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Thermal Conformability of Developed Fibrous Wound Dressings

Abstract

A novel concept, based on collagen boosting agent treatment, has been explored in this study, wherein the developed nonwoven structures were treated with two different collagen promoting agents Vitamin C and zinc oxide (ZnO) at 0.5% and 3% levels by using a spray method. With the rapid demand of modern and smart wound dressings, it is vital that an effort has to be made to develop novel wound dressings by making use of known collagen promoting agents to enhance wound healing especially cavity and difficult-to-heal wounds. It is in this context, an attempt was made to design and develop novel 'all-in-one' collagen-booster therapeutic nonwoven wound dressings. A significant contribution in this paper is that a CMC/PLA containing hybrid structure has been developed for the first time. The collagen booster loaded structures are fully characterised and evaluated in terms of thermal comfort properties.

Keywords: Thermal comfort; Collagen; Wound dressing; PLA; CMC; Water vapour permeability

Research Article

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Introduction

Thermo physiological comfort testing

Alambeta: The thermo physiological properties of the nonwoven fabrics were determined by using the Alambeta and Permetest instruments (Sensora Instruments, Czech Republic). The Alambeta instrument provides values for thermal conductivity, thermal resistance (insulation), thermal absorptivity (warmth-to-touch), fabric thickness and thermal diffusivity as shown in Figure 1. The test instrument was used to analyse the transient and steady state thermo physical properties of the fabrics. The specimens of 20cm×20cm were prepared and placed in between two plates. With the two plates the heat flow through the fabric due to the different temperature of the bottom measuring plate (at ambient temperature) and the top measuring plate which is heated to 40°C. The thermal absorptivity of the textile structure is a measure of the amount of heat conducted away from structure's surface per unit time (1). The test was performed on the dry and wet states of the nonwoven fabrics which were wetted with 0.2ml of distilled water in the centre of the fabrics and allowed 4 minutes before retesting, in order to allow for the thermal recovery of the fabric. All the tests were carried out on both faces of each specimen and the mean values were calculated [1,2].

Permatest: The water vapour permeability and the resistance to evaporative heat loss of the fabrics were tested by using the Permetest Instrument, Sensora Instruments, and Czech Republic in Figure 2. This instrument is based on the skin model, which simulates dry and wet human skin surface in terms of its moisture, water vapour and evaporative heat permeation. The instrument uses the same principle as specified in ISO 11092 developed by Hohenstein Institute, whereby a heated porous membrane is used to simulate the sweating skin. The heat required for the water to evaporate from the membrane, with and without a fabric covering, is measured (1).

A heated porous membrane is used to simulate sweating skin. A current of air removes the micro-climate that develops above the surface of the membrane. The heat required evaporating the water from the membrane with and without a test fabric covering is measured. The fabric produces resistance to evaporation and therefore less heat is required. The results are used to calculate the relative water vapour permeability as a percentage of the control test without the fabric covering, and the resistance to evaporative heat loss in m^2PaW^{-1}. The specimens that were used for measuring the thermal properties in the Alambeta instrument were also used for testing on the Permatest apparatus.

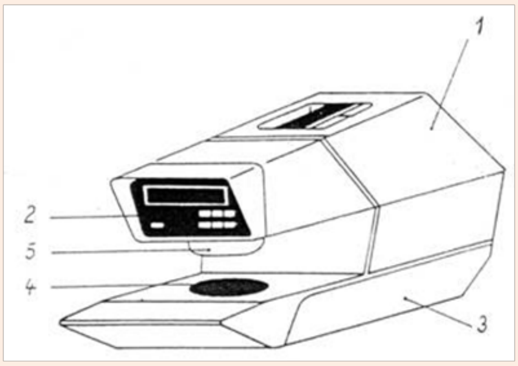

Figure 1: Alambeta Instrument by Sensora, Czech Republic; (1) control and evaluation unit; (2) control panel with display; (3) frame and housing unit; (4) measuring plate; (5) measuring head.

Figure 2: Sensora Permatest water vapour permeability apparatus.

Results and Discussion

Flexural rigidity and air permeability

The flexural rigidity and air-permeability values of the fabrics are given in Table 1. It is apparent from this table that the flexural rigidity and air-permeability properties of the fabrics were not affected by the treatment process as well as the collagen booster ratios or types. It is clearly demonstrated that both the flexural rigidity and the air-permeability properties depend on the fabric area density and fibre types present in the structure. This study has produced the results which are more or less similar to the previous study. The HPES fibres containing fabrics had the lowest flexural rigidity values compared to the other fabrics tested. It was also found that the untreated PLA reinforced CMC composite fabrics had considerably lower flexural rigidity values than single-fibre CMC fabric. It is well-known that a lower flexural rigidity gives higher conformability, softness and flexibility to the wound dressing. It can thus be concluded that the flexural rigidity properties of CMC fabrics can be enhanced by using PLA or HPES fibres. This enhancement can have a positive effect on the conformability properties of the dressings, which could directly affect the wound healing process.

