Evaluation of Hydrophilic Property Changes as Result of Enzyme Washing Treatment

Sabri Halaoua[1], Mohamed Hamdaoui[2], Sadok Roudesli[1]

[1]Laboratoire of Interfaces and Advanced Materials (L.I.M.A.)
University of Monastir, 5019 Monastir, Tunisia.

[2]Textile Materials and Processes Research Unit (M.P.Tex.),
Monastir National School of Engineers, University of Monastir, Tunisia.

Abstract

In this paper, we present the results of an experimental study of the influence of enzyme washing treatments of jeans on its hydrophilic property. It provides a systematic analysis of the changes in hydrophilic property between two textile substrates: treated and untreated jeans dyed fabrics. The change of the hydrophilicity of the fabric as a result of the washing treatment is evaluated by measuring the contact angle. Then, a mathematical model was found and established to follow the spreading and diffusion kinetic of the water drop deposited on the surface of the Denim textile.

Key Words: *Hydrophilicity, Contact angle, Jean fabric, Scanning electron microscope(SEM), Washing treatments.*

---

1. INTRODUCTION

Textile materials and clothing play an important role in every day human's life. Indeed, increasing demands for comfort and aesthetic textile products causes the development of new treatment and techniques for processing and designing textiles [1-3]. One of the most preferred and popular clothing of today's youth is the Denim fabrics, especially the washed-out jeans or the Denim jeans with old look. This textile fabric is made by cotton.

Cotton is still the "king" of fibers because most of the world's fabric is made of cotton. It is characterized by a good strength and it is considered to provide comfort due to its good moisture adsorption and wicking properties [4].

Water can interact with textile surfaces differently depending on whether the surface is hydrophilic or hydrophobic. Indeed, hydrophilic materials are those having surfaces that are easy to be wet, with water contact angle of < 90°. However, hydrophobic means that the textile does not combine or mix well with water. Cotton, a cellulose-based material, is a natural material. It has strong polar groups (-OH) that readily interact with water, giving a good hydrophilicity property.

It is well known that generally the wettability, the hydrophilicity and the absorption ability of the cotton fiber change with chemical and mechanical finishing treatments performed on the fabric [5-7]. The literature shows several works being interested in the survey of the spreading and impregnation of liquid on treated and untreated textile fabrics to characterize the hydrophilic property of the material. The capillary rise phenomena in fibrous porous media are of great importance in wetting and wicking in textile structure and extensive publications are available [8-12]. The surface tension, the gravitational forces, the viscous forces and the contact angle have been considered and studied and investigated to characterize the wettability of textile and porous materials [13-15].

In this article, we are interested in the changes of hydrophilic property of jeans dyed fabrics as a result of washing treatment. The wettability of the untreated and treated jeans fabrics is evaluated by measuring the contact angle using the GBX Digidrop apparel. Also, a mathematical model has been developed to predict the complete profile of the horizontal wicking through the woven fabrics considering different influencing parameters, i.e. pH of the bath and the concentration of the enzyme. By using the developed model, we can too determine the diffusion kinetic parameters of the water in the textile.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

The basic denim was selected for this study. A summary of the fabric characteristics used in this investigation are shown in Table 1.

Table 1. Characteristics of untreated denim

<table>
<tr><th colspan="2">Composition</th><th>100% Cotton</th></tr>
<tr><td colspan="2">Weave structure</td><td>Twill 4</td></tr>
<tr><td rowspan="2">Density (yarns / cm)</td><td>Warp</td><td>30</td></tr>
<tr><td>Weft</td><td>20</td></tr>
<tr><td rowspan="2">Linear density (Tex)</td><td>Warp</td><td>96</td></tr>
<tr><td>Weft</td><td>100</td></tr>
<tr><td colspan="2">Surface density (g/m²)</td><td>430</td></tr>
</table>

The selected fabric has been processed by different industrial washing treatments, which are often used for final finish of the denim garments. These treatments were acidic enzyme wash and neutral enzyme wash (Table 2).

