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Effect of Resin Finishing on Some Properties of 100% Cotton Light Weight Woven Fabric

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Abstract: In this study, experimental investigation was conducted to assess the wrinkle-resistance performance of resin-treated 100% cotton light-weight fabric. Resin (Dimethyloldihydroethylene urea, DMDHEU) was used for treating 100% cotton light-weight fabric with different treatment parameters (resin concentration: 30 g/L, 45 g/L, 60 g/L; pick-up: 60%, 70%, 80%; drying temperature: 110 °C, 120 °C; and curing time: 2 min, 2.5 min, 3 min). After resin treatment, wrinkle properties, as well as the tearing strength and dimensional stability, of the resin treated fabrics were evaluated. Experimental results revealed that the resin concentration, pick-up, drying temperature, and curing time are inter-related, which could affect the final performance of the 100% cotton light-weight woven fabric. Thus, the effects of different parameters on the performance of the 100% cotton light-weight woven fabric were compared and discussed. Generally speaking, the resin finishing improved the wrinkle properties and dimensional stability but reduced the tearing strength of 100% cotton light-weight woven fabric.

Keywords: cotton; woven fabric; light weight; wrinkle resistant; resin

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1. Introduction

Shirt fabrics are produced with reference to the season, e.g., the higher the density of shirt fabrics, the lower the coefficient of air permeability, which is important in winter clothing [1]. 100% cotton light-weight woven fabric is commonly applied for making shirts in the garment industry, since it has various advantages. Cotton is a soft staple fiber that grows in a protective capsule known as boll around the seeds of cotton plant [2,3]. Cotton fiber has good strength and abrasion resistance. It is hydrophilic, absorbs moisture quickly and dries quickly, and has no static or pilling problems [4,5]. However, cotton light-weight woven fabric (fabric weight around 100–125 g/m^2) gets wrinkled easily. As a shirting fabric, this is not preferable. In order to tackle this problem, many wrinkle-resistant treatments have been developed to improve the wrinkle properties. In cotton fibers, hydrogen bonds play a vital role in several intra- and inter-cellulose molecules in both crystalline and amorphous phases. It is believed that disruption of the hydrogen bonds under moist conditions and formation of new hydrogen bonds after moisture removal results in wrinkling and shrinking of cotton fabrics [6–9]. Therefore, the mechanism of the finish is inhibition of easy movement of the cellulose chains via crosslinking with appropriate resins [10–12]. During this finishing process other molecules can be simultaneously bonded to improve the wear comfort [10].

Resin treatment based on dimethyloldihydroethylene urea (DMDHEU) is widely used as a wrinkle-resistant treatment because of the stability and durability it offers. DMDHEU, as the final product of the reaction between urea, glyoxal and formaldehyde, reacts with the cellulose and forms a crosslinking net [9,10,13–16]. However, formaldehyde is toxic and carcinogenic in nature and thus various techniques have been developed to minimize formaldehyde release by producing modified DMDHEU products [17]. Modified DMDHEU causes formation of ether linkages by the two hemiacetals of aldehyde with hydroxyl groups of cellulose at elevated temperatures [9,18]. We found that resin treatment does enhance wrinkle-resistant properties of cotton woven fabric, but can reduce tear strength at the same time. Tear strength is an important property of fabric which is required during exposure of the cloth to severe environmental conditions. It is usually the most common kind of strength failure of fabrics in use [2]. Tearing can be described as the sequential breakage of yarns or groups of yarns along a line through a fabric. The tearing strength is affected by changes in yarn geometry, fabric geometry, relaxation of the fibers and their frictional characteristics [19–22]. Weak tearing strength of textile products reduces their useful life.

Researchers must look for a balance between improvement in crease recovery and retention of the fabric's tear strength [23–25]. It is well known that the pad-dry-cure process is the most important continuous large-scale production method used in the textile finishing industry. This process is accomplished by padding fabric through an aqueous solution of finishing agents to a certain wet pickup, drying at moderate temperature, and curing at an elevated temperature [26]. With the most used pad-dry-cure processing method, chemical quantities applied and reaction conditions such as temperature and time are critical to the operation effectiveness and cost. Thus, the purpose of this study is to investigate the wrinkle-resistance of 100% cotton light-weight woven fabric with different resin treatment conditions, and then to evaluate tearing strength and dimensional stability of the resin treated cotton woven fabrics. This study is expected to help optimize the resin treatment parameters related to better results with 100% cotton light-weight woven fabric. The novelty of this work is to study the relationship between different resin finishing treatment parameters (resin concentration, pick-up, drying time and curing temperature) and the final performance of 100% cotton light-weight woven fabric, which is commonly used in fashion and textile products, after it has been treated like this.

2. Experimental

2.1. Fabric

100% cotton woven fabric was used (supplied by Lai Tak Enterprises Limited, Kowloon, Hong Kong) with a fabric weight of 125.3 g/m^2. The fabric density was 140 yarns per inch and 76 yarns per inch in warp and weft directions, respectively. Yarn count for both warp and weft yarns was 13 Tex. The fabric was conditioned at 20 ± 2 °C and 65 ± 2% relative humidity for at least 24 h before using.

2.2. Resin Treatment

Commercially available resin—modified DMDHEU with self-catalysing crosslinking system (supplied by DyStar, Kowloon, Hong Kong)—was used without further purification. The resin treatment on cotton woven fabric is based on the pad-dry-cure process, and Table 1 shows the resin treatment parameters used in this study. After resin treatment, the fabrics were conditioned at 20 ± 2 °C and 65 ± 2% relative humidity for at least 24 h before evaluation.

Table 1. Resin treatment parameters.

Process	Parameters	Variable
Pad	Concentration DMDHEU (g/L) *	30, 45, 60 **
Pad	Pick-up (%)	60, 70, 80 ***
Dry	Drying temperature (°C)	110, 120
Cure	Curing temperature (°C)	150
Cure	Curing time (minutes)	2, 2.5, 3

* pH of resin solution is adjusted to approximately 4.5–5 by acetic acid (60%). ** E.g., 30 g/L means dissolve 30 g DMDHEU in 1 L of water. *** E.g., if the original weight of dry fabric is 100 g, 60% pick–up means we added 60% of the chemical based on the dry weight of fabric before padding. After padding, the wet fabric weight will be 160 g.

2.3. Fabric Recovery Angle

The fabric recovery angle was measured by AATCC Test Method 66–2014 (Wrinkle Recovery of Woven Fabrics: Recovery Angle) using a wrinkle recovery angle tester (Daiei Kagaku Seiki Ltd, Kyoto, Japan). The recovery angle of untreated fabric was 82.3°.

2.4. Fabric Appearance

The wrinkle recovery of fabric was evaluated by fabric appearance. This property was evaluated by AATCC Test Method 128–2013 (Wrinkle Recovery of Fabrics: Appearance Method) using an AATCC Wrinkle Tester (James H. Heal & Co. Ltd, Halifax, UK). The appearance was rated by AATCC Wrinkle Recovery Replicas ratings were defined as Grade 1, Grade 2, Grade 3, Grade 4 or Grade 5, in which Grade 5 represents the smoothest appearance and best retention of original appearance while Grade 1 represents the poorest appearance and poorest retention of original appearance. There are 3 specimens in a set and 3 judgments for giving a grade. For reporting the result, the grades were averaged to the nearest tenth of a rating. The fabric appearance grading of untreated fabric was Grade 1.

2.5. Smoothness of Fabric Appearance after Repeated Home Laundering

The smoothness of fabric appearance after repeated home laundering was evaluated by AATCC Test Method 124–2014 (Smoothness Appearance of Fabrics after Repeated Home Laundering). The washing mode was set at "Permanent Press" with washing temperature of 41 ± 3 °C, tumble dried after washing. The specimens were washed for five cycles and the smoothness was assessed after the 1st, 3rd and 5th washing cycles. The smoothness was rated by AATCC 3-D smoothness appearance replica Ratings were defined as Grade 1, Grade 2, Grade 3, Grade 4 or Grade 5, in which Grade 5 represents a very smooth, pressed and finished appearance, while Grade 1 represents a crumpled, creased and severely wrinkled appearance. A set of specimens had 3 specimens and 3 judgments for giving a grade. For reporting the result, the grades were averaged to the nearest tenth of a rating. The grading of smoothness of fabric appearance after repeated home laundering of untreated fabrics after the 1st, 3rd and 5th washing cycles were all Grade 1.

2.6. Tearing Strength

The tearing strength of the woven fabric was determined by BS EN ISO 13937-1:2000 (Tear Properties of Fabrics, Determination of Tear Force, using Ballistic Pendulum Method (Elmendorf)) by a pendulum testing machine (James H. Heal & Co. Ltd, Halifax, UK).

2.7. Dimensional Stability

The dimensional stability of the fabric was evaluated by AATCC Test Method 96-2012 (Dimensional Changes in Commercial Laundering of Woven and Knitted Fabrics Except Wool). The length and width of the three reference benchmarks on each specimen were averaged. The average length and width of the three specimens for a set of samples would then be averaged. For analyzing the result, percentage change in area dimensional change was evaluated. By evaluating the area dimensional change, effect of both width and length was evaluated.

3. Results and Discussions

3.1. Fabric Recovery Angle

Table 2 summarizes the fabric recovery angles of all fabric samples treated under different combinations of treatment parameters. The greater the fabric recovery angle, the better the fabric recovery. The recovery angle of the untreated fabric is 82.3° in this study. Our data shows that the cotton fabric samples treated under different conditions achieved better fabric recovery than untreated cotton fabric.

Table 2. Fabric recovery angle.

Pick-Up (%)	Dry Temperature (°C)	Curing Time (Minutes)	Resin Concentration (g/L)		
			30	**45**	**60**
60	110	2	88.2	98.0	113.8
		2.5	96.0	103.0	100.3
		3	100.0	110.8	114.2
	120	2	87.5	93.5	108.7
		2.5	95.7	103.7	110.5
		3	100.0	100.0	107.0
70	110	2	94.3	105.3	111.8
		2.5	97.3	105.3	105.8
		3	95.0	102.3	116.5
	120	2	102.2	106.2	111.3
		2.5	98.0	104.8	115.8
		3	96.5	97.3	117.0
80	110	2	96.2	104.0	116.8
		2.5	98.7	103.0	110.3
		3	96.5	109.8	119.2
	120	2	96.7	102.2	114.0
		2.5	99.2	109.2	117.0
		3	101.2	111.7	122.7

3.1.1. Effect of Resin Concentration

Table 2 shows the changes in recovery angles due to the change of resin concentration. It is noted that with the same drying temperature, curing time and pick-up, the recovery angle increases when the resin concentration increases. There is a trend that with a higher resin concentration, the resin treated fabric samples have a higher recovery angle when other parameters remain constant. It shows that resin concentration improves the wrinkle recovery performance of the 100% cotton light-weight woven fabric.

3.1.2. Effect of Pick-Up

Table 2 shows the changes in recovery angle due to the change of pick-up and it illustrates that with the same drying temperature, curing time and resin concentration, the recovery angle increases when pick-up increases. There is a general trend that for a higher pick-up, the resin treated fabric samples have a higher recovery angle with other parameters being kept constant. It shows that pick-up improves the wrinkle recovery performance of the 100% cotton light-weight woven fabric.

3.1.3. Effect of Curing Time

Table 2 also shows that with the same drying temperature, resin concentration and pick-up, the recovery angle increases when the curing time increases in general. There is a general trend that for a longer curing time, the resin treated fabric samples have a higher recovery angle when other parameters are kept constant. The trend is a lot more remarkable when the data of a 2 min curing time and a 3 min curing time are directly compared. It shows that curing time improves the wrinkle recovery performance of the 100% cotton light-weight woven fabric.

3.1.4. Effect of Drying Temperature

Table 2 shows that with the same pick-up, resin concentration and curing time, the recovery angle increases when the curing time increases in general. There is a general trend that for a higher drying temperature, the resin treated fabric samples have a higher recovery angle when other parameters are kept constant. It shows that drying temperature improves the wrinkle recovery performance of the 100% cotton light-weight woven fabric.

3.1.5. Summary on Fabric Recovery Angle

In the case of recovery angle evaluation, our data has shown that higher resin concentration, higher pick-up, higher drying temperature and longer curing time lead to better performance and a higher wrinkle recovery angle (Untreated: 82.3°; Resin-treated: ranged from 88° to 119°). Compared with the untreated fabric, all fabrics that have been treated by the resin have a significant improvement in the recovery angle of the 100% cotton light-weight woven fabric. Therefore, the crosslinking effect introduced by the resin can improve the recovery angle due to restricted cellulose molecular chain movements under the testing condition.

3.2. Fabric Appearance

Table 3 summarizes the wrinkled appearance of all fabric samples treated under different combinations of treatment parameters. The greater the grade, the less wrinkled the appearance. The wrinkled appearance of untreated fabric is grade 1.5 in this study. It is obvious that the cotton fabric samples treated under different conditions achieve a less wrinkled appearance than untreated cotton fabric

Table 3. Fabric appearance.

Pick-Up (%)	Dry Temperature (°C)	Curing Time (Minutes)	Resin Concentration (g/L)		
			30	**45**	**60**
60	110	2	2.5	2.5	2.7
		2.5	2.5	2.5	2.7
		3	2.5	2.7	3.0
	120	2	2.5	2.5	3.0
		2.5	2.5	2.7	2.3
		3	2.5	2.5	2.8
70	110	2	2.5	2.7	2.5
		2.5	2.3	2.7	2.5
		3	2.7	2.7	2.7
	120	2	2.5	2.5	2.5
		2.5	2.3	2.5	2.5
		3	2.3	2.7	3.2
80	110	2	2.7	2.8	2.8
		2.5	2.7	2.7	2.8
		3	2.7	2.5	2.8
	120	2	2.5	2.5	3.3
		2.5	2.3	2.7	3.7
		3	2.2	2.7	2.7

3.2.1. Effect of Resin Concentration

Table 3 shows that with the same drying temperature, curing time and pick-up, the smoothness appearance of the fabric is better when resin concentration increases. There is a trend that a higher resin concentration yields a better performance in wrinkle recovery of the resin-treated fabric samples when other parameters are kept constant. It shows that resin concentration improves the wrinkle recovery performance of the surface of 100% cotton light-weight woven fabric.

3.2.2. Effect of Pick-Up

Table 3 shows that with the same drying temperature, curing time and resin concentration, smoothness appearance is better when pick-up increases. There is a general trend that a higher pick-up provides better smoothness appearance to the resin-treated fabric samples when other parameters are kept constant. It shows that pick-up improves the wrinkle recovery performance of the surface of the 100% cotton light-weight woven fabric.

3.2.3. Effect of Curing Time

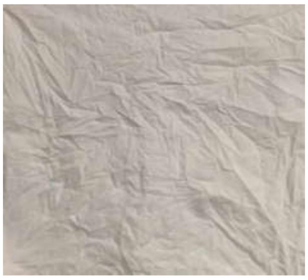
Table 3 shows that with the same drying temperature, pick-up and resin concentration, the wrinkle recovery grading increases or decreases when curing time increases. There is no trend showing that a longer curing time improves or worsens wrinkle recovery of the resin treated fabric samples when other parameters are kept constant. It shows that curing time has a limited effect on the wrinkle recovery of the 100% cotton light-weight woven fabric.

3.2.4. Effect of Drying Temperature

Table 3 shows that with the same resin concentration, pick-up and curing time, there is a slight increase in wrinkle recovery grading when the drying time increases in general. There is a general trend that a higher drying temperature means better performance of the resin-treated fabric samples in terms of smoothness appearance when other parameters are kept constant. It shows that drying temperature improves the smoothness appearance of the 100% cotton light-weight woven fabric.

3.2.5. Summary on Fabric Appearance

Compared with the untreated fabric, all resin-treated fabric samples have a significance improvement in smoothness appearance (Untreated fabric: Grade 1; resin-treated fabric: Grade 2 to Grade 3) (as shown in Figure 1). Our data has shown that resin treatment can improve the smoothness appearance performance of the 100% cotton light-weight woven fabric.


(**a**)


(**b**)

Figure 1. Fabric appearance: untreated (**a**) and resin-treated (**b**).

However, because of the similar performance and closely graded results (mostly about Grade 2 to Grade 3), contrast between effects of changes of the treatment parameters is not strong.

In assessing the fabric appearance, it can be concluded that with higher resin concentration, higher pick-up and higher drying temperature, the fabric samples have better performance in wrinkle recovery grading. We have also shown that the effect of curing time on wrinkle recovery grading is limited. This may be because the fabric being used in this study is thin and light in weight. Two minutes is long enough for the resin to carry out crosslinking reaction at a high curing temperature. Saturation of the reaction is nearly reached in two minutes curing time. Therefore, a longer curing time may not encourage more crosslinking reaction to improve the wrinkle recovery grading. However, the experimental results proved that the resin used in this study can introduce crosslinking effects so that the cellulose molecular chain moments are restricted under the testing conditions, withno adverse effect in the fabric appearance.

3.3. Smoothness of Fabric Appearance after Repeated Home Laundering

Smoothness appearance after home laundering is a key characteristic of an easy care garment. For a fabric which has come under repeated laundering, laundering creases are formed. Laundering creases are an unintended result of laundering. These are folds and lines running without any specified direction on a washed fabric. A shirting fabric with good smoothness appearance after home laundering is always preferable. AATCC Test Standard 124 Smoothness Appearance of Fabrics after Repeated Home Laundering was the standard used to evaluate the smoothness appearance after repeated home laundering for flat fabric specimens. The results for the AATCC Test Method 124 were generated according to the standard method. Results were taken after the 1st, 3rd and 5th washing cycle.

3.3.1. Effect of Repeated Home Laundering

Table 4 shows the grading of smoothness appearance after the 1st, 3rd and 5th washing and drying cycles. It shows that with the same drying temperature, pick-up, curing time and resin concentration, grading of smoothness appearance decreases when the number of washing cycles increases. There is a trend that for resin-treated specimens, the greater the number of washing and drying cycles of the specimens, the lower the grading on smoothness appearance when other parameters are kept constant. Wrinkle resistance effect of the resin was reduced by a certain degree after repeated laundering. It shows that repeated home laundering negatively affects smoothness appearance performance of the 100% cotton light-weight woven fabric.

Table 4. Smoothness of fabric appearance grading (Grade 5 is the best while 1 is the worst).

Pick-Up (%)	**Dry Temperature (°C)**	**Curing Time (Minutes)**	**Resin Concentration (g/L)**								
			30			**45**			**60**		
			Washing Cycle								
			1	**3**	**5**	**1**	**3**	**5**	**1**	**3**	**5**
60	110	2	2.3	2.0	2.0	3.0	3.0	2.3	2.3	2.3	2.3
		2.5	2.3	2.7	2.0	3.0	2.3	2.0	3.0	3.0	2.3
		3	2.3	2.3	2.3	3.2	2.7	2.0	2.7	2.7	2.7
	120	2	3.0	3.0	2.7	3.0	2.7	2.3	3.0	2.7	2.7
		2.5	3.0	3.0	2.7	3.0	3.0	2.7	3.0	3.0	3.0
		3	3.0	2.7	2.3	3.0	2.7	2.7	3.2	3.0	2.7
70	110	2	3.0	2.7	2.0	3.0	3.0	2.7	3.0	3.0	3.0
		2.5	2.7	2.3	2.0	3.0	2.7	2.7	3.0	3.2	3.0
		3	3.0	2.7	2.3	3.0	2.3	2.3	3.0	3.0	3.0
	120	2	2.7	2.3	2.7	2.7	2.3	2.7	3.0	3.0	3.0
		2.5	3.0	3.0	2.7	2.7	2.7	2.3	3.0	2.7	2.3
		3	3.0	2.0	2.3	3.0	2.7	2.7	3.2	3.2	3.0
80	110	2	3.0	2.7	2.7	3.0	3.0	3.0	3.2	3.0	3.0
		2.5	3.0	2.7	2.3	3.0	2.7	2.0	3.0	2.7	3.0
		3	3.0	3.0	2.0	3.2	3.0	2.7	3.2	3.0	3.0
	120	2	3.0	2.3	2.3	3.0	3.0	2.3	3.0	3.0	3.0
		2.5	3.0	2.7	2.0	3.0	3.0	2.7	3.3	3.2	3.0
		3	3.0	2.7	2.0	3.0	3.0	2.3	3.2	3.0	3.0

3.3.2. Effect of Resin Concentration

Table 4 shows the differences in smoothness appearance due to changes in resin concentration. It shows that with the same drying temperature, curing time, pick-up and number of washings, the smoothness appearance improves when the resin concentration increases. There is a trend that a higher resin concentration provides a better smoothness appearance performance when other parameters are kept constant. It shows that resin concentration improves the smoothness appearance of the 100% cotton light-weight woven fabric.

3.3.3. Effect of Pick-Up

Table 4 summarises the differences in smoothness appearance due to the change of pick-up. It shows that with the same drying temperature, curing time and resin concentration, the smoothness appearance improves when pick-up increases. There is a general trend that a higher pick-up means the resin-treated specimens would have a higher grading on smoothness appearance when other parameters are kept constant. It shows that pick-up improves the smoothness appearance performance of the 100% cotton light-weight woven fabric.

3.3.4. Effect of Curing Time

Table 4 shows the differences in smoothness appearance due to changes in curing time. It shows that with the same drying temperature (110 °C), pick-up and resin concentration, the wrinkle recovery grading increases slightly when curing time increases. There is no trend showing that a longer curing time leads to a better performance in smoothness appearance grading when the other parameters are kept constant. It shows that curing time has limited to no effect on the smoothness appearance grading after repeated home laundering of the 100% cotton light-weight woven fabric.

3.3.5. Effect of Drying Temperature

Table 4 shows the smoothness appearance performance of the resin-treated fabric samples according to the drying temperature at which they have been treated. It shows that, generally, the fabric samples which have been treated at higher drying temperature have better smoothness appearance performance. Meanwhile, the fabric samples which have been treated at higher drying temperature have more stable grading. It shows that drying temperature improves the smoothness appearance and stabilizes the performance of the 100% cotton light-weight woven fabric.

3.3.6. Summary of Smoothness of Fabric Appearance after Repeated Home Laundering

Compared with the untreated fabric (smoothness appearance rating is Grade 1), all fabric samples subjected to resin treatment with any combination of parameters have a significant improvement in smoothness appearance. It is clear that the resin treatment improves the smoothness appearance after repeated home laundering on the 100% cotton light-weight woven fabric.

The result and trend of AATCC Test Method 124 Smoothness Appearance of Fabrics after Repeated Home Laundering (untreated fabric: Grade 1; resin-treated fabric: Grade 2 to Grade 3) is similar to the result of AATCC Test Method 128 (untreated fabric: Grade 1; resin-treated fabric: Grade 2 to Grade 3.5). This is because the numerical difference between the grading is not large and the performances are closely graded (mostly about Grade 2 to Grade 3.5). The contrasts between results based on the change of the parameters are not so strong. Therefore, some effects of the change in treatment parameters are not as remarkable as in the other test method. However, some trends could still be shown. With the resin treatment, the resin will crosslink the cellulose molecules in cotton. Thus, when even laundering was conducted, the cellulