Effect of Microwave Irradiation on the Physical Properties and Structures of Cotton Fabric

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ABSTRACT

Microwaves are high frequency radio waves which are capable of penetrating many materials and causing heat to be generated in the process. To investigate the effect of microwave irradiation on the physical properties, chemical structure, surface morphological structure and fine structure of cotton fabric, cotton fabric was treated with microwave irradiation under variety of conditions in terms of the power and the time of microwave treatment. The breaking strength, breaking elongation, and whiteness of the treated cotton fabric in wet state were investigated. The structures of the untreated and treated cotton were investigated with Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), differential scanning calorimetry (DSC) and X-ray diffraction (XRD). The results show that the physical properties of the treated cotton fabrics were changed with microwave irradiation time and power. The chemical structure and the surface morphological structure did not significantly change. Crystallinity of the treated cotton was changed.

Keywords: cotton fabric; microwave; structure; physical property

INTRODUCTION

Cotton is one of the most widespread natural polymers; it has been widely used throughout the world and has a wide variety of applications in apparel, home furnishings, and industrial products. A conventional curing system used for finishing of cotton fabric involves heat transfer to the material by convection, conduction, and radiation. The surface of the material becomes hotter than the interior, leading to baking and nonuniform crosslink distribution throughout the material. Microwave irradiation is a powerful technique of non-contact heating by causing vibration and rotation of permanent dipoles in the microwave field. Microwave curing is a possible alternative to conventional curing for improving the properties of crosslinked textile materials. This method can generate heat uniformly throughout the textile substrate [1, 2].

Cotton fabric finishing using microwave heating has been reported by several authors [2-6]. Microwave heating has proven to be more rapid, uniform and efficient than other heating methods. However, the microwave irradiation could affect the chemical structure, fine structure, physical properties and surface morphological structure of cotton fabric. Systematic reporting of the effect of microwave irradiation on the physical properties and structure of wet cotton fabric is scarce. Research on the structural and property changes of cotton fabric in the wet state during microwave irradiation can set the stage for further application of microwave heating in the wet finishing of cotton fabrics.

In this paper, cotton fabric was treated with microwave irradiation at varying times and power levels. The effect of microwave irradiation on the structure of cotton was investigated with Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), differential scanning calorimetry (DSC) and X-ray diffraction (XRD). The physical properties of the treated cotton were also characterized.

EXPERIMENTAL

Materials

100% bleached cotton weave fabric was obtained from Color of Light Textile Company (Shandong, China). Specifications of the cotton fabric used: 10S ×10S, 46×36/inch, weight: 186g/m^2.

Microwave Irradiation Treatment of Cotton Fabric

The microwave oven, Yk-01, used in this study had adjustable power of 100～1000W. The microwave frequency of 2450 MHz was chosen it is widely used in industrial, scientific and medical applications.

Cotton fabrics in the wet state were enclosed in polyethylene film and then treated with microwave irradiation at various power settings (119W, 280W, 462W ,595W ,700W) for various lengths of time (30, 60, 90, 120, 140, 160, 180, 200, 220, 240 and 300S). The fabrics were removed from microwave oven and slowly cooled under vacuum for 24h. Cotton fabrics were immersed in the water bath for 30min and padded at room temperature until the liquor pickup was 70% of the weight of the dry fiber.

Fabric Performance Evaluation.

The breaking strength and elongation of the fabric was measured according to GB/T 3923.1-1997. Whiteness was evaluated using a WSB-3A digital whiteness instrument (Darong textile instrument Ltd, China). The chemical structures of untreated and microwave-treated cotton fabrics were measured by an IRPrestige-21 infrared spectrometer (SHIMADZU, Japan). The surface morphological structure of untreated and microwave-treated cotton fabrics was measured by a SNG-3000 scanning electron microscope (SEC Ltd, Korea). Decomposition temperatureas of untreated and microwave-treated cotton fabrics were measured by a differential scanning calorimeter (Perkin-Elmer Ltd, USA). Crystallinity of untreated and microwave-treated cotton fabrics were measured by an Empyrean X-ray Diffractometer (PANalytical Ltd, Holland), which used Cu-K target at 40 kV, 300 mA and k = 1.54056.