Table 1: Flexural rigidity and air-permeability values of treated fabrics.

Fabrics	Flexural Rigidity (µNm)	Air Permeability ($cm^3 sec^{-1}$)
100% CMC untreated	320	350
100% CMC 0.5% VC	125	612
100% CMC 3% VC	130	509
100% CMC 0.5% ZnO	115	713
100% CMC 3% ZnO	142	491
75/25% CMC/PLA untreated	243	412
75/25% CMC/PLA 0.5% VC	162	689
75/25% CMC/PLA 3% VC	171	591
75/25% CMC/PLA 0.5% ZnO	196	601
75/25% CMC/PLA 3% ZnO	180	655
75/25% CMC/HPES untreated	230	489
75/25% CMC/HPES 0.5% VC	105	897
75/25% CMC/HPES 3% VC	111	915
75/25% CMC/HPES 0.5% ZnO	122	908
75/25% CMC/HPES 3% ZnO	145	710

The air permeability is a quantitative measurement of how well a material allows the passage of air through it. It can be defined the volume of air in mm^3 which is passed through the dressing in one second from 100 mm^2 of the fabric at a pressure of 10 mm head of water. The air permeability is one of the important parameters of wound dressings, which prevents maceration and (2) gives a better comfort to the patients. In a recent in vivo study on wound healing and antibacterial performance of electrospun nano fibre membranes, the authors concluded that the porosity and air permeability characteristics have a strong influence on facilitating the wound healing, especially at the early healing stages (3). It can also be noticed from the data in Table 1 that the air-permeability values of the fabrics increased when the fabrics' area densities decreased. Another important finding was that the air-permeability of the reinforced fabrics was found to be greater than the single-fibre CMC fabrics. The HPES fibres reinforced fabrics had higher air-permeability as compared to all other fabrics tested due to its hollow structure. One of the important properties for a wound dressing is its air-permeability, which helps in preventing maceration and providing better comfort to the patients (4) [3].

Thermo physiological comfort

The present test was designed to determine the effect of the treatments on the fabrics' thermo physiological comfort properties.

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Thermal resistance of nonwoven fabrics in dry and wet state

The thermal resistance and % recovery values of the fabrics tested after 4 minutes of wetting the fabric are given in Table 2. The thermal resistance of the fabrics ranged from 99 to 142 $W^{-1}K\ m^2 \times 10^{-3}$ for the dry state and from 68 to 114 $W^{-1}K\ m^2 \times 10^{-3}$ for the wet state. The thermal resistance values of the fabrics decreased significantly in the wet state. The difference between the untreated single-fibre CMC fabric and PLA or HPES fibres reinforced fabrics was considered to be worth mentioning. The thermal resistance properties of the single-fibre CMC fabrics were increased significantly due to the vitamin C and ZnO treatment. On the other hand, the thermal resistance properties of the PLA or HPES fibres containing fabrics decreased after the treatment. It can be suggested that the treated composite fabrics can have better comfort properties because of its relatively lower thermal resistance value. In most of the cases, the % recovery of the treated fabrics was found to be lower than their untreated counterparts [2].

Table 2: Thermal resistance (r) properties of treated fabrics.

Fabrics	Dry ($W^{-1}K\ m^2 \times 10^{-3}$)	Wet ($W^{-1}K\ m^2 \times 10^{-3}$)	% Recovery After 4 Minutes Wetting
100% CMC untreated	115	101	86.1
100% CMC 0.5% VC	142	100	58
100% CMC 3% VC	130	80	37.5
100% CMC 0.5% ZnO	135	110	77.3
100% CMC 3% ZnO	121	75	38.7
75/25% CMC/PLA untreated	123	95	70.5
75/25% CMC/PLA 0.5% VC	99	73	64.4
75/25% CMC/PLA 3% VC	107	68	42.6
75/25% CMC/PLA 0.5% ZnO	131	114	85.1
75/25% CMC/PLA 3% ZnO	107	87	77
75/25% CMC/HPES untreated	137	110	75.5
75/25% CMC/HPES 0.5% VC	107	78	62.8
75/25% CMC/HPES 3% VC	99	78	73.1
75/25% CMC/HPES 0.5% ZnO	129	101	72.3
75/25% CMC/HPES 3% ZnO	108	79	63.3

Thermal absorptivity of nonwoven fabrics in dry and wet state

The thermal absorptivity results are presented in Table 3. The results of this study show that the thermal absorptivity values of the fabrics were affected by the fibre and the treatment types. The single-fibre CMC fabric had higher thermal absorptivity than CMC/PLA and CMC/HPES fabrics. It was also found that the treated fabrics had lower absorptivity than their untreated counterparts. The differences between the untreated and treated fabrics were found to be significant. There is no observed difference between vitamin C and ZnO treatment neither for the ratio of 0.5% nor for the ratio of 3%. Table 3 also shows that the thermal absorptivity of fabrics in the wet state generally was found to be higher than the thermal absorptivity of fabrics in the dry state.

