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A cost-effective superabsorbent polymer composite for prospective wound healing applications

Bharti[1]*, Priyanka Tyagi[2], and Mainak Basu[3,4]

[1]School of Engineering & Sciences, GD Goenka University, Gurgaon, India
[2]Department of Botany, Maitreyi College, University of Delhi, New Delhi, 110021 India
[3]School of Engineering & Sciences, GD Goenka University, Gurgaon, India
[4]SciCept Advanced Technologies (OPC) Pvt. Ltd., Kolkata, India
*Corresponding author: bhatnagarbharti1996@gmail.com

Abstract

Wound healing is essential for maintaining the physiological functions of the skin. Any disruption of the skin may lead to wound formation, which can result in mortality if left unattended. The most regular or standard therapy is to cover the wound with a dressing, which reduces the risk of infection and secondary damage. Wound healing is a continuous process accompanied by many other associated biological processes. Available market products to aid in wound healing, have some disadvantages, such as the formation of blisters, pain, and delayed healing. The present work is focussed on the development of a new material based upon the theory of super-absorption using cheap and food grade products. These materials are called hydrogels, which can absorb a substantial amount of water and have several applications. One of the applications is for wound healing as the absorption of bloodallows the agglomeration of the platelets, and other proteins which accelerates the wound healing process Although lyophilized hydrogels are lightweight and capable of absorbing large volumes of water, they are extremely brittle and lack structural integrity when absorbed. In this study, we have used Sodium Carboxymethyl Cellulose (NaCMC) and Polyvinyl Alcohol (PVA) polymers with a crosslinker (Boric Acid) to form apolymer composite capable of considerable water absorption to accelerate the wound healing process while retaining the benefits of strong mechanical characteristics, biodegradability, good water absorption, retention, and biocompatibility at a low cost. FTIR and DSC studies have been performed to estimate the chemical composition of the polymer composite and good crosslinking was observed with increasing amounts of the crosslinker.

Keywords: Wound healing, Hydrogel, Crosslinking, Mortality, Lyophilized

Introduction

The skin performs several functions that are required for ideal health and vitality, and as a general defence against external elements. Any disruption in the skin can cause wound formation (laceration, burns, etc.) and increase the chance of mortality, if left unattended (1). Chronic wounds, which can be caused by pressure ulcers, burns, and diabetic foot ulcers, take longer to heal than acute wounds because the normal skin regeneration phases are disrupted and inflammation is extended.(2). Each type of wound has some exudate, which is frequently observed in chronic wounds (particularly venous leg ulcers, diabetic foot ulcers, and certain pressure ulcers(3). This understanding has generated an increasing interest in biomaterial engineering, which focuses on the development of innovative wound dressings to accelerate wound healing (4).

An ideal wound dressing should have the ability to absorb wound exudates, have good porosity and antimicrobial capacity, and

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provide a moist environment to the wound area. (5). Wound dressings can be made from a variety of natural and synthetic materials that are capable of displaying the beneficial behaviors mentioned above, and various forms are currently available on the market. The available solutions can be subdivided into (i) Film (thin, elastic, semipermeable, and transparent) (6,7)for superficial wounds; (ii) Hydrocolloid dressings (two layers; outside semipermeable and interior hydrocolloid (8)); (iii) Foam dressings, which are suitable to moderately and extensively leaking wounds (2) and (iv) Hydrogels are 3D networks of hydrophilic polymers with high water content(9).

Conventional dressings keep the wound area dry and absorb all exudate from the wound. (10), causing saturation. As a result, exudates leak out of the dressing, promoting bacterial attack. The scab covers the entire wound region, decreasing the speed of epithelialization and inhibiting the healing process. These dressings are known as dry dressings (10), which have several limitations, in that they do not favour keratinocyte migration and fibroblast formation. The construction and design of current wound dressings rely on the concept of generating a humid environment surrounding the wound zone (11).

Various biopolymers have been designed and implemented for the applications mentioned above with high biodegradability, biological compatibility, low cost, and the ability to accelerate wound healing (6,9). Many synthetic polymers used for wound healing (12) that have a high water absorption capacity, are also designed to be biodegradable. Recently, there has been growing interest in the use of derivatives of some biopolymers because of their ability to absorb a significant amount of water, gelling ability, and accelerating wound healing (13,14), specifically, the use of nanomaterials has also played a crucial role in the medical industry. Various nanomaterials have been used to form wound hydrogels or scaffolds (through the chelation process), along with antimicrobial activity. (15). In previous studies, different composites have been prepared as superabsorbents. (2). In all of the aforementioned studies, the materials have been developed with the intention of or exploit super absorbency as a property. Although this yields a highly superabsorbent material, it also reduces the mechanical strength, which reduces its effectiveness for wound healing. This is due to the reduced mechanical strength upon super-absorption, which probably leads to leaching into the open wound. In turn, this requires a cytotoxic study of the material that may or may not be beneficial for the stated purpose. Thus, in this study, the choice of materials to develop polymer composites was made with the intention of utilising materials that are already available in commercial space, but utilised in a different manner to allow for both super-absorption as well as higher mechanical strength upon the same.

