

Wettability of Easy-Care Finished Cotton

Abstract

The easy-care finishing of cotton cross-links adjacent molecular chains in a cellulose structure, whereby the wettability of finished cotton fabric is significantly reduced or becomes unwettable. The pigment printing of easy-care finished cotton fabric was investigated. The residual catalyst content on the fibre surface and the cross-linked molecular structure both influence fabric wettability. The finished cotton fabric would become unwettable following after-wash treatment, resulting in the reduced absorption of the pigment paste in fibres. The type of catalyst used in easy-care finishing has a direct influence on pigment printing; generally, it enhances the fabric wettability of finished fabric that has received wash-off treatment. The catalyst content on the surface of fibres also affects the colour strength (K/S value) and lateral spreading of aqueous print paste on the finished fabric.

Key words: catalyst salt, cotton fabric, DMDHEU, easy-care, wettability.

Introduction

The wetting of cotton fabric is highly desired in textile wet processing. The various wetting phenomena of fibres such as spreading, adsorption, diffusion, and capillary penetration may occur when they are in contact with a liquid. The primary stage in the wetting of a fibre surface involves the gradual replacement of the solid-air (vapor) interface by a solid-liquid interface. In spontaneous wetting the migration of liquid through a solid surface continues until a thermodynamic equilibrium is established. However, in forced wetting an external hydrodynamic or mechanical force is required to increase the area of the liquid-solid interface.

The wetting of cotton depends upon the properties of the fibre surface and the liquid which is going to wet it [1]. The surface energy of a textile structure in the uppermost layers is important in the wetting and adhesion of liquids [2]. The fabric surface energy is largely dependent upon the structure of the fibre, as well as on the yarn, fabric, capillary forces, cover factor, area density, level of projected fibres, and surface roughness [3]. It was found that laundering increases the wettability of unfinished cotton and polyester fibres (4-RHEE-TRJ), presumably resulting from the surface roughening of fibres and the removal of oil-based contaminants. The surface energy of fabric is influenced by the finishes, which react with the fibres or self-cross link on the fibre surface, and the residual content of salt or catalyst used. Moreover, the alkaline or acidic bath used in finishing also affects the level of projected fibres and roughness of the fabric surface.

The subject of the wettability of cotton has been extensively investigated with a view to producing water repellent yarn or fabrics [5 - 7], where fibres are coated with polystyrene by admicellar polymerisation with or without a cross-linking agent. However, the cross-linking agents used in the easy-care finishing of cotton reduce the wettability to a level which is significantly smaller than that achieved in polystyrene coated cotton. Such coated cotton yarn absorbed only 3% of the water retained by the unmodified yarn [5], and the wetting time of coated cotton for a water droplet was found to be greater than 30 minutes [6].

The subject of cotton wettability and its effects on subsequent printing has not been significantly investigated. This research paper reports and discusses some results for the wettability of easy-care finished (cross-linked) cotton fabric in relation to the catalysts selected and their effects on pigment printing.

Measurement of the absorption and spreading rate of liquid by complex substrate-like textiles is important in several areas of textile technology, including dyeing, printing, finishing, wet coating, and the design of medical dressings and diapers [8]. The presence of water soluble salt or catalyst content on the surface of liquid may influence the wetting phenomenon of the textile substrate. In gen-

eral, the addition of simple inorganic salt to water modified the bulk and surface structure of the water [9].

Since cross-linking in a cellulose molecular structure belongs to hydroxyl groups, and the cross-linking agent introduces a molecular network, subsequent chemical processing would experience reduced accessibility and availability of cellulose hydroxyl groups. For example, a reduction in fabric wettability and water absorption are found in cross-linked cellulose. The dyeability of cross-linked cotton fibres is similarly modified, resulting from the available number and size of accessible pores for coplanar sorption [10].

The theories depicting the wetting process of a solid surface in an ideal condition are based on a smooth, homogenous, impermeable and non-deformable solid surface. Although these properties do not exist in a textile fabric, the wetting phenomena can be significantly explained using principles associated with the wetting process in ideal conditions. Several wetting phenomena are linked with liquid migration through a fabric, such as wicking, absorption, spreading, adsorption and penetration. However, one of these may dominate the others. For example, penetration, absorption and adsorption will occur in printing where an aqueous paste is applied under forced conditions on the fabric surface; depending upon

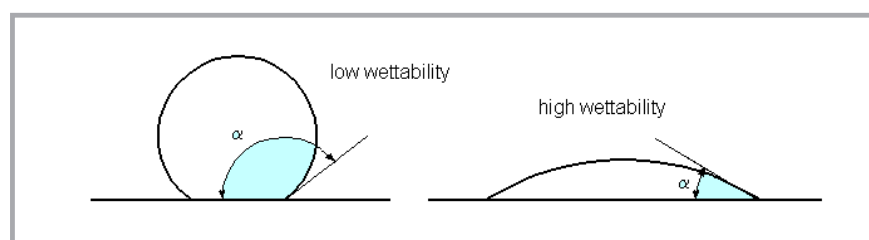


Figure 1. Wetting of a solid surface with a liquid at an angle α .

the fabric surface energy, and the surface tension and rheology of the paste, there would be a spreading of the paste.

The mechanism of wetting a fabric surface can be described as follows: a liquid drop resting on a solid surface which exhibits a contact angle of ' α ' at the liquid-solid interface. This is shown in *Figure 1*. This is the angle in the liquid at the solid-liquid-air (vapor) interface obtained from the tangent to the liquid-vapor interface and solid-liquid interface [11]. The magnitude of the contact angle is a measure of fabric wettability, and the equilibrium contact angle indicates the wettability of a solid surface for the liquid. If the contact angle is lower than 90 degrees, the liquid will wet the solid, whereas if this angle is greater than 90 degrees, the solid surface will not be wettable [12].

The wetting process of a fabric by an aqueous media resting on its surface is mainly wicking progress by the capillary forces, which involves the following stages:

1. spreading and penetration in the fibres underneath, and
2. radial spread by the absorption and adsorption of the liquid in the substrate under capillary forces.

Wicking increases with a rise in the viscosity of the liquid and decreases with an increase in the surface tension of the liquid, capillary radius, and contact angle [1].

More than one wetting mechanism is usually operating simultaneously when a textile fabric is in contact with a liquid. A relatively simple procedure to assess the wettability of a textile-fabric surface is to note the time taken by a liquid drop to disappear from the surface. A standard wettability test procedure can be used for this purpose.

This paper reports the results of work done on modifying the wettability of cotton fabric cross-linked with a dimethyloldihydroxyethyleneurea (DMDHEU) type finishing agent. The influence of the various catalysts used was investigated with respect to the wettability of the finished fabric. Subsequently, these results were compared with the performance of aqueous print paste applied to the finished fabric to indicate the influence of cellulose cross-linking and/or the catalyst content on pigment printing.

■ Experimental

Materials

Fabric

The fabric used was of plain woven 100% cotton construction with 25 ends and 23 picks per centimetre square and an area density of approximately 142 g-m⁻². The fabric was commercially desized (enzymatically), scoured and bleached by continuous pad-steam process treatment.

Chemicals and colorants

The crease recovery finishing agent used was Fixapret CP (BASF), based upon dimethyloldihydroxyethyleneurea (DMDHEU). The selected catalysts used were 2-amino-ethanesulphonic acid (2AESA), ammonium chloride and magnesium chloride.

The two pigment colorants used (as supplied by BASF) were Helizarin Red GR conc. (CI Pigment Red 112) and Helizarin Blue BGT conc. 92 (CI Pigment Blue 15). The pigment print system was supplied by BASF and comprised Binder ET (polyacrylate and anionic surfactant in water), thickener, Lutexal HP (polyacrylate and mineral oil in water), and Fixing Agent LF (methoxymethylated melamine & polycondensate in water/solvent).

Methods

Finishing procedures

The woven cotton fabrics prepared were padded in a bath at 80 ± 5% pick-up on a laboratory two roll vertical padder using a speed of 1.2 ± 0.2 m min⁻¹ and squeezing pressure of 85 ± 5 psi. In all the finishing processes, the pad-dry-cure method was used. The aqueous finishing bath contained only a catalyst and the finish DMDHEU. A 125 g-l⁻¹ concentration of the finish was used in all the pad baths to give a 10% add-on according to the weight of the fabric. The catalyst concentrations of amino acid and magnesium chloride used were 5, 10 and 15% of the weight of the resin present; i.e. equivalent to 0.64, 1.25 and 1.84% of the finishing bath's concentration, whereas the concentrations of ammonium chloride used equated to 0.25, 0.50 and 0.75% of the finishing bath.

The padded fabrics were immediately set on a pin frame and subjected to drying at 60 °C for 7 minutes, followed by curing at 160 °C for 3 minutes. Both these operations were performed in a laboratory hot air oven. The properties of the

finished fabric were evaluated without subsequent wash-off.

To investigate the effect of the catalyst on fabric wettability, the cotton fabric prepared was also padded in a bath containing only a catalyst using the same concentration, method and conditions of drying and curing applied in the finishing procedures described above.

The influence of a thickener and binder films on fabric wettability was studied using a separate thickener and stock paste applications. Thickener paste contains a thickener only, whilst stock paste contains a thickener, binder, and fixing agent. The concentrations of these reagents and their method of application to fabric were the same as those used in the pigment print paste preparation and application.

Printing procedures

The pigment print paste used was produced using a concentration of Lutexal HP of 2.35 - 2.5% w/w (to maintain the 70 - 80 poise viscosity range recommended by the supplier), which was added, with continuous high speed stirring, to the volume of water required. The binder (15%) was then added gradually with stirring, and the completion of 100% stock paste was made with the addition of 0.9% of Fixing Agent LF, with continuous stirring, giving a final stock paste viscosity of 70 - 80 poise. Each print paste was prepared with 3% pigment colour and 97% stock paste. In both the stock and print paste preparation, vigorous high speed stirring for 10 minutes was required to obtain a homogenous paste after adding all the reagents.

The fabrics prepared were printed on a Zimmer MDF lab-printing machine with an open mesh screen of 90 threads per cm, and magnet squeegee bar (diameter: 12.48 mm). The processing sequence used was print-dry (60 °C, 7 min in a hot flue drying machine) - cure (160 °C, 3 min in a lab Roaches oven on a pin frame).

Evaluation of fabric properties

The wettability of selected CR finished fabrics were assessed using a drop test of 50% sugar solution as described in British Standard BS 4774:1974. Those fabrics which do not absorb the solution drop within 200 seconds are described as unwettable.

Table 1. Wettabilities of easy-care finished cotton fabric [9].

Catalyst	Concentration, %	Wettability, time, seconds	
		Unwashed	Washed
No catalyst (control- unfinished)	0.00	66	-
MgCl ₂ ·6H ₂ O	0.64	29	> 200
	0.89	44	> 200
	1.25	130	> 200
2AESA	0.64	59	> 200
	0.89	29	> 200
	1.25	35	> 200
2AESA+ NH ₄ Cl	0.64 + 0.25	28	> 200

The influence of cellulose cross-linking and the catalyst content on the spreading of pigment print paste was evaluated for the finished fabrics. An appropriate mechanical technique was devised, which involved a dropping pipette containing a set volume of print paste (poise viscosity: 60) positioned 1 ± 0.2 cm above the fabric sample, held horizontally on a glass plate. The paste drop was released pneumatically, and the fabric was immediately removed to a vertical position in a shielded cabinet. Since the drop spread was not in an ideal circular form, the maximum length and width of the drop after spreading for 15 minutes were recorded as an objective indicator of the paste spread resulting from the reduced wettability of easy-care finished fabric. Each wettability measurement reported is a mean of 15 individual assessments taken for three fabric specimens with five assessments of each specimen.

As an assessment indicator of print paste penetration through the fibres, the shade depth values were assessed in terms of the colour strength, spectrophotometrically expressed by the Kubelka-Munk (K/S) relationship, on the reverse side of the printed fabric.

Results and discussion

Fabric wettability

Influence of the thickener, binder, and fixing agent

The control cotton fabric (deisized – scoured-bleached) used had a wetting time of 69 seconds. However, the coating of polyacrylate thickener film significantly reduces this time to 26 seconds. The reduction is attributed to the hydrophilic nature of the polyacrylate based thickener, which enhances fabric wetting. The thickener does not introduce any cross-link structure resistant to water sorption. However, when a paste containing a thickener, binder and fixing agent was

applied to the fabric, it became unwettable. Binder and fixing agents are known to impart a cross-link structure to the surface of fibres that significantly reduces the sorption and accessibility of water molecules in the fibres, making them unwettable.

Influence of the catalyst on the wettability of finished fabric

The catalysts selected were used in the easy-care finishing of cotton fabric, the affect of which on fabric wettability is shown in **Table 1** [13]. The wettabilities were measured after finishing and following after-wash. Wash-off treatment following the finishing process using any catalyst removes residual catalyst content from the surface of fibres. The cross-linked structure of fibres has an increased level of surface tension that makes them unwettable.

The presence of magnesium chloride on the finished fabric surface reduces the wetting time compared with control-unfinished fabric. However, in any case the increasing content of this salt on the fibre surface maintains the wetting time, and with the highest content used, i.e. 1.25%, it reaches twice the time taken by control-unfinished fabric. It is possible that the reduced concentration of magnesium chloride mainly produces the decrease in fabric surface tension, resulting in a decreased wetting time compared to unfinished fabric. However, an increased concentration of salt also affects the viscosity and surface tension of the liquid.

The solubility of magnesium chloride in water is 167 g/100 ml at 20 °C [14]. When the forces of cohesion are greater than the those of adhesion, the liquid will take more time or may not wet the surface; however, when the forces of adhesion are greater than those of cohesion, the liquid will wet the surface [12]. The wicking of liquid through the fibre sur-

face increases with a rise in liquid viscosity, and decreases with an increase in the surface tension of the liquid [1].

Therefore it is assumed that a higher content of magnesium salt on the fibre surface, following its solubilisation in the liquid drop, enhances the cohesiveness or surface tension of the liquid and/ or reduces its viscosity; consequently, higher wetting times are achieved. The surface energy of the fabric, surface tension of the liquid, and the viscosity of the liquid are the primary factors directly influencing the level of the wetting time of liquid in the fibres. Other factors like the pH and temperature of the liquid, the contact angle, and the temperature and hydrophilicity of the fibres also contribute [15].

The catalyst content of 2AESA in fibres enhances liquid adhesion, resulting in a reduced wetting time at any level of concentration used in control-unfinished fabric. The wetting time decreases significantly from 59 seconds to 29 seconds with an increase in concentration from 0.64% to 0.89%. Further increases in catalyst concentration result in a slight change.

Influence of the catalyst on unfinished fabric wettability

The changed wettability of finished cotton fabric is the result of cellulose cross-linking and the presence of catalyst on the fibre surface. To assess the effects on fibre wettability caused by the catalyst only, the fabrics were finished using a liquor bath containing a catalyst only, while all the finishing conditions (concentration and processing) were the same as those used in easy-care finishing. Ammonium chloride concentrations are also studied in this section, which were used in one of the easy-care finishing compositions.

Among all the catalysts used, magnesium chloride showed a significant increase, at any concentration used, in the wetting time of the fabric treated. This increase at concentrations of 0.64%, 0.89% and 1.25% are 26.89%, 69.54% and 194.61%, respectively, for easy-care finished fabric. This also indicates the ability of magnesium chloride to reduce fabric wettability in the absence of cellulose cross-linking.

Compared with unfinished-control fabric, the presence of any catalyst initially enhances the fabric wettability. However, the presence of an increased concentra-

tion of magnesium chloride reduces fabric wettability. The higher solubility of magnesium chloride (167 g/100 ml of water at 20 °C) presumably imparts increased cohesiveness to the aqueous drop, resulting in a reduced level of wettability.

Any concentration of 2AESA or ammonium chloride used enhances the wettability of unfinished-control fabric. Such an enhancement is more significant when using ammonium chloride. The water solubility of ammonium chloride is 385 g/l at 25 °C (or 38.5 g/100 ml of water) [16], which has the tendency to have increased solubility in water with an increasing temperature. Therefore, at 20 °C its solubility would remain at least four times less than that of magnesium chloride; and its presence on the fibre surface helps to increase fabric wettability. The lowest wetting time (i.e. highest wettability) is exhibited by ammonium chloride, a salt of strong acid and weak base, which modifies the liquid properties and/or increases the surface energy of fibres.

Almost all the catalysts showed a similar trend in the level of fabric wettability, as was seen in the case of easy-care finished fabric. In the case of the combined application of 2AESA and ammonium chloride, a similar level was obtained.

Effects of the catalyst on the spread of aqueous print paste

One important application of fabric wettability is understanding the behaviour of aqueous paste/ liquid applied to a fabric surface in the case of direct pigment printing. In order to have sharp outlines of print images, the aqueous print paste must wet the fabric instantaneously to prevent any later spreading beyond the print outlines.

A catalyst content present on the surface of fibres would have a direct influence on the lateral and downward transport of the print paste. And in case of the reduced wettability of the fabric, the chance of the lateral spreading of the paste or the loss of the print outline would increase.

The surface of a textile substrate does not meet the requirement of an ideal solid surface, and the spreading of an aqueous drop is influenced by the varying capillary forces, as a result of which the liquid produces a 'fingering pattern' [13]. This fingering pattern could be

Table 2. Spread of a drop of aqueous print (Helizarin Red GR) paste on easy-care finished fabrics¹ [9]; ¹Fabrics were not washed after finishing.

Catalyst used in finishing	Concentration, %	Spread of drop, cm	
		Max. width	Max. length
MgCl ₂ ·6H ₂ O	0.64	1.63	1.71
	0.89	1.97	2.00
	1.25	1.94	1.94
2AESA	0.64	1.38	1.42
	0.89	1.38	1.42
	1.25	1.36	1.44
2AESA+ NH ₄ Cl	0.64 + 0.25	1.52	1.44
Control- unfinished	0.00	1.41	1.57

Table 3. Colour strength on the reverse side of finished-print fabric¹; ¹Fabrics were first finished (no washing was done), then pigment printed.

Catalyst used in finishing	Concentration, %	Wavelength, nm	Colour strength (K/S) values
MgCl ₂ ·6H ₂ O	0.89	520	1.81
		550	1.85
2AESA	0.89	520	2.54
		550	2.57
2AESA+ NH ₄ Cl	0.64 + 0.25	520	2.47
		550	2.52
Control- unfinished	0.00	520	2.27
		550	2.31

Table 4. Wettabilities of various catalyst treated fabrics¹ (using 50 % sugar solution); ¹Fabrics were padded with aqueous catalyst solution without any finish content, then dried (60 °C for 7 minutes), and cured (160 °C for 3 minutes).