RESULTS AND DISCUSSION

Physical Properties of the Microwave-Treated Cotton Fabric

Breaking Strength and Elongation

Microwave power and treating time under microwave irradiation condition may impact the breaking strength and elongation at break of cotton fabric. The breaking strength and elongation at break of untreated and treated cotton fabric in the wet state with microwave at various power settings (119, 280, 462, 595, 700W) for various lengths of time (30, 60, 90, 120, 140, 160, 180, 200, 220, 240 and 300s) are presented in *Tables I* and *II*.

TABLE I. Breaking strength of the cotton fabric in wet state treated with microwave irradiation.

	119W	280W	462W	595W	700W
30S	330.4	333.7	335.3	348.7	354.1
60S	344.3	344.5	347.1	352.4	355.5
90S	346.2	347	351.4	352.6	358.4
120S	347.3	348.8	352.7	353.6	361.7
140s	348.8	354.1	361.6	362.7	363.6
160S	354.5	365.2	367	368.3	371.3
180S	355.3	364.9	371.6	375.5	387.5
200S	362.9	363.9	370.3	374.4	384
220S	370	361.1	367.2	373.3	382.2
240S	369.7	360.8	367.3	370.2	379.5
300S	358.8	359.8	360.2	360.9	379.5

Note: Breaking strength of the untreated cotton fabric is 362.4N.

Compared with the untreated cotton, the breaking strength of the treated cotton fabric in the wet state decreased with 30s treating time. This is caused by heat generated through free water molecules. Longer heating times result in increasing breaking strength. Cotton fabric in the wet state contains free water molecules and the fibers absorb little microwave energy. Microwaves are high frequency radio waves which are capable of penetrating water molecules in cotton fibers and causing heat to be generated in the process. The electric field energy is converted into heat through the dielectric losses of the water in wet state. In the presence of the high frequency electromagnetic field the water molecules oscillate synchronously with it [7].

Cotton fabric in nature under humid conditions contains bound water molecules which undergo less thermal effect with increasing treatment time. The dielectric loss constant (ε) of cotton yarn is 6.0. Individual fibers can also adsorb more microwave energy. The reason for such an increase in breaking strength was considered to be due to the existence of water molecules in cotton fiber, which promoted adjustment of the fine structure of cotton fibers due to absorption of microwave energy and elimination of residual stress in the cotton fibers [8].

The breaking strength of the treated cotton fabric in the dry state was decreased with increasing treatment time in the range of 160~300s. Cotton fabric in the dry state doesn't contain water molecules and microwave energy is mainly focused on cotton fibers. This makes intermolecular position adjustment and elimination of residual stress difficult [8].

TABLE II. Breaking elongation of the cotton fabric in wet state treated with microwave irradiation.

	119W	280W	462W	595W	700W
30S	14	14.2	14.4	14.4	14.3
60S	14.1	14.2	14.5	14.5	14.5
90S	14.1	14.1	14.5	14.5	14.5
120S	14.2	14.1	14.7	14.6	14.8
140s	15.1	15.1	15.2	15	15.1
160S	15.1	14.9	15	15.4	15.6
180S	15	14.7	14.7	14.8	16.1
200S	14.9	14.7	14.7	14.8	15.9
220S	14.8	14.7	14.6	14.7	15.7
240S	14.8	14.5	14.5	14.7	15.7
300S	14.3	14.3	14.5	14.6	15.5

Note: Breaking elongation of the untreated cotton fabric is 13.9%.

From *Table 2* the elongation at break of cotton fabrics in the wet state increases over that of untreated fabric at longer microwave irradiation times. This can be attributed to heat shrinkage of cotton fibers in the wet state.

