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Structure Properties Change of Ready to Use Nonwoven Wiping Materials over Storage Time

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Abstract. An efficient cleaning and disinfection practice plays a crucial role in preventing cross-contamination in food industry, domestic situations as well as nosocomial environment. Pre-impregnated disinfecting wipes (ready-to-use disinfectant wipes) are broadly applied in above-mentioned conditions. Regarding the effectiveness of the disinfectant pre-impregnated wipes, research still stays in case study phase and no comprehensive investigation has been carried out to evaluate the structure and function change of the ready-to-use disinfecting wipes over storage time. This work studied the ageing of the disinfecting wipe over storage time. Chloramine as surface disinfectant and 3 commercial wiping materials of polyester (PET), 55% cellulose/45%PET and pure cellulose have been selected. The FTIR (Fourier-transform infrared spectroscopy) and DMA (Dynamic mechanical analysis) result revealed that oxidation occurred on the textile substrates during the storage of the pre-impregnated disinfecting wipes with special emphasis to the cellulose polymer. Moreover, the occurred oxidation changed the mechanical properties of the cellulose-containing wipes increasing their viscous properties over the elastic ones.

1. Introduction

Healthcare-associated infections (HAIs) caused by the transfer of nosocomial pathogens from high-touch environmental surfaces and medical devices are responsible for significant patient morbidity, mortality and economic cost [1–3]. Nosocomial pathogens shed by patients can contaminate hospital surfaces at concentrations sufficient for transmission, surviving for extended periods and persisting despite attempts to remove them [4]. An effective cleaning and disinfection practice plays a key role in preventing cross-contamination and spread of HAIs [5–7]. Traditionally, healthcare staff has used the “bucket method”, which consists of towels saturated with diluted disinfectant contained in a bucket. This method exhibits several limitations such as improper disinfectant dilution, inadequate saturation, uneven moisture distribution, unknown material compatibility and possible contamination from reusing [8,9]. Among the most effective surface disinfection methods, the nonwoven ready-to-use disinfectant wipes are increasingly accepted for decontamination of high-touch surfaces because of its convenience and reliable performance [10,11].

Though some research has been investigated on the effectiveness of commercial available disinfecting wipes in practical use [1,12–14]. Despite, several absorption issues due to active ingredients onto textile materials have been previously reported in the literature, the knowledge regarding the ageing of



wipe materials in presence of disinfectant under storage conditions remains vague [15-17]. The selection of an inappropriate wipe material could interact with the adsorbed active ingredient resulting in lower or even abolished disinfectant efficacy.

This project studied the ageing of the disinfecting wipe over storage time. Chloramine, as surface disinfectant and 3 commercial wiping materials, composed of polyester, cellulose, and their combinations have been selected for the investigation. The bulk disinfectant solution and the wipes before and after disinfectant contact were analysed by the means of FTIR (Fourier-transform infrared spectroscopy) and DMA (Dynamic mechanical analysis).

2. Material and methods

2.1. Sample preparation

The tests were carried out at standard condition of 65% relative humidity (RH) and 20°C. The surface disinfectant chloramine-t-trihydrate (C₇H₈ClNO₂S₃H₂O.Na) solution from Acros Organics® was prepared at the concentration of 10% (w/w) in distilled water. Each textile wipe sample (Table 1) was prepared with the weight of 1 g ± 0.5%. Every experiment includes a control raw sample, a control treated in water and a sample iterated with the disinfectant solution. The wipes were tested for immersion times at 1, 3, 7, 15, and 31 days. All the experiments were replicated 2 times.

Table 1. Composition and Structure of the Used Wipes

Substrate	Composition	Structure
W1	100% PET	Nonwoven hydroentangled
W2	55% cellulose/45%PET	Nonwoven hydroentangled
W3	100% cotton	1/1 plain weave

2.2. Fourier transform infrared spectroscopy (FTIR)

A Shimadzu FTIR spectrophotometer (IR-Affinity 1) with an attenuated total reflectance accessory (ATR) was used to record the FTIR spectra of the fabric samples. Spectra were collected in the region of 4000-700 cm⁻¹ and at the resolution of 4 cm⁻¹ with 45 scans at room temperature. All the treated wipe samples were dried in an oven at 40°C for 24h before testing.