Table 2. Description of the denim industrial treatments

Treatment	**Description**
Acidic enzyme wash	The enzyme is introduced in acidic bath (pH=5). The concentration of enzyme is 40 g for a load of 1 kg of the merchandise. The temperature is raised up to 50°C and items are turned for 50 minutes.
Neutral enzyme wash	This one is analogous to the Acidic enzyme washing, only the enzyme used is neutral (pH = 7). Equally, we used 40 g/kg of enzyme concentration and the duration of treatment was about 50 min.

2.2 Measurements

In order to quantify the influence of washing treatments on the hydrophilicity of the jeans fabric and to evaluate the wetting property of the textile surface, contact angle measurements were investigated. The contact angles of water and oil were measured with the drop shape analyzer (Digidrop GBX Contact angle Meter - France) equipped with video-camera system and computer software. The contact angle of the liquid was measured using 5µL droplet which was gently deposited on the surface using the syringe.

2.3 Characterization

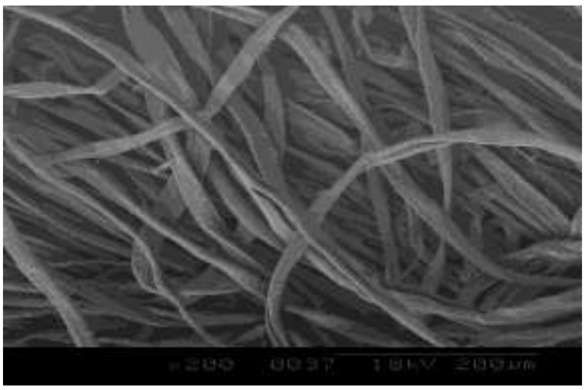
The treated (washed) and untreated fabrics were characterized via the Scanning Electron Microscopy (SEM). This technique allows visualization of the surface of the textile and then detects the changes in roughness degree. Samples (washed and unwashed) were cut at 4 cm² pieces. Specimens were examined at approximately 100 and 200 X magnification.

3. RESULTS AND DISCUSSION

3.1 Experimental data

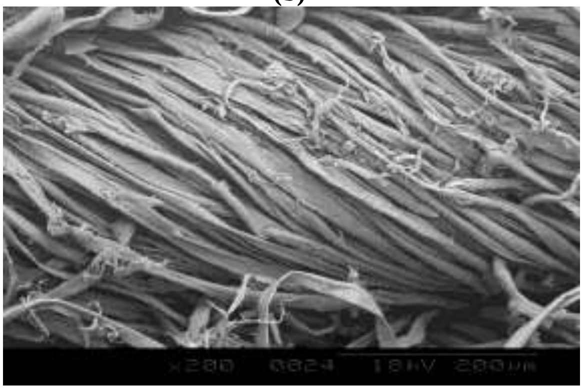
Figure 1 displays the SEM images of the original fabric (the unwashed fabric) vs. the treated one (washed fabric) at 200X magnification. It is clear and easy to distinguish the difference on the topographical properties of the surface between the three substrate samples.

From the figure 1, it is observed that the surface of sample washed in acidic bath with 40 g/kg of enzyme at 50°C for 50 minutes is somehow more worn than the surface of the sample washed in the neutral bath at the same conditions of duration, temperature and enzyme concentration. Moreover, it is noticed some sign of fiber fracture, and roughness. The mechanism of wear at acidic enzyme wash is characterized by signs of fiber fracture, debris and roughness formation.



(a)

(b)



(c)

Figure 1- SEM micrographs at magnification of 200x. (a) Micrograph of the original jean fabric, (b) Micrograph of the fabric treated by 40g/Kg enzyme at pH=7 for 50 minutes, (c) Micrograph of the fabric treated by 40g/Kg enzyme at pH=5 for 50 minutes

Wetting of water on the textile surface depends not only on the chemical nature but also on the morphological structure and topographical properties of the surface. For this reason, we are study the wettability of the original jean fabric and the washed one by measuring the contact angle of the substrate with the water. The volume of water used for the contact angle measurements was 50µL. The well-known young equation describes the balance at the three-phase contact angle of the textile, water and vapor.

$$\gamma_{tex,v} = \gamma_{tex,w} + \gamma_{w,v} \, cos \, \theta_y$$

Where:

$\gamma_{tex,v}$, $\gamma_{tex,w}$ and $\gamma_{w,v}$ are the surface tension of the textile/vapor interface, of the textile/water interface and of the water/vapor interface respectively.

