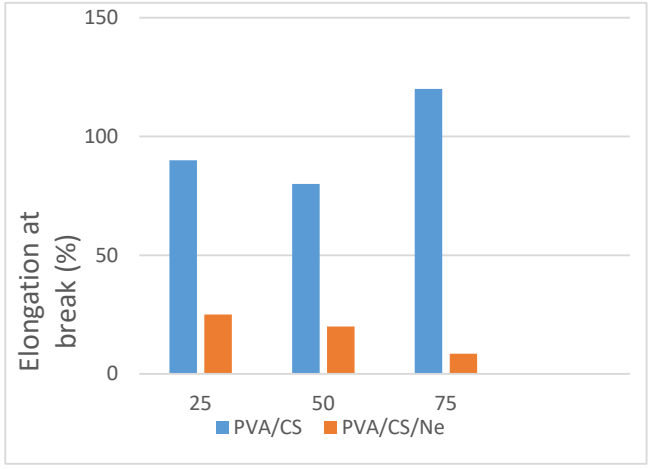

Figure (5): elongation at break.

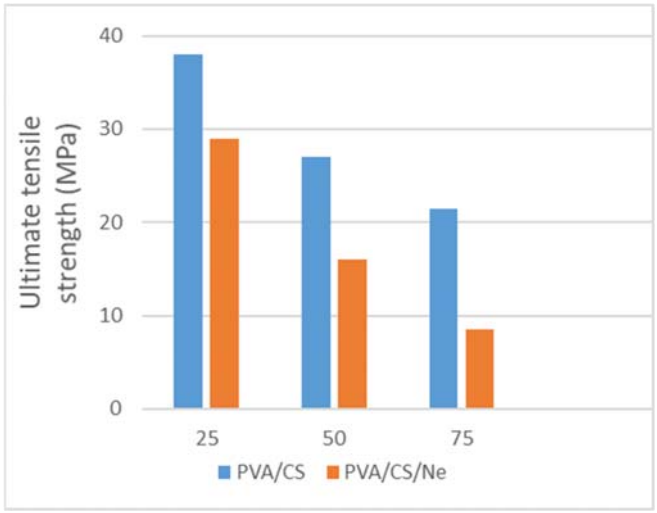

Figure (6): ultimate tensile.

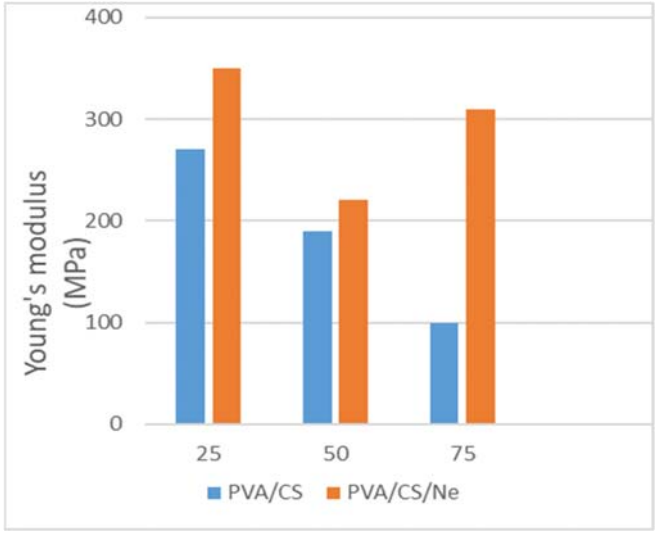

Figure (7): Young's modulus measurements.

Where tensile strength and tensile stress are given by the following equations:

$$s = \frac{P}{a}$$

$$\sigma = \frac{F}{A}$$

Where:

s: Tensile strength.

σ: Tensile stress.

P: The force required to break.

a: The cross-sectional area.

F: The applied force.

A: The area.**[4]**

Results and Discussion

In this paper, Hydrogel has been prepared using PVA and Chitosan with different ratios. Thus, using different samples, the physical properties are studied and determined (tensile strength and water absorption). For the PVA/CS (25:75), PVA/CS (50:50) and PVA/CS (75:25), the values of tensile strength equaled 39 ± 0.53 , 27 ± 0.37 and 22 ± 0.30 (MPa) respectively. When it comes to water absorption, hydrogel is a better choice compared with cotton gauzes. Depending on the previous results, it can be reckoned that PVA/CS (25:75) is the best hydrogel satisfying the tensile strength property of an ideal hydrogel. An ideal wound-dressing is marked by certain features such as: preventing the bacterial infection and simultaneously allowing air to get to the wound. Another criterion is having the ability to adhere to the damaged area without clinging to the wound itself or hurting the wound. The suggested design, which has three layers, fulfills the aforementioned criteria.

Conclusion

Treatment of skin wounds aims to fulfill two objectives. The first objective is to stop the hemorrhaging and prevent the exsanguination. The second objective is to prevent the bacterial infection, permanent damage and the loss of function. As a consequence, modern wound-dressings are becoming increasingly more sophisticated by providing a compatible environment for fast healing and securing therapeutic agents delivery. Studying tensile strength and water absorption is the preliminary stage for synthesizing a biocompatible hydrogel wound-dressing with standard specifications and physical properties. Many researches have been accomplished in the field of hydrogel wound dressings on the world-wide scale. Syria, as a developing-country, is still importing these wound-dressings instead of working on their local manufacturing due to many obstacles. Therefore, this paper comes in the context of withstanding these obstacles in order to enforce the local industry in our country.

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