Uncontrolled bleeding remains the leading cause of preventable mortality following any sort of trauma, whether on the battlefield or in a civilian trauma scenario. Approximately half of the deaths occur before reaching the hospital (16). The problem becomes more complicated when the pattern of injuries becomes significantly more complex. In all these cases, the application of topical hemostatic drugs can be life-threatening. Hence, wound dressings should have the ability to rapidly stop bleeding. However, hemostatic dressings are not accessible everywhere, and hence, are the genesis of this work. Some of the favorable properties of such dressings would include the ability to absorb a considerable amount of water, non-leeching, or low toxicity of the component chemical species in the material, and preferably, the ability to load and discharge specific chemical compounds that can aid in wound healing.

The premise of this study is based on the principle of super-absorption, where the material can absorb a considerable amount of water, which for some of the necessary conditions for the acceleration of the wound-healing process. Hence, in this work, we have used a class of chemical compounds

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called 'Hydrogels' which are extremely lightweight, and can absorb considerable amounts of water but are extremely fragile and incapable of structural integrity in the water-absorbed state.

In recent years, polymers derived from natural sources have gained considerable attention because of their biodegradability, cost-effectiveness, and prospect of abundant supply. Despite these advantages, the primary problem with composites derived from the aforementioned materials is their mechanical weakness. Hence, we chose polyvinyl alcohol (PVA) and sodium carboxymethyl cellulose (Na-CMC) as precursors for the polymeric superabsorbent composite. PVA is a semi-synthetic polymer with excellent water absorption properties (17) and tissue adherence capabilities (18), which are also used in many biomedical applications (19). Several previous studies have used PVA-based wound dressings (20-23). However, in the majority of the work, the presence of only PVA, provided some disadvantages in terms of the dissolution of the hydrogel under water absorption. However, when a composite was devised with a crosslinker and other polymers, the mechanical strength increased, but the water absorption capability decreased. Thus, the addition of a second polymer was necessary for stability, of the composite. Na-CMC is a derivative of cellulose used in the food industry (24) and also possesses the ability to absorb and retain considerable amount of water (25 - 27). Considering this fact, the present study was designed to prepare a novel polymer composite to ascertain some of its physical parameters and determine its potential use as a composite for the wound healing process.

The predecessor materials (namely Na-CMC and PVA), mentioned above have significant superabsorbent capability, but minimal mechanical strength, for application as a wound dressing. Thus, to enhance the mechanical strength and maintain super-absorption of the material, a polymer composite has been envisioned with the predecessor materials. To maintain mechanical stability, a cross-linker is required to form the bridge-linkages between the different chains of the constituent polymers. This in turn, may reduce the absorption capability of the composite because the cross-linker would utilise the same chemical sites for cross-linking as those used for hydrogen bonding with the water molecule. The aim of this article is to study the effects of the absorption of the polymer composite of Na-CMC and PVA on the amount of the crosslinker used. Another preliminary study investigated in this article is the loading of the polymer composite with a material that can be released into the wound during the healing procedure. The aforementioned polymeric superabsorbent materials with a crosslinking agent (Boric acid (BA)) were fabricated in various concentrations to test their absorption capability. Boric Acid is a good precursor of boron which has been reported as beneficial for tissue regeneration and is recognised as a predominant element for homeostasis of the human body. Past research studies have shown that boron interacts with collagenase, elastase and trypsin-like enzymes to enhance the production of an Extracellular matrix (28).

The polymer composite has been developed using a simple heating and stirring method to keep costs low. Further, the semi-solid product is cooled, freeze dried and lyophilized to produce the necessary product. The product samples were then tested for their water absorption, water retention and, porosity estimation (as the samples were lyohpilized), minimal chemical structural identification (via FTIR) and the response to ambient temperature (DSC).

Materials and Methods

The primary material utilized in this study, as mentioned aboveis Na-CMC (High Viscocity, 500-600 cps, P-Code: 13440) by Molychem Mumbai, India, which is available as a powder suitable for use in the food industry. Na-CMC powder is superabsorbent

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and can retain or absorb a significant amount of water. And another material is PVA (P-Code: 16945) by Molychem Mumbai, India, which is available in a small crystalline form and is also a biodegradable polymer that is soluble in hot water. However, the absorbent material lacks mechanical stability and can be effectively utilized as a wound healing dressing. Thus, to enhance the mechanical stability, Na-CMC and PVA were crosslinked using boric acid as the crosslinking agent, as shown in Figure 1. The effectiveness of the gelling agent determines the quality of the of the final polymer material to maintain the delicate balance between mechanical stability and water absorption capability.

All the gelling agents were mixed with Na-CMC, heated, and stirred for a period of 1.5-2 hours at 70º -80ºC, to initiate polymerization. Among all the gelling agents, a combination of Boric Acid, Na-CMC and PVA provided optimal crosslinking to maintain the mechanical stability and retain the capability to absorb water. However, it must be noted that the water absorption capacity of the polymerized and lyophilized Na-CMC composite is lower than that of the Na-CMC powder, the latter of which lacks mechanical strength. To enhance antibacterial activity, menthol was added to the mixture after the polymer blend was prepared.

The constituent chemical species of the polymer composite that is Na-CMC, PVA, Boric Acid and menthol individually provide sufficient biocompatibility and antibiotic properties. Menthol is also known to have anti-inflammatory properties, which is conducive for wound healing. Thus, it is an estimate that the polymer composite would also be biocompatible and have the necessary antibiotic properties, required for biomedical applications.