2.3. Dynamic Mechanical Analysis (DMA)

DMA was performed using a DMA 7100 from Hitachi® (Japan) in programmed tension mode with a heating rate of 3 °C min⁻¹ scanned from 30 to 200 °C at 4 Hz of frequencies. The geometry of the testing sample was 20 mm length, 10 mm width and 0.002 mm thickness. Specimens were prepared in duplicate to conduct mechanical analyses. These analyses were carried out under nitrogen purge of 200 ml min⁻¹. The wipe samples were dried in an oven at 40°C for 24h before testing.

3. Result and discussion

When chloramine is brought into contact with water, it slowly breaks down to generate hypochlorous acid and hypochlorite, which in turn releases chlorine and oxygen that are responsible for the bactericidal and bacteriostatic action. However, they are also strong oxidizing agents that can damage the textile fibres. It is reported that the hypochlorous acid and hypochlorite that supposed to work on the microbicidal effect diminishes when they interact with the textile substrate [15-17].

The ATR-FTIR spectrum of untreated W1 and W2 fabrics exhibits peaks of the polyester component (W1) and of the polyester blend (W2) at 1710 cm⁻¹ assigned to stretching vibration of C=O group in ester, 1250 cm⁻¹ assigned to asymmetric stretching of aromatic ester, 710 cm⁻¹ attributed to aromatic C-H bending vibrations and 871 cm⁻¹ attributed to C-C out of plane bending vibrations of the

benzene rings (Fig. 1) [18]. The spectra of W2 and W3 displays the strong bands at 1160, 1100 and 1020 cm^{-1} assigned to the vibrations of the C-O-C bond of the glycoside bridges of the cellulose structure. The broad and strong bands at 3340 and 3270 cm^{-1} observed in W3 and with minor intensity in W2 are attributed to the stretching vibration of the hydroxyl (OH) group of the cellulose structure [20]. The strong peaks in W3 at 1150, 1100 and 1020 cm^{-1} are from the vibrations of the C-O-C bond of the glycoside bridges of the cellulose structure [19].

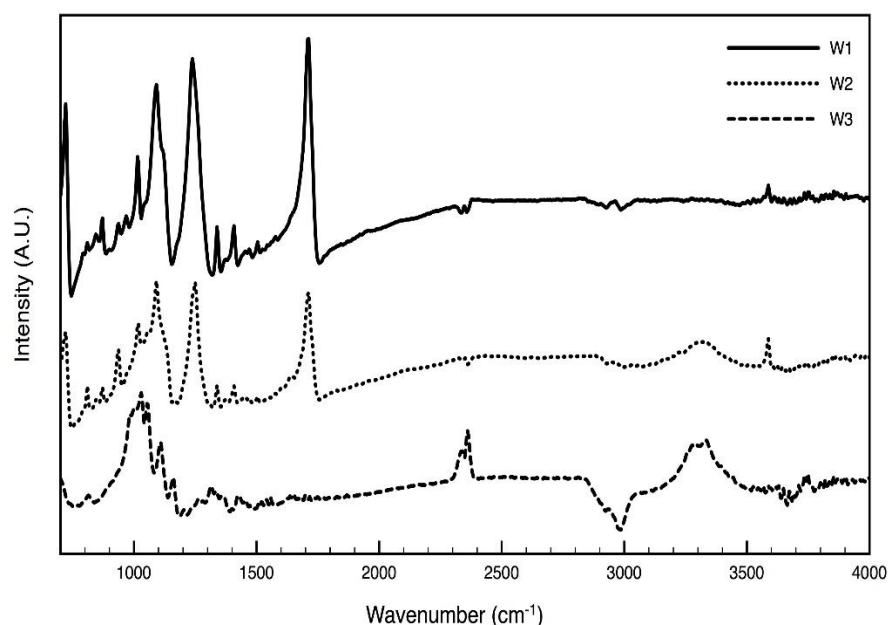


Figure 1. ATR-FTIR spectrum of W1, W2 and W3 samples in the range between 700 and 4000 cm^{-1} .