Whiteness

Treating time and power under microwave irradiation condition may also impact the whiteness of cotton fabric. The whiteness values of cotton fabrics treated in the wet state at various power settings (119, 280, 462, 595, 700W) for various lengths of time (30, 60, 90, 120, 180, and 240S) are presented in *Figure 1*.

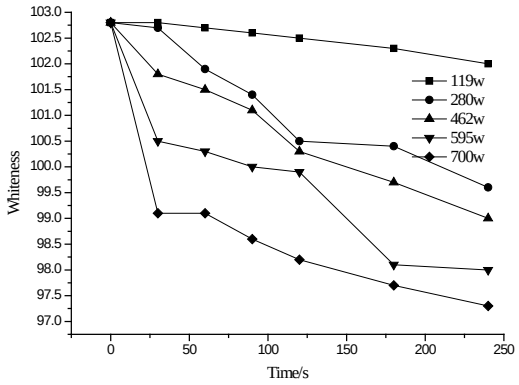

FIGURE 1. Whiteness of untreated cotton and microwave-treated cotton.

It can be seen from *Figure 1* that compared with the untreated cotton, the whiteness of cotton fabrics subjected to microwave treatment were slightly decreased.

FTIR Analysis

To investigate the influence of treatment with microwaves on the chemical structure of cotton fibers, experiments with cotton fabric in the wet state under microwave irradiation at 700W power for various lengths of time (60, 120, 180, 240 and 300s) were carried out. *Figure 2* shows the FTIR curve of the untreated and treated cotton samples.

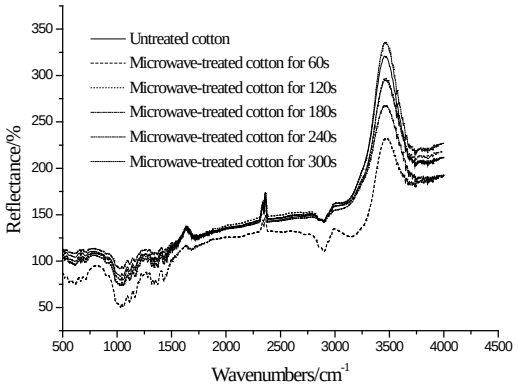

FIGURE 2. FTIR spectra of untreated and microwave-treated cotton.

It can be seen from *Figure 2* that compared with the untreated cotton, the FTIR curve of the treated cotton with microwave is essentially unchanged. Microwave irradiation had no significant influence on the chemical structure of cotton fibres.

SEM Analysis

To investigate the influence of microwave treatment on the surface morphological structure of the cotton fibres, experiments with cotton fabric in the wet state under microwave irradiation 700W power for various lengths of time (60, 180 and 300S) were carried out. The scanning electron microscopy photographs of surface morphological structure of the cotton samples untreated and treated with microwave are showed in *Figures 3a- 3d.*