Preparation of Boric acid crosslinked polymer composite

Sodium Carboxymethyl Cellulose (Na-CMC) and Polyvinyl Alcohol (PVA) were dissolved in warm water with different concentrations of boric acid, which was used as the crosslinking agent. To test the efficacy of the crosslinking agent on the water absorption capability of the final product, five samples were developed (as shown in Table 1), which consisted of one (SC_1) without the use of boric acid, to test the efficacy of the proposed polymer sample for water absorption. SC_2–SC_4 were developed using different concentrations of BA. A previous study showed that boric acid inhibited Candida and CA growth, reduced microbial diversity, and improved the microecological flora of mouse skin (29). It

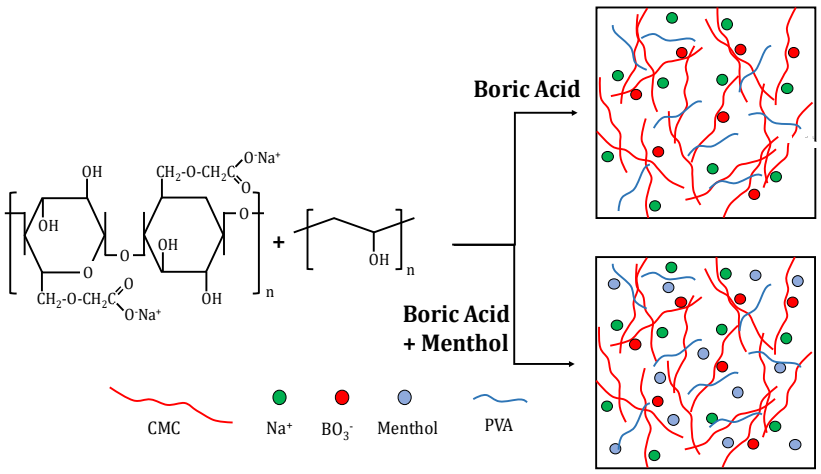

Figure 1: The preparation of the proposed polymers using Na-CMC and PVA

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must be noted that there are some alternative crosslinking agents like citric acid, $CaCl_2$ and additives like gelatin which can be used to increase the adherence power and biocompatibility. However, in this study our choice of Boric Acid is based upon its potential advantage in the acceleration of the wound healing process due to the presence of the Borate ion (30).SC_5 had a specific concentration of BA (0.5 g of menthol in 100% ethanol). The components, with differing concentrations as mentioned in the table, were dissolved in 100 ml of distilled water and magnetically stirred for 1.5-2h to obtain a well-blended reaction mixture. For samples containing menthol, the menthol solution was added dropwise at room temperature, and the effective concentration was determined analogous on a previous study (31). The mixture was poured into a petri dish, kept at -40ºC for 12 h, and then freeze dried (Labconco Freeze Dryer for 24 h). The weight of the components was taken as the weight percentage of 100 ml of water. A flowchart of sample fabrication is shown in Figure 2.

It must be noted that the samples derived from this fabrication process, is required to be Lyophilized before the commencement of further tests.

Characterization Methodologies

Several tests were performed to characterize the stated samples in terms of the characteristics required for wound healing. These include, the following:

(i) Fourier Transform Infra-Red Spectroscopy (FTIR)
(ii) Differential Scanning Calorimetry (DSC)
(iii) Liquid Absorption to estimate the amount of water that can be absorbed.
(iv) Porosity indicator to test for the quantity of liquid which may be absorbed.
(v) Water Retention for the ability to hold onto the water, to accelerate the wound healing.

Table 1: Composition of SC1 – SC5 Polymer Blends (wt. % age in 100 ml of water)

Sample No.	Na-CMC (wt. %age)	PVA (wt. %age)	Boric Acid (wt. %age)	Menthol (wt. in 100% Ethanol)
SC_1	6%	3%	Nil	N/A
SC_2	6%	3%	0.5%	N/A
SC_3	6%	3%	1%	N/A
SC_4	6%	3%	2%	N/A
SC_5	6%	3%	2%	0.5g

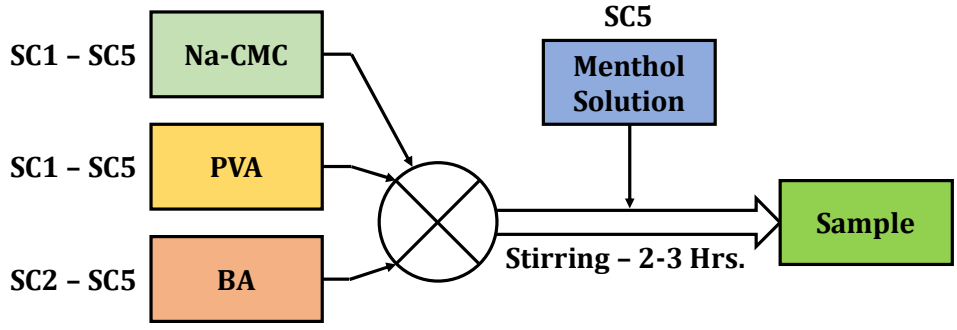

Figure 2: The flowchart for the fabrication of the Na-CMC polymer Samples

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Fourier Transform Infra-Red Spectroscopy (FTIR)

The FT-IR spectroscopy mainly used to identify the functional groups in prepared samples. Samples are being placed directly into the infrared beam. When we run the sample IR beam pass through the sample, the transmitted energy is measured and a spectrum is generated. Prepared samples in this study are in lyophilized form of hydrogel. And the generated spectrum of every prepared sample was observed.