FTIR analysis was performed to understand the change of the wipe samples after different treatment time with disinfectant solution. The measures were taken at different immersion times at 1, 3, 7, 15 and 31 days. All the samples treated with disinfectant solution showed the formation of a new band at 3587 cm^{-1} that was attributed to the oxidation action of chloramine on the textile material [21,22]. No change in the FTIR spectra was noted in control wipes treated with distilled water in the same conditions. The new band can be assigned to the hydroxyl band -OH due to the oxidation of the polyester and cellulose surface and gradually increase with the immersion time [23]. Fig. 2-a and 2-b below exhibit the FTIR result from W1 and W2 immersed in the chloramine solution at different times. The observed oxidation peak displays an increasing behaviour up to 7 days. After this period the band intensity starts to decrease. This phenomenon can be explained by a removal of polyester molecules on the surface. When an entire layer of the oxidized polymer chain is removed from the surface the bulk unreacted PET is exposed to the surface reducing the oxidation peak. However, since W1 is composed of pure polyester and the W2 by a mixture of cellulose and polyester, the higher oxidation of W2 can be explained by the higher local chloramine concentration due to cellulose adsorption.

Cellulose is also oxidized by chloramine and W3 sample showed more changes in the FTIR spectra (Fig. 2-c) compare to the others. Different from PET, the oxidation increases over time showing the higher peak at 31 days (data not shown). However, the cellulose sample shows other changes in its chemical structure especially between 700 and 1500 cm^{-1} (Fig. 2-c). New peaks at 1250, 1140, 1090, 940 and 810 cm^{-1} appear with the simultaneous disappearing of the intense peaks of the glycoside bonds of the cellulose structure. These changes indicate a radical change in the cellulose structure with the formation of carbon moieties and the chemical substitution of the hydroxyl groups due to the

formation of methylated derivative [24].