t=0s, θ=87.1°   t=0.20s, θ=37.3°   t=0.36s, θ=8.5°

Figure 2- Evolution of the water – enzyme treated fabric (pH=7, W=40g/Kg, t=50min) contact angle vs. time

Considering results given in figure 2 which illustrates the evolution of water contact-angle on the textile substrate, we can observe that the contact angle on the sample washed by enzyme at neutral medium changes as a function of time from 87.1°, at the first contact, until 8.5° after 0.36s due to its good moisture adsorption and hydrophilic properties. In figure 3, we have reported experimental data of the evolution of the water contact-angle on all samples used in this study as a function of time when water drop deposited on the surface. From curves, it was noted that at the same time the water-denim fabric contact angle is significantly influenced by the washed treatment. The lowest contact angle value was noted for the fabric washed in acidic bath and the highest one was noted for the untreated fabric.

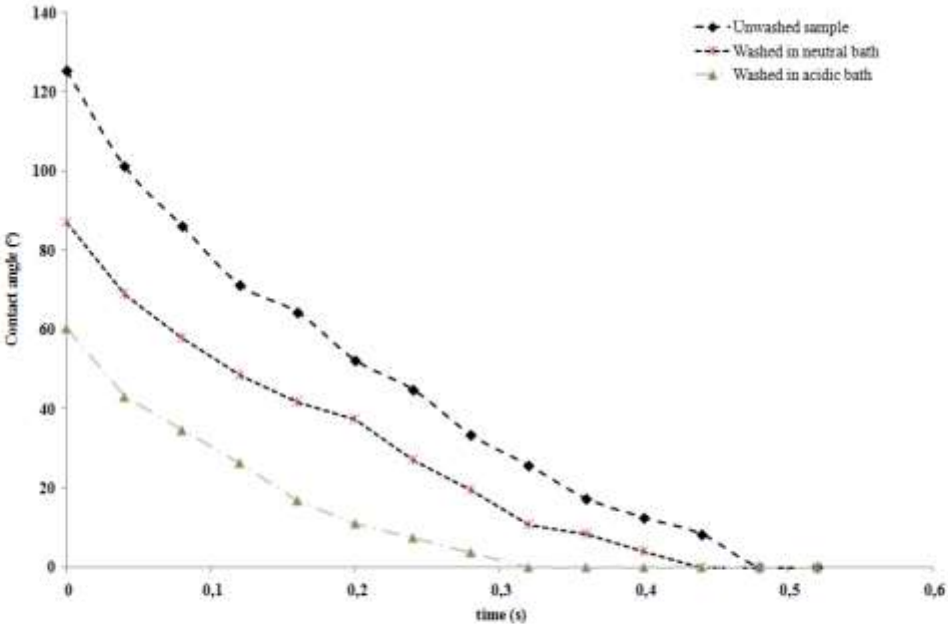


Figure 3- Evolution of the water – denim fabrics contact angles vs. time

3.2 Spreading kinetics of the water drop deposited on denim fabric

In order to better understand the influence of enzymatic wash treatment on hydrophilic properties of textile and to interpret the spreading kinetics of water drop deposited on textile surface, the experimental mass of water-fabric contact angles at each time were curve fitted using MatLab to the exponential kinetics model (Figure 4, 5 and 6). This model has a double exponential form as given by the following equation [16]:

$$\theta = \theta_{\infty} \exp(-K_1 t)$$

Where θ is the water-fabric contact angle at time "t" and the terms θ_{∞} are the water-fabric contact angles at first contact (time=0s). K1 is the spreading kinetic of water drop.