Differential Scanning Calorimetry (DSC)

DSC technique is being used for thermal analysis that measures the temperature and heat flow related to material transformations over time and at different temperatures.

Liquid absorption

Wound dressings should have a good fluid absorption capacity to avoid tissue dehydration in the wound bed and cell death, as well as to promote angiogenesis and heal injured tissues. The polymeric scaffold samples were tested for water absorption capacity at room temperature by weight variation after immersing a piece of pre-weighed sample in water until it was completely saturated with the liquid. Distilled water at 37 °C was used for immersion, after which the samples were removed, and any extra water on the surface was absorbed using filter paper. The capacity of water absorption of the prepared polymeric sample was determined by using the following equation (4)

$$Liquid\ Absorption\ (\%) = \left(\frac{W_1 - W_0}{W_0}\right) * 100 \quad (1)$$

Where $W_0$and W_1 represent the weight of the scaffold before and after water absorption.

Porosity Estimate

Porosity is a crucial physical indicator for ideal wound dressing because it influences exudate absorption capacity, colonization rate, cell structure, and angiogenesis. The liquid displacement method was used to determine the porosity of the samples (32). The samples, were weighed under dry condition (W_0), before soaking in absolute ethanol to reach a saturation point. After 30 minutes, the samples were removed from ethanol and weighed again W_1.

The porosity of the samples was calculated by using the following equation[4]:

$$Porosity\ \% = \left(\frac{W_1 - W_0}{\rho V}\right) * 100 \quad (2)$$

Where ρ is the density of the sample and V is the volume of the dry sample under consideration.

Water Retention

Water retention activity is an important parameter for hydrogel-based wound-healing polymers, which operate based on the principle of water absorption. The longer the polymer sample is capable of holding water, the better are the conditions that lead to wound healing. in order to perform the experiment, the samples were dried at 37°C in an oven for 24 h to remove any traces of water that could influence the recording. The weights recorded at this stage were W_0. The samples were then completely soaked in deionized water for 24 h, and the water retention was measured based on sample weighing at predefined intervals (W_i, where i = 1,2,3…, N), while the samples were placed in a 37 °C oven. The water retention rate of the samples was calculated using the following formula (4):

$$Retention\ (\%) = \frac{W_i}{W_0} * 100\ldots.. \quad (3)$$

Results and Discussions

The results obtained from different avenues, as mentioned in Section 2.2, are summarized as follows:

Fourier Transform Infra-Red Spectroscopy (FTIR)

The prepared hydrogels were characterized using FT-IR spectroscopy, as shown in Figure 3. In this study, FTIR spectroscopy was used to investigate the

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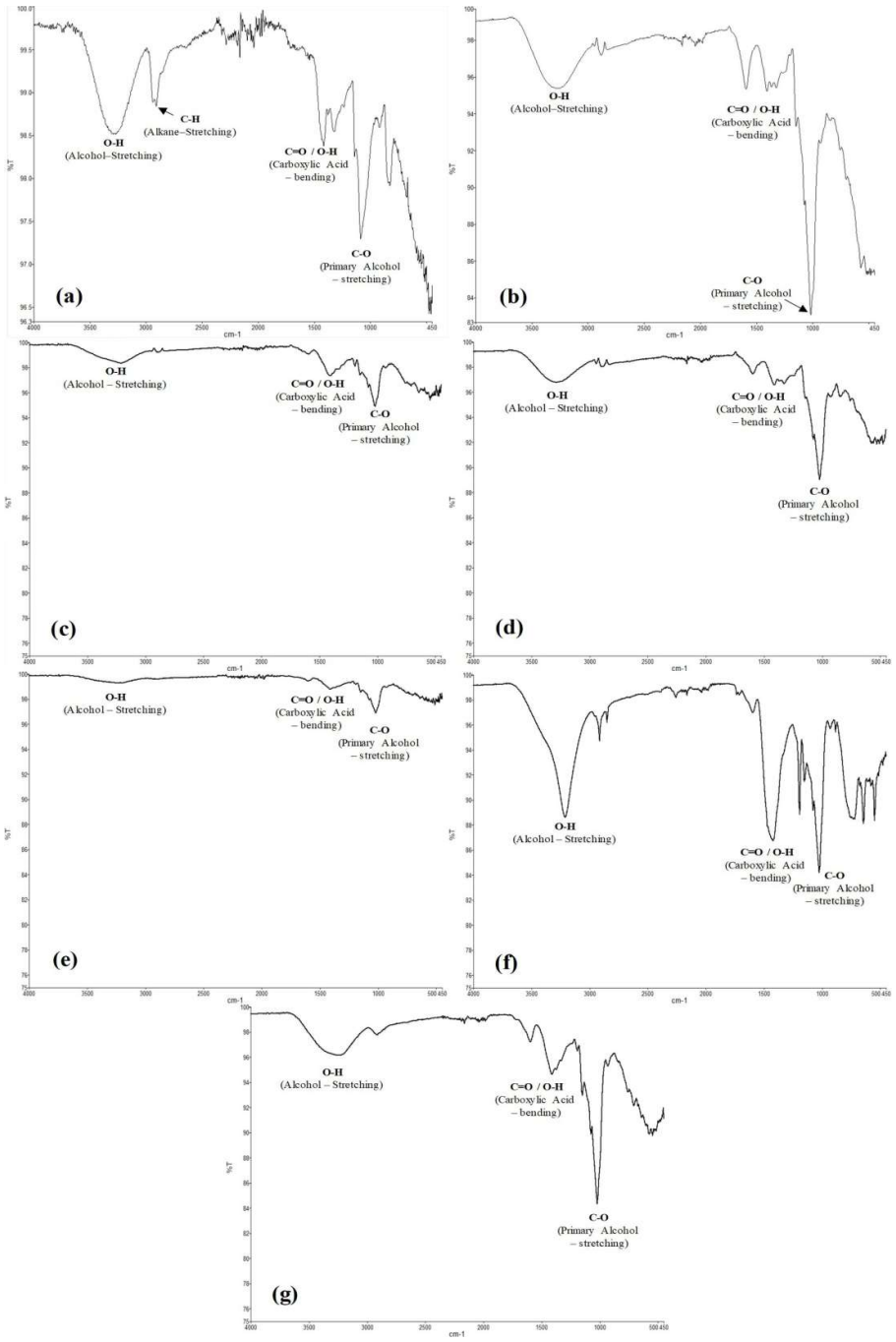