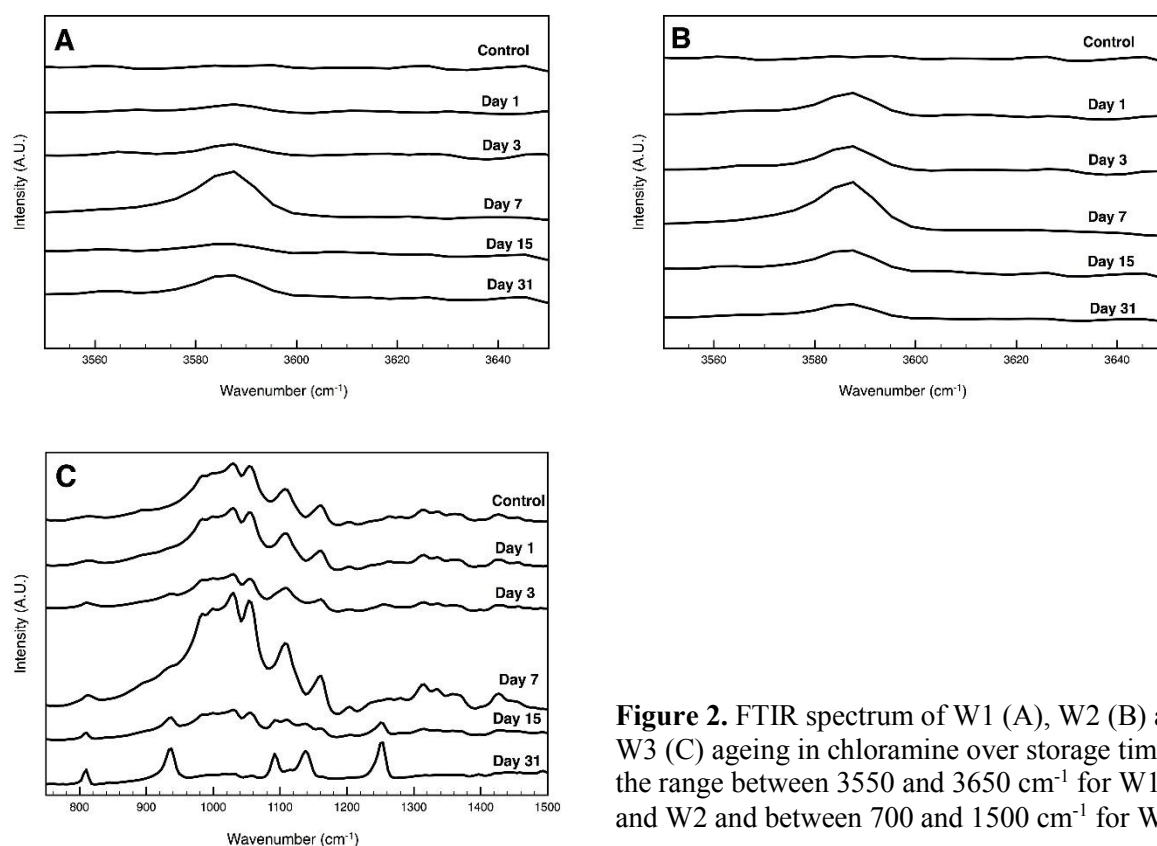


Figure 2. FTIR spectrum of W1 (A), W2 (B) and W3 (C) ageing in chloramine over storage time in the range between 3550 and 3650 cm^{-1} for W1 and W2 and between 700 and 1500 cm^{-1} for W3.

The dynamic mechanical analysis (DMA) was applied to study the effect of temperature on the mechanical properties of the wiping materials. The DMA parameters including tan delta, loss and storage moduli provide important information about the stiffness of the polymer, molecular motion, relaxation process, structural hetero groups, and morphology of the polymer blend systems [25]. Fig. 3 shows that in the cellulose-containing samples (W2 and W3) after chloramine treatment showed significant differences. In W1 (Fig. 3-a) the water and chloramine treated samples do not show significant differences. W1 sample is made of pure PET and despite the disinfectant is able to chemically interact with the PET structure (see FTIR discussion) this do not change the mechanical properties of the wipe. These samples showed a decrease in their moduli from 100 °C up to 160 °C. In the W2 sample (Fig. 3-b), the storage modulus at 30 °C compared with the 65 GPa of the samples treated in pure water have decreased to 1 GPa, which is a decrease of 98%. Similar behaviour was observed for the loss modulus decreasing from the 6.5 GPa in water to 0.1 GPa in chloramine. These measures maintained stable up to 100 °C. After this temperature, the storage and loss moduli of the water treated sample start to decrease due to the increased mobility of the polymer chains. However, the chloramine treated samples after 100 °C, showed a slight increase of the storage and loss moduli attributed to the chloramine-altered intermolecular bonding that limits the mobility of the polymer chains in the wipes [26]. The pure cellulose sample (Fig. 3-c) shows similar storage and loss moduli at 30 °C. However, this sample is clearly temperature dependent showing divergent behaviour in the water and chloramine samples. The storage and loss moduli of the water treated sample increased with the temperature reaching values of one order of magnitude higher. Contrarily the storage and loss moduli of chloramine treated samples showed a decrease in moduli from 120°C to 160°C. The storage modulus decreased from 20 GPa to 4 GPa and the loss modulus from 1.5 GPa to 0.45 GPa.