Thermal conductivity of nonwoven fabrics in dry and wet state

Table 4 gives the thermal conductivity results. The thermal conductivity of the treated fabrics was lower than their untreated counterparts. It is somewhat surprising that ZnO treated fabrics also had decreased thermal conductivity. It was expected that the ZnO treatment would increase the thermal conductivity due to its conductive nature. In a previous study by the author, it was determined that silver treatment increases the thermal conductivity of the single-fibre CMC nonwoven fabrics. This study confirms that the thermal conductivity of fabrics in the wet state were significantly higher than in the dry state. This is obvious, as the water is a good conductor of heat [2].

Water vapour permeability and resistance to evaporative heat loss (Permetest)

The water vapour permeability (WVP) and resistance to evaporative heat loss results are given in Table 4. The water vapour permeability values of the treated fabrics were found to be higher than the untreated fabrics. This may be associated with the decrease in the absorbency of the fabrics. The evidence from this study suggests that the PLA reinforcement increases the single-fibre CMC fabric's WVP value, while the HPES fibres reinforcement significantly decreases the CMC fabric's WVP value.

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Table 3: Thermal absorptivity (b) properties of treated fabrics.

Fabrics	Dry (Ws^{1}/2 m^{-2} K^{-1})	Wet (Ws^{1}/2 m^{-2} K^{-1})	% Loss in Warmth-to-Touch Feeling
100% CMC untreated	54	60	11.1
100% CMC 0.5% VC	40	52	30
100% CMC 3% VC	47	64	36.2
100% CMC 0.5% ZnO	38	28	26.1
100% CMC 3% ZnO	48	67	39.6
75/25% CMC/PLA untreated	49	78	59.2
75/25% CMC/PLA 0.5% VC	40	183	357.5
75/25% CMC/PLA 3% VC	54	241	346.3
75/25% CMC/PLA 0.5% ZnO	47	150	219.1
75/25% CMC/PLA 3% ZnO	42	142	238.1
75/25% CMC/HPES untreated	43	46	7
75/25% CMC/HPES 0.5% VC	40	60	50
75/25% CMC/HPES 3% VC	36	47	30.6
75/25% CMC/HPES 0.5% ZnO	37	42	13.5
75/25% CMC/HPES 3% ZnO	39	45	15.4

Table 4: Thermal conductivity and Permatest results of treated fabrics.

Fabrics	Dry (W/mK×10^{-3})	Wet (W/mK×10^{-3})	Water vapour permeability (%)	Resistance to evaporative heat loss (m^{2}PaW^{-1})
100% CMC untreated	33.8	39	30.2	11.8
100% CMC 0.5% VC	33.2	43.9	34.5	12.1
100% CMC 3% VC	32.8	57	32.6	11.7
100% CMC 0.5% ZnO	32.6	35.1	29.4	13.6
100% CMC 3% ZnO	32.2	48.5	33.9	11.8
75/25% CMC/PLA untreated	32.1	40.3	36.8	9.9
75/25% CMC/PLA 0.5% VC	31.1	41	37.7	9.2
75/25% CMC/PLA 3% VC	31	48.7	36.7	9.8
75/25% CMC/PLA 0.5% ZnO	32.4	35.4	40.8	12.7
75/25% CMC/PLA 3% ZnO	31	36.1	42	8.7
75/25% CMC/HPES untreated	35.1	42.6	26.7	13.7
75/25% CMC/HPES 0.5% VC	29.7	51.6	39.5	8.8
75/25% CMC/HPES 3% VC	30.6	31.7	38.2	9.3
75/25% CMC/HPES 0.5% ZnO	31.8	32.1	33.3	11.2
75/25% CMC/HPES 3% ZnO	31.7	34.1	35.6	9.9

Conclusion

The findings of this study suggest that the flexural rigidity properties of CMC dressings can be enhanced by using PLA reinforcement. The thermo physiological comfort properties of the dressings vary and depend largely on the types of fibres present within the wound dressing structure.

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