Figure 3: The FTIR spectra of (a) Pure PVA; (b) Pure Na-CMC; (c) SC_1; (d) SC_2; (e) SC_3; (f) SC_4; (g) SC_5

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chemical structure of the lyophilized composite and the probable interactions between the functional groups of PVA and NaCMC polymer blend scaffold. The aim of this study was to determine the number of sites available for water absorption via hydrogen bonding. From Figure 1, it is necessary to mention that during the blending process, the sites on both molecules that participate in the polymerization are also sites that are required for hydrogen bonding with water for its absorption. Although a greater number of bonds dictates that the mechanical strength is comparatively higher, it also dictates that the number of absorption sites and, in turn, the absorption capability of the material is reduced. Hence, the study of FTIR can be indicative of the number of available sites for water absorption with varying mechanical strengths.

Additionally, in this technique, a crosslinker, boric acid, was used for the crosslinking of PVA and the NaCMC polymer. Blend polymer compatibility is indicated by changes in the vibrational frequency of the peaks in the system. Figure 3(a) shows the FTIR spectrum of pure PVA, which is characterized by broad O-H stretching. The spectra of the Na-CMC/PVA and boric acid blends in Figure 3 (c) show that the OH bands in the PVA: NaCMC blend system broadened in size with decreased intensity, which indicates a reduction in PVA crystallinity. The O-H, C-O, C-H, and C =O vibrational peaks were used to identify the distinctive bands of the prepared samples, which contributed to the formation of hydrogen bonds within the hybrid polymer matrix. PVA polymers have a strong propensity for hydrogen bonding with other polymers, including CMC, which contains many electronegative groups. It is important to note that the PVA structure contains carbonyl functionalities owing to the remaining acetate groups from the hydrolysis of polyvinyl acetate that remained after PVA synthesis. The FTIR spectra showed that the response of hydrophilic functional groups, such as C=O, C-O, and O-H, decreased across increasing BA concentration while, the bandwidths of the C=O and O-H groups increased.It should be emphasized that while using a cross-linker decreases the number of available sites for cross-linking in each precursor molecule, there are instances where this can lead to the formation of porous spaces. These porous areas are capable of absorbing and retaining more water than would be possible in a non-porous structure. As the FTIR absorption percentage of the specific groups havedecreased with increasing BA concentration, it can be estimated that the cross linker has provided effective crosslinking between the different polymer molecules, to create porous spaces which can absorb, and hold large quantities of water. This can also be estimated from the increased absorption of the incident IR radiation corresponding to the different functional groups and the porosity estimation values of the different samples mentioned later.

Differential Scanning Calorimetry (DSC)

DSC of the samples is important for understanding the thermal stability of the compounds and their prospective water absorption capability before and after heating. Although the nominal temperatures for the fabricated materials, when utilized in prospective wound healing applications, are around the body temperature, it is also necessary to determine their glass transition and melting points to ascertain their range of operation.

DSC thermograms of the samples prepared using different concentrations of PVA, NaCMC, boric acid, and menthol. The DSC profiles of the prepared polymer composites shown in Figure 4 have endothermic peaks because of physical changes in the samples, which confirms the retention of moisture content in the samples owing to the hydrophilicity of the polymer system.

Sample SC_1, which includes only PVA and NaCMC, showed two main

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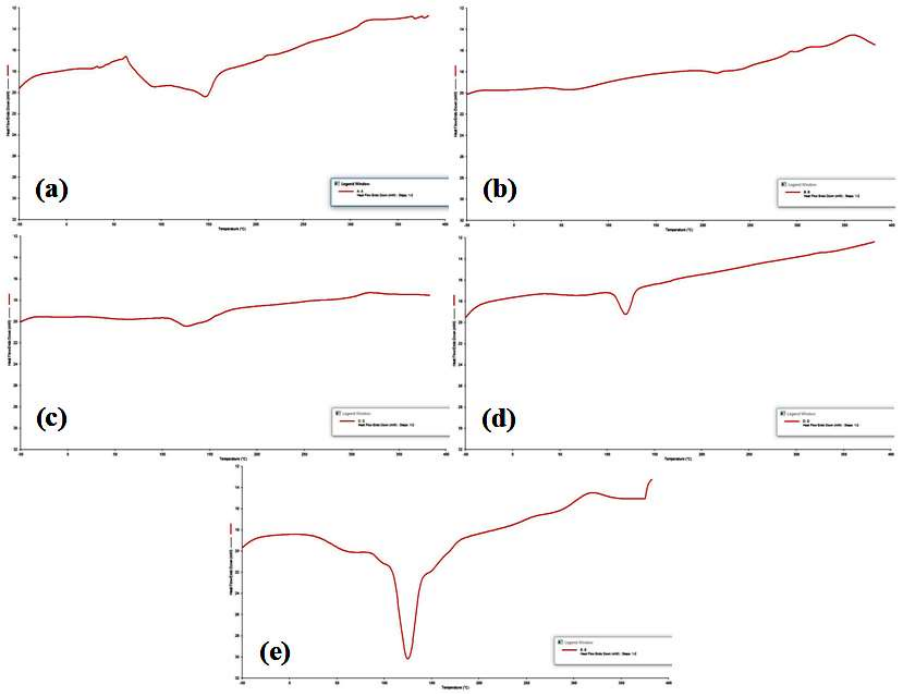

Figure 4: The DSC Thermographs of Samples (a) SC_1; (b) SC_2; (c) SC_3; (d) SC_4 and (e) SC_5

transitions corresponding to the glass transition temperature of approximately 700^0C and the melting temperature of approximately 140^0C. SC_2 and SC_3 showed a single short and broad endothermic peak at 125^0C because of the 'powdered' nature of the sample. SC_4 showed a marginally narrow endothermic peak at 125^0C. SC_5, which contained PVA, NaCMC, boric acid, and menthol, showed a sharp endothermic peak at 125^0C because of the crystalline nature of menthol in the sample. An increase in the thermal stability with an increase in the concentration of boric acid in the prepared scaffold suggests conformational changes in the alkyl chains of the polymer, and this increase in crosslinking causes an increase in the thermal stability Table 2.

It may be estimated that the sharpening of the 125^0C endothermic melting peaks for samples SC_3 to SC_5 is characteristic of the increased number of uniform bond formation between the cross linker and the predecessor materials. However, in SC_5 the loading of menthol also contributes to a much sharper melting peak, as the same would evaporate while the sample also melts and changes phase.

Liquid absorption studies

Figure 5 shows the comparative weights of each sample under dry and water-soaked conditions, as mentioned in Section 2.2.3.

The data and the corresponding Liquid Absorption (%) is tabulated in Table 3.

From the above data, it can be estimated that with increased crosslinking, the porosity of the samples increased, allowing a large volume of water to be absorbed. However, Sample SC5, which contains menthol, does not absorb water readily because of the insolubility of menthol in water and SC4 sample absorb and retained a good amount of water.

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Table 2: FTIR frequency range and functional groups present in the prepared polymeric sample

Sample	Functional Group (cm^{-1})			
	O-H (Alcohol-Stretching)	C-H (Alkane-Stretching)	C+O / O-H (Carboxylic Acid/Alcohol-Bending)	C-O (Primary Alcohol-Stretching)
Pure PVA	~3330 (Broad)	~2860 (Relatively Sharp)	~1713 (Relatively Sharp)	~1085 (Relatively Sharp)
Pure Na-CMC	~3330 (Broad)	Not Prominent	~1350 (Relatively Broad)	~1050 (Relatively Sharp)
SC_1	~3330 (Broad)	Not Prominent	~1350 (Relatively Broad)	~1050 (Relatively Sharp)
SC_2	~3330 (Broad)	Not Prominent	~1350 (Relatively Broad)	~1050 (Relatively Sharp)
SC_3	~3330 (Broad)		~1350 (Relatively Broad)	~1050 (Relatively Sharp)
SC_4	~3330 (Broad)	~2860 (Relatively Sharp)	~1450 (Relatively Broad)	~1050 (Relatively Sharp)
SC_5	~3330 (Broad)		~1450 (Relatively Broad)	~1050 (Relatively Sharp)

Table 3: Liquid Absorption Test Data

	SC_1	SC_2	SC_3	SC_4	SC_5
W_0	100 mg	100 mg	100 mg	100 mg	100 mg
W_1	560 mg	620 mg	650 mg	700 mg	700 mg
Liq. Abs. (%)	460	520	550	600	600

Table 4: The estimated melting temperatures of the samples

Sample	SC_1	SC_2	SC_3	SC_4	SC_5
DSC melting temperature	140^0C	N/A	120^0C	125^0C	125^0C

Table 5: Porosity Estimate Test Data

	SC_1	SC_2	SC_3	SC_4	SC_5
W_0	100 mg	100 mg	100 mg	100 mg	100 mg
W_1	290 mg	300 mg	612 mg	650 mg	650 mg
Porosity Est. (%)	~5.9	~6.25	~16	~17.18	~17.18

Table 6: Water Retention of the samples (all weights in milligrams)

	SC_1			SC_2			SC_3			SC_4			SC_5		
	Wt.	Ret. (%)	Loss (%)	Wt.	Ret. (%)	Loss (%)	Wt.	Ret. (%)	Loss (%)	Wt.	Ret. (%)	Loss (%)	Wt.	Ret. (%)	Loss (%)
W_0	100	N/A	N/A	100	N/A	N/A	100	N/A	N/A	100	N/A	N/A	100	N/A	N/A
W_1	560	--	--	620	--	--	650	--	--	700	--	--	700	--	--
W_2	500	89.3	10.7	610	98.4	1.6	473	72.7	27.3	640	91.4	8.6	685	97.8	2.2
W_3	450	80.4	10	547	88.2	10.3	430	66.2	9.1	640	91.4	0.0	590	84.3	13.9