The damping factor or tan delta is the ratio between the loss and storage modulus in a viscoelastic material. A high tan delta value is indicative of a material that has a high, non-elastic strain component, while a low value indicates one that is more elastic. As expected the W1 sample did not show a significant difference in tan delta between water and disinfectant treated samples (Fig. 4). An increase in the viscous properties is noted until 120 °C then the system became more elastic reaching a plateau at 180°C. The tan delta of the sample W2 also showed similar results however the presence of disinfectant seems to reduce the temperature of the viscous peak increase probably due to the presence of disinfectant-oxidized surface modifications that increase the stiffness of the material at lower temperatures.

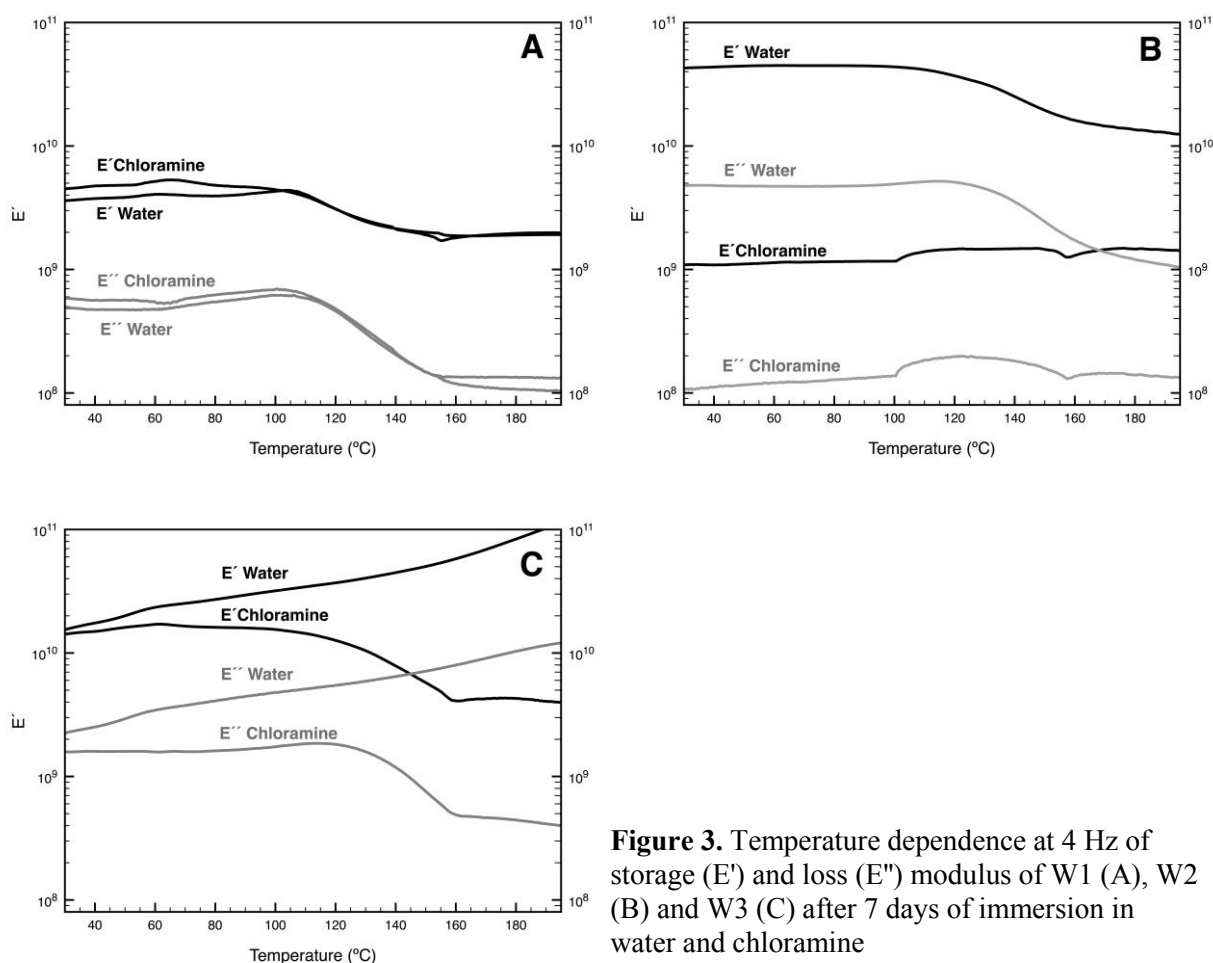


Figure 3. Temperature dependence at 4 Hz of storage (E') and loss (E'') modulus of W1 (A), W2 (B) and W3 (C) after 7 days of immersion in water and chloramine

Despite the shift in temperature, the values of the Tan δ remained very similar suggesting that in the blend the thermoplastic PET network is not perturbed by the non-thermoplastic cellulose polymer network in terms of its viscoelastic properties [27]. Sample W3 is clearly the most affected in its mechanical properties by the chloramine action. The water control did not show significant events in tan delta analysis while the disinfectant-treated sample significantly increased its viscous component between 100 and 160 °C. This seems to occur in response to molecular interactions, mainly hydrogen bonding, between the PET oxidized molecules and the cellulose or between the cellulose structure itself promoting conformational changes that alter the mechanical behaviour of the wipes [28].

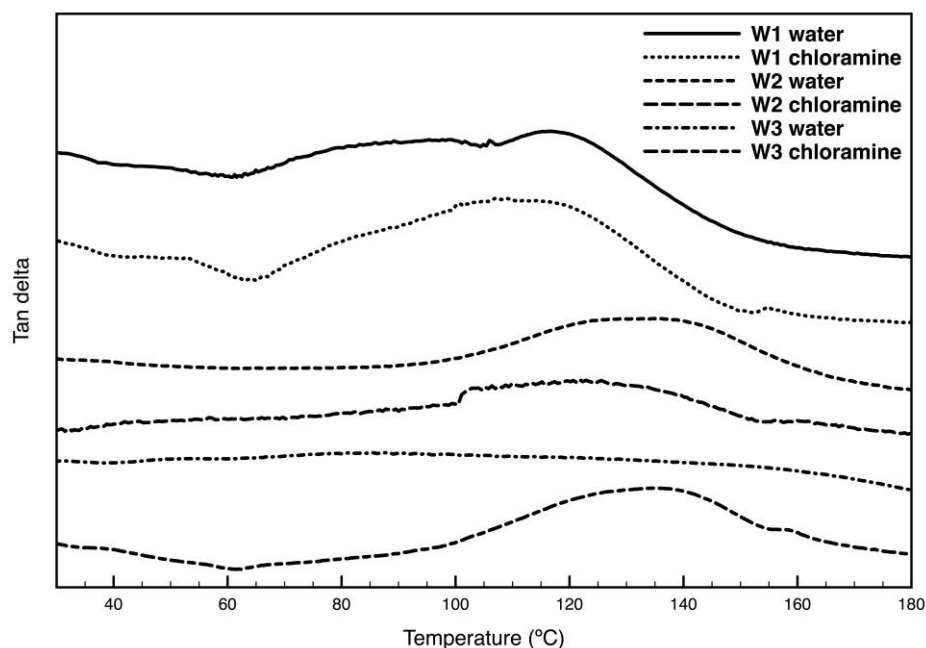


Figure 4. Temperature dependence of tan delta of W1, W2 and W3 after 7 days of immersion in water and chloramine.

4. Conclusion

The results of this study fill in the gap of the absorption issue between active ingredients and wiping materials over storage time. The chloramine is able to oxidize both the wipe materials with a higher action on cellulose structure than on PET. A significant change in mechanical properties was observed for cellulose-containing wipes while the PET viscoelastic properties did not show significant changes. The next step of the work will be to measure the effectiveness of the disinfectant antimicrobial action after adsorption on the wipes at different times of exposure. In addition, the generated outcome knowledge will provide a reference of the guideline for the hospital cleaning and disinfection in practice as well as ensure hospitals daily workflow from unnecessary risk of infection outbreak and complement the products' user manual of disinfectant and wipes in the market.

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