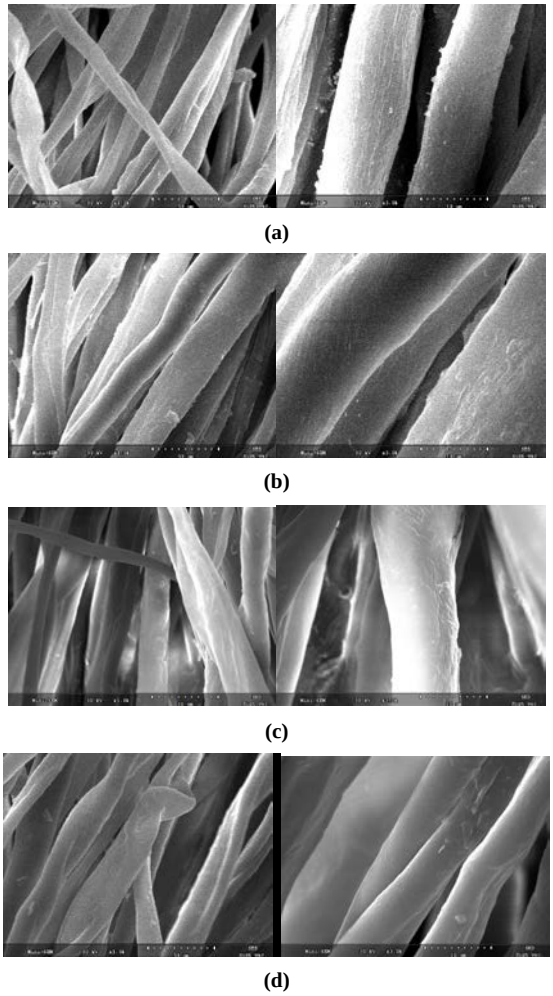

FIGURE 3. SEM micrographs of (a) untreated cotton and microwave-treated cotton (b) 60s, (c)180s, (d) 300s.

Figure 3 shows the microwave irradiation had no obvious damaging effect on the surface morphology structure of cotton compared with the untreated cotton fabric.

DSC Analysis

To investigate the influence of the microwave treatment on the decomposition temperature of the cotton fibers, experiments with cotton fabric in the wet state under microwave irradiation at 700W power for various lengths of time (60, 120, 180, 240 and 300s) were carried out. Decomposition temperatures of the untreated and treated cotton samples are shown in *Figure 4*.

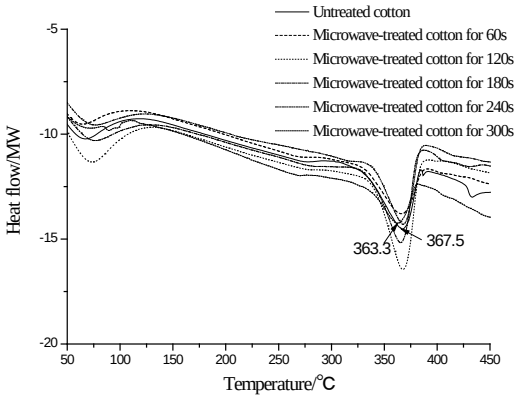

FIGURE 4. DSC Curve of untreated cotton and microwave-treated cotton.

It can be seen from *Figure 4* that the decomposition temperature of untreated cotton is 367.5℃. Compared with the untreated cotton, the decomposition temperature of the microwave-treated cotton almost unchanged at treating times less than four minutes. At treating times of 240s and 300s, the decomposition temperature of the cotton treated decreases. Microwave irradiation had a slight influence on the fine structure of cotton fibers.

XRD Analysis

To investigate the influence of microwave treatment with on the crystallinity of the cotton fibers, experiments with cotton fabric in the wet state under microwave irradiation at 700W power for various lengths of time (60, 120, 180, 240 and 300s) were carried out. The crystallnity of the cotton samples untreated and treated with microwave are showed in *Figure 5*.

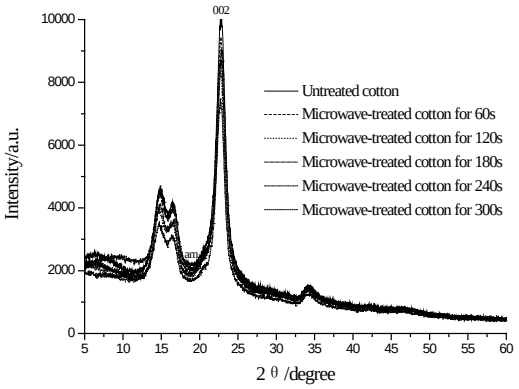

FIGURE 5. XRD Curve of untreated cotton and microwave-treated cotton.

The crystallization index (CI) of cotton fibres is calculated by the following equation [9].

$$Cl\ (\%) = (I_{002} - I_{am})/ I_{002} \quad (1)$$

Where I_{002} is the intensity at $2\theta = 22°$ and I_{am} is the intensity at $2\theta = 18°$.