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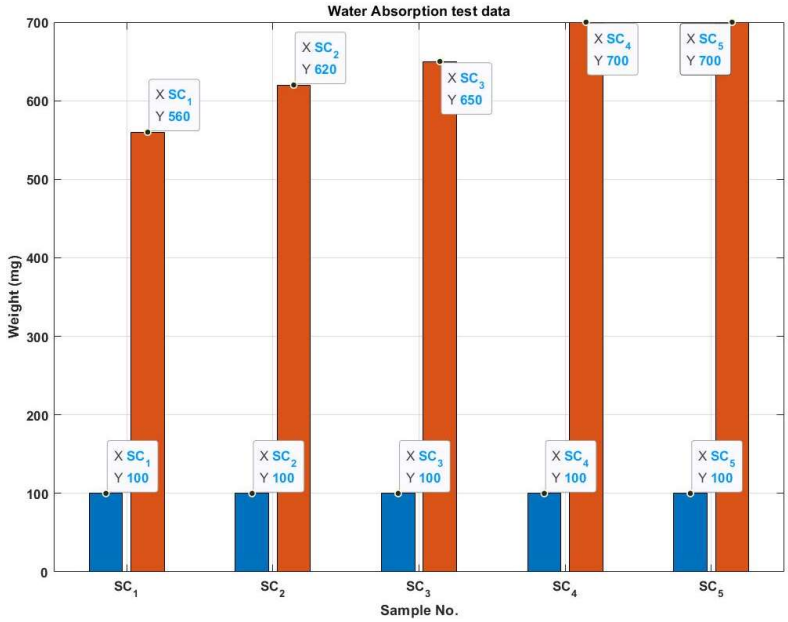

Figure 5: The water Absorption test data showing the weights of the different samples under dry and soaked conditions

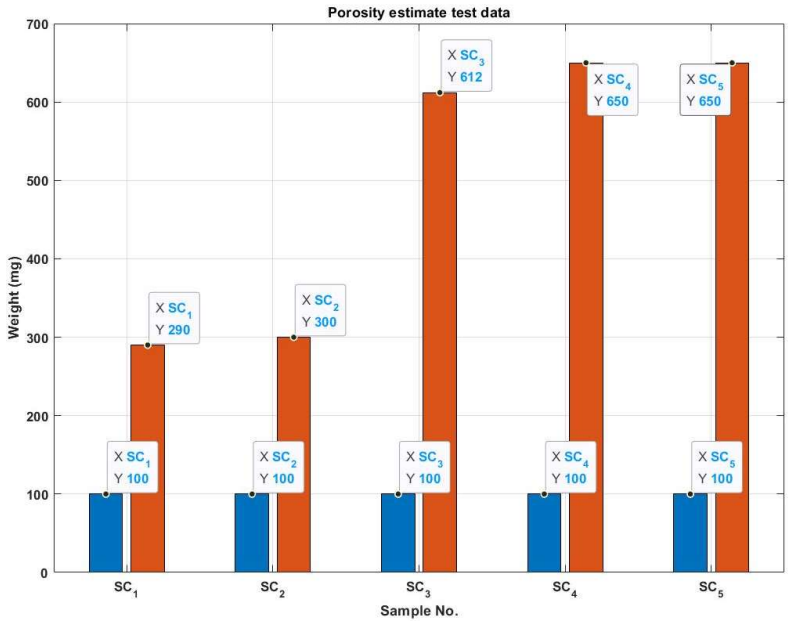

Figure 6: The porosity estimates test data showing the weights of the different samples under dry and ethanol-soaked conditions

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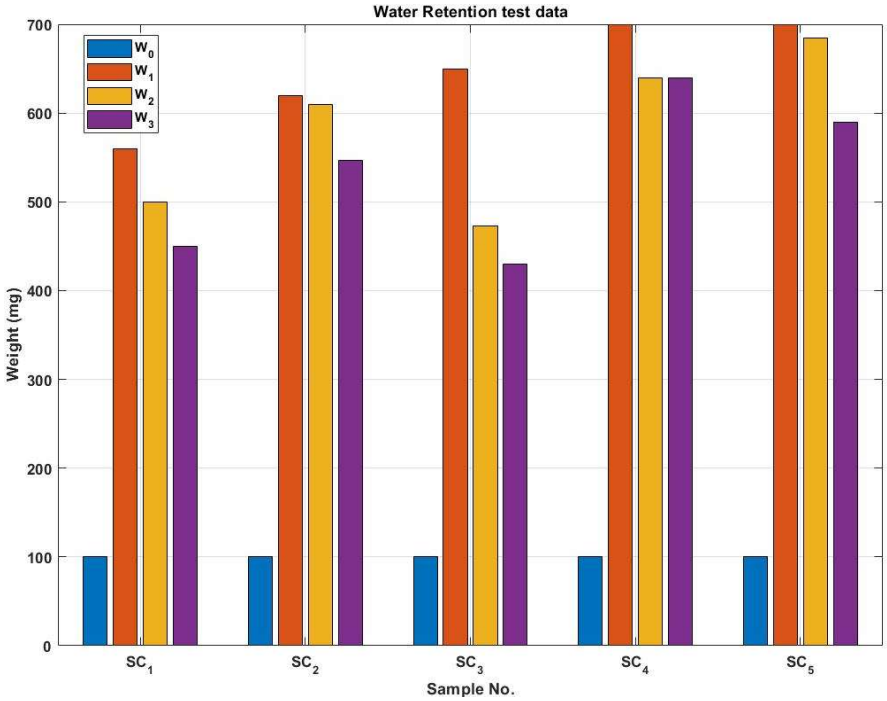

Figure 7: The water retention study data showing the weights of the different samples under dry and subsequent conditions every 30 minutes

Porosity Estimate studies

Figure 6 and Table 5 shows the porosity estimate study on the scaffold samples with ethanol as mentioned. The volume of each lyophilized scaffold sample used for the testing was ~ 2cm^3.

The corresponding data and the porosity estimate for the different scaffold samples are tabulated in Table 4.

In a similar manner of the data as compared to the water absorption test, scaffold SC5 shows a higher percentage of porosity and the crosslinking

Water Retention studies

To evaluate the water retention ability of the scaffold samples, their weights were measured at predefined intervals. Four instances of the weights were taken, each after a period of 30 minutes. Figure 7 shows the data pertaining to water retention of each sample.

The tabulated data and the estimated water retention percentage have been tabulated in Table 6.

Although it is difficult to estimate a standard water retention value, all samples showed a promising capability of retaining a significant amount of water absorbed. The loss percentage was calculated as a relative factor to estimate the rate of water loss every 30 min in an 370^{0}C oven. Some samples showed an increase in the loss rate, while others showed a decreasing trend. This can occur because of an innumerable number of conditions, which also include the effective area open to the heat of the oven.

The polymer composite material proposed in this article was developed with the beneficial properties mentioned in Section 1. In addition, several conditions were followed to implement the same in a cost-effective manner. The choice of materials has been restricted to natural

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derivatives, which are already in use in the biomedical domain. This would ensure an abundant material supply while simultaneously reducing cytotoxicity in the body. Both composite precursors mentioned in this article are either used by the food industry or have biomedical applications, thereby justifying their low, if not non-existent, cytotoxic nature. However, it must be noted that the toxic effects of such a polymer composite still need to be studied for its leeching (seep-out) and overall cytotoxic properties. Owing to the use of food/biomedical-grade materials that are widely available in commercial space, it may be assumed that the cost of the final product per weight would be comparable to the sum of the cost per weight of the individual chemicals. As the production process merely relies on stirring and heating without the addition of any specialized chemicals, the final cost of the product per unit weight would be considerably lower than that currently available in commercial space.

It is also to be noted that the water absorption and porosity estimation studies have to be performed under exacting condition and timings in order to acquire accurate data. There are many possible factors which can cause variations which includes the ratios of the materials, time period and blending procedures, Lyophilization conditions and storage of the material. In order to avoid any discrepancies in the data, all materials were prepared under the same blending procedures, i.e. 70-80^{0}C for 1.5-2 hr. with equal initial volume (100ml) and were directly freeze dried and lyophilized.

The prepared polymer composite showed promisingresults as a superabsorbent and was mechanically stable, which provided a template on which to build it. After this next phase of the work, which is currently ongoing, the development of loading in this kind of material or embedding in other kinds of biocompatible polymers so that it can be embedded in the skin for direct application.

Conclusion

Recently, considerable focus has been directed towards natural polymer-based hydrogels and their potential applications in the biomedical domain, largely due to their biocompatibility, biodegradability, abundance in nature, and customizable mechanical properties. In this study, The choice of the materials is governed by many different factors. For the present work, ease of availability dictated the use of long-chain polymers, and materials which are already used in the food or biomedical industry. Hence the choice of Na-CMC and PVA as mentioned before. This allows the cost of development and the unit cost of the final product to be lowered, while also ensuring availability. Coupled with the cost effective procedure of heating and stirring, the cost per unit weight of the material can be kept low in competition with contemporary solutions. NaCMC and PVA were used as gelling agents with the crosslinker boric acid and were formulated into NaCMC-BA-PVA to develop a biocompatible material with broad-range effects for wound application. Properties such as complexation, blending, and thermal stability were determined using FTIR and DSC. The FTIR results demonstrated that the polymer composite was successfully prepared through blending and casting polymerization, and the shatter value of the polymeric structure increased with increasing boric acid content. The factors affecting the water absorbency, retention, and porosity were also investigated. It was observed that under optimal synthesis conditions, the polymeric composites (SC4 and SC5) exhibited the best water absorbency with increased amounts of boric acid and good porosity. The crosslinking behavior and ability to absorb water increased with an increase in the amount of crosslinking agent. Boric Acid is capable of considerable water absorption to accelerate the wound healing process while retaining the benefits of strong mechanical characteristics, biodegradability, good water retention, absorption, and biocompatibility at a low cost. Good crosslinking was observed with increasing amounts of the crosslinker. The

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proposed chemical composite was devised as a template to build and develop a cost-effective superabsorbent polymer composite that may have prospective wound healing applications. Further comprehensive cell and animal studies are required to be performed to translate the prepared polymer composite for clinical use. These additional studies will provide valuable insights into its safety, efficacy, and long-term performance, thereby advancing its clinical application, but the preliminary studies mentioned in this article suggest that the proposed composite may be a good dressing for hemostatic wound healing.

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