Catalyst	Concentration, %	Wettability, seconds
No catalyst (control- unfinished)	0.00	66.0
MgCl ₂ ·6H ₂ O	0.64	36.8
	0.89	74.6
	1.25	383.0
2AESA	0.64	53.0
	0.89	50.0
	1.25	33.5
NH ₄ Cl	0.64	19.0
	0.89	19.0
	1.25	22.7
2AESA+ NH ₄ Cl	0.64 + 0.25	28.4

more visible when the drop contains a colorant. The results obtained from assessing the spread of an aqueous pigment paste drop on finished cotton fabric with selected catalysts are shown in **Table 3** [13].

The fabric finished with magnesium chloride as a catalyst showed the highest level of spreading in both the length and width directions. The least concentration of magnesium chloride, 0.64%, produces a spreading of the aqueous print paste drop greater than the highest concentration, 1.25%, of 2AESA, or the combined concentration of 2AESA and ammonium chloride. This is a similar trend to the one observed in the wettability of fabric finished with these catalysts. The cata-

lyst 2AESA produces spreading in both directions smaller than that obtained for the unfinished-control fabric.

The Polyacrylate based thickener present in the print paste is sensitive to electrolyte; its viscosity decreases depending on the solubilising electrolyte content [18]. An increased level of paste spread in presence of magnesium chloride may be attributed to reduced aqueous wettability and the electrolytic thinning of the print thickener laterally on the fabric surface. However, the surface content of 2AESA and combined catalyst (2AESA and ammonium chloride) produces reduced thinning and more penetration of the print paste, as can be seen spectrophotometrically in the following section.

Colour strength values on the reverse side of the printed fabric

The pigment printing of cotton fabric requires the paste to transport in the fibres instantaneously in defined areas of the print image. The reduced wettability of the fabric will result in decreased absorption, and the penetration of the aqueous paste through the fibres. Therefore more surface print or print paste spreading is possible.

Measurement of the colour strength on the reverse side of the printed fabric would indicate if the print was more on the surface, hence not flowing down in the fibres. The results shown in **Table 3** (see page 61) describe the colour strength (K/S) values of cotton fabric printed with Helizarin Red GR containing print paste.

The least value of colour strength was obtained for fabrics with magnesium chloride on the fibre surface. However, fabrics containing 2AESA or 2AESA with ammonium chloride produce a color strength higher than any of the control-unfinished and magnesium chloride-containing fabrics. The same trend was noted in the wettability of fabrics finished with these catalysts in the previous results (**Tables 3 & 4**, see page 59). The reduced wettability of fabric induced by magnesium chloride limits the print paste more on the fibre surface.

In terms of the catalyst used, the two factors that significantly affect print paste penetration through the finished fabric are:

- i. its cationic activity and mobility, which influence the electrolytic thinning of the polyacrylate synthetic thickener; and
- ii. the wettability of fabric induced by the catalyst used.

The penetration of aqueous print paste more or less results from the relative sig-

nificance of these factors. The finished cotton fabric with increased wettability allows the aqueous paste or media to absorb in and penetrate fibres more rather than lateral spreading. Consequently, the print image has a higher possibility of remaining in the defined outline.

Conclusions

The wettability of cotton fabric following easy-care finishing is significantly reduced. The cross-linked cellulose structure becomes unwettable after wash-off treatment. However, when the finished fabric is not washed, the type of catalyst content on the fibre surface has a direct influence on the finished fabric's wettability. Fabrics finished with magnesium chloride exhibit reduced wettability compared to those finished with 2-aminoethanesulphonic acid and/or ammonium chloride.

One important area of interest for further research is to study the effect of the various salts and electrolytes used in easy-care finishing on the surface tension and viscosity of water, as well as the influence of any aqueous media including dye bath on the wettability of cotton fabric.

The aqueous print paste, based on polyacrylate type thickener, applied to the surface of easy-care finished cotton fabric containing magnesium chloride showed reduced penetration and increased lateral spreading on the fibre surface compared to the fabrics finished with 2-aminoethanesulphonic acid and/or ammonium chloride.

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