On the basis of Eq. (1), the CI results of the untreated cotton and microwave-treated cotton fibres are listed in *Table III.*

TABLE III. CI value of untreated cotton and microwave-treated cotton.

Wool samples	I_{am}	I_{002}	CI
Untreated	2133.7	11075.4	0.81
Treated with 60s	2000.6	9284.6	0.78
Treated with 120s	1840.1	8591.9	0.79
Treated with 180s	1970.4	9102.6	0.78
Treated with 240s	1866.7	8713.7	0.79
Treated with 300s	1684.9	7375.1	0.75

It can be seen from *Table III* that compared with the untreated cotton, the crystallinity of the treated cotton in the wet state with microwave irradiation decreased from 240s to 300s, which can be attributed to the effect of longer exposure to the high temperatures produced by the microwave irradiation.

CONCLUSION

It can be concluded that microwave irradiation can impact the breaking strength and elongation at break of wet cotton fabrics. The whiteness of cotton fabrics subjected to microwave treatment was decreased. The chemical structure and surface morphological structure of microwave-treated cotton had no obvious changes. Microwave irradiation had no obvious damaging effect of cotton compared to the untreated cotton fabric. It was also found that microwave irradiation also affected the fine structure of cotton. The decomposition temperature and crystallnity of the treated cotton in wet state with microwave irradiation decreased after longer exposure times. Microwave irradiation treatment has significant potential for wet finishing of cotton fabric as microwave is a clean, environmentally friendly, highly efficient heating technology. Research on the structure and property changes of cotton fabrics in the wet state following microwave irradiation should lay a good foundation for further application of microwave technology in the wet finishing of cotton fabrics.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author.

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REFERENCES

[1] Xue Zhao, Jie Min, Jin-xin He. Effect of microwave curing on antimicrobial activity of chitosan biguanidine hydrochloride treated wool fabrics [J]. The Journal of the textile institute, 2011, 102(9): 801-807.

[2] R Purwar, M Joshi.Effect of microwave curing on easy care finishing of cotton using glyoxal/glycol [J]. Aatcc review, 2009, 9(7): 38-42.

[3] Soraya Ghayempour, Sayed Majid Mortazavi. Microwave curing for applying polymeric nanocapsules containing essential oils on cotton fabric to produce antimicrobial and fragrant textiles [J]. Cellulose, 2015, 22(6): 4065-4075.

[4] Ji Hwan Park, Hyung-Min Choi, Kyung Wha Oh. Simultaneous crosslinking and cationization of cotton cellulose by using dialdehyde and choline chloride: comparison between the pad-dry-cure and microwave irradiation process [J].Cellulose, 2014, 21(4): 3107-3119.

[5] Moustafa M.G. Fouda, A. El Shafei, S. Sharaf, A. Hebeish. Microwave curing for producing cotton fabrics with easy care and antibacterial properties [J]. Carbohydrate Polymers, 2009, 77: 651-655.

[6] Ana Budimir, Sandra Bischof Vukusic , Sandra Grgac Flincec. Study of antimicrobial properties of cotton medical textiles treated with citric acid and dried/cured by microwaves [J]. Cellulose, 2012, 19(1): 289-296.

[7] Zhao Xue, He Jin xin, Zhan Yi zhen. Synthesis and characterization of chitosan biguanidine hydrochloride under microwave irradiation [J]. Polymer Journal, 2009, 41(12): 1030-1035.

[8] J. Jacob, L. H. L. Chia, F. Y. C. Boey. Thermal and non-thermal interaction of microwave radiation with materials [J]. Journal of Materials Science, 1995, 30(21): 5321-5327.

[9] Segal L. An empirical method for estimating the degree of crystallinity of native cellulose using the X-ray diffract meter [J].Textile Research Journal, 1959, 29: 786-794.

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