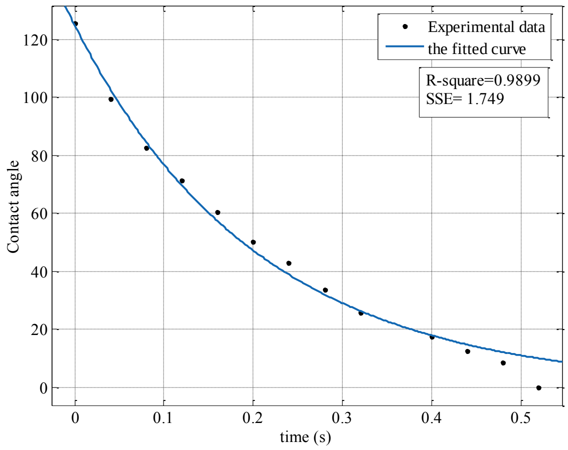


Figure 4- Fitted curve of the water – untreated denim fabrics contact angles vs. time

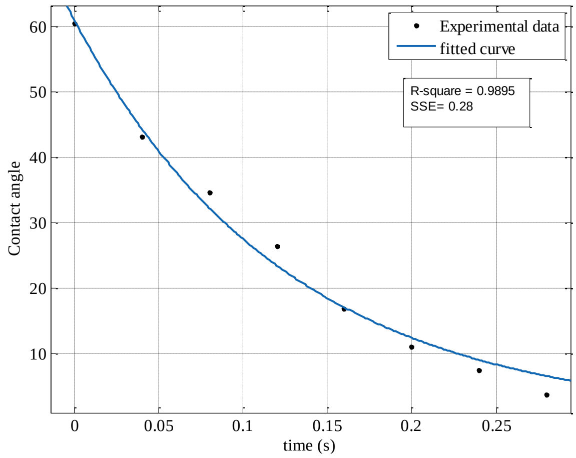


Figure 5 - Fitted curve of the water – acidic enzyme washing denim fabrics contact angles vs. time

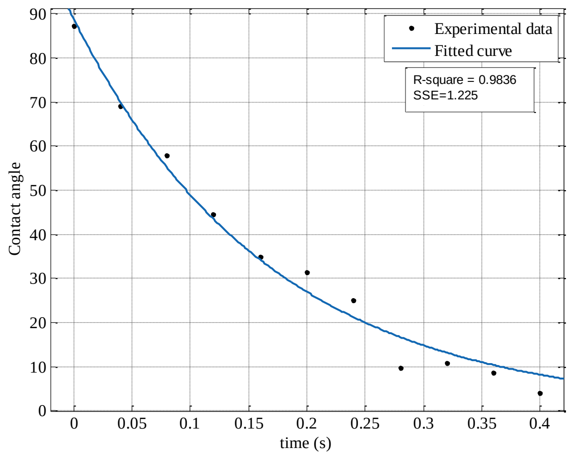


Figure 6- Fitted curve of the water – neutral enzyme washing denim fabrics contact angles vs. time

In figures 4, 5 and 6 the lines were the best fit of the mathematical model to the kinetics experimental data. The validity of the exponential model in the three fabric cases in describing the kinetic data is checked by the correlation coefficient (R-square) and the sum of square due to error (SSE). R-square and SSE were defined as:

- Sum of Squares Due to Error (SSE) which measures the total deviation of the response values from the fit to the response values. A value closer to 0 indicates that the model has a smaller random error component;
- R-square is the square of the correlation between the response values and the predicted response values. It can take on any value between 0 and 1, with a value closer to 1 indicating that a greater proportion of variance is accounted for by the model.

Table 3 summarizes the exponential model fitting parameters, the R^2 and the SSE coefficients for samples.

Table 3: Goodness-of-fit statistics parameters in different cases of treatment

Sample	θ_{∞}	K_1	SSE	R-square
Untreated	124.7	4.867	1.748	0.9899
Acidic enzyme wash	61.02	7.959	0.282	0.9895
Neutral enzyme wash	88.9	5.972	1.225	0.9836

The exponential model proposed to describe the evolution of water contact angle with time is tested by comparing the theoretical curve with the experimental one. As shown in table 3, for all samples, the high R^2 values (>0.98) and the law SSE values (<1.8) indicate that the experimental data are well correlated to the exponential model.
From the exponential model, it could be found that the initial water-fabric contact angles for the untreated, neutral washed and acidic washed fabrics were equal to 124.7°, 88.9° and 61.02°, respectively. The kinetic parameter for the untreated, neutral washed and acidic washed fabrics (“K_1 (s^{-1})”) were found to be equal to 4.768 s^{-1}, 5.972 s^{-1} and 7.959 s^{-1}, respectively. These results indicate that the hydrophilic property of the denim fabric depends on the type of washing treatment. Indeed, using values of measurement of contact angles as the primary data, we can study the degree of wetting when the denim fabric and the water interact and then the hydrophilic property of the textile. For example, a large angle (124.7°>> 90°) as observed in the case of the untreated fabric correspond to low wettability and therefore the fiber can be considered as hydrophobic. However, a small contact angles (61.2°<<90°) as observed in the case of the acidic enzyme washed fabric correspond to high wettability and then the denim fabric can be considered as hyrdrophilic.

4. CONCLUSION

In this work, after visualization of the surface of the washed and unwashed denim fabric via SEM technique at 100 and 200 X magnification and evaluation of roughness changes, we have investigated the experimental study of the dynamic spreading of water drop on three different cotton denim fabrics using an exponential model. The simulation curves by MatLab showed good fits with the experimental data of the water – textile surface contact angles. The validity of the mathematical model in describing the kinetic data is checked by the correlation coefficient (R-square) and the sum of square due to error (SSE). Finally, we noted that the enzyme washing treatment of the denim fabric have a significant influence on the kinetic rate of spreading of water drop. Indeed, results show that the spreading kinetic rate was raised when the textile was washed. It was very important in the case of acidic enzyme washing treatment.

REFERENCES

1. Angé Mickeviciené, Daiva Mikucioniené, Rasa Treigiené. The influence of antimicrobial treatment on air permeability and water absorption of knits. Materials Science. 21 (1) 2015 pp. 62-67.
2. Tomšič, B., et al. Sol-Gel Coatings of Cellulose Fibers with Antimicrobial and Repellent Properties Journal of Sol-Gel Science Technology 47 2008: pp. 44 – 57.
3. Xing, Y., Yang, X., Dai, J. Antimicrobial Finishing of Cotton Textile Based on Water Glass by Sol-Gel Method Journal of Sol-Gel Science Technology 43 2007: pp. 187 – 192. http://dx.doi.org/10.1007/s10971-007-1575-1
4. Edward Menezes and Mrinal Choudhari. Pre-treatment of textiles Prior to Dyeing. Textile Dyeing. Prof. Peter Hauser (Ed.) InTech, ISBN: 978-953-307-565-5 (2011).
5. A. Rashidi, H. Moussavipourgharbi, M. Mirajalili and M. Ghoranneviss. Effect of low-temperature plasma treatment on surface modification of cotton and polyester fabrics, Indian Journal of Fibre and Textile research 29, 74-78 (2004).
6. Wing-yu Iris Tsoi, Chi-wai Kan and Chun-wah Marcus Yuen. Using ageing effect for hydrophobic modification of cotton fabric with atmospheric pressure plasma. BioRessources 6 (3), 3424-3439 (2011).
7. Hamdaoui, M., Fayala, F., & Ben Nasrallah, S. (2007). Journal of Applied Polymer Science, 104:3050-3056.
8. Hamdaoui, M., Fayala, F., & Ben Nasrallah, S. (2006). Journal of Porous Media, 9:381-392.
9. Hamdaoui, M., Fayala, F., P. Perré, & Ben Nasrallah, S. (2008). AUTEX Research Journal, 8(2):44-48.
10. Fayala, F., Hamdaoui, M., P. Perré, & Ben Nasrallah, S. (2008). Journal of porous Media, 11(3):231-240.
11. Hamdaoui M, Achour N S, & Ben Nasrallah S, Journal of Engineered Fibers and Fabrics, 9 (1) (2014) 101-106.
12. Hamdaoui, Ben Nasrallah, S. Capillary rise kinetics on woven fabrics – experimental and theoretical studies. Indian Journal of Fibre and Textile research 40 (2), 150-156 (2015).
13. S. M. Kumar and A. P. Deshpande, Colloid. Surface A., 277, 157 (2006).
14. Q. Wei, Y. Liu, D. Hou, and F. Huang, J. Mater. Process. Technol., 194, 89 (2007).
15. T. Karbowiak, F. Debeaufort, D. Champion, and A. Voilley, J. Colloid Interf. Sci., 294, 400 (2006).
16. Hamdaoui M, Baffoun A, Ben chaaben K, & Hamdaoui F, Journal of Engineered Fibers and Fabrics, 8 (3) (2013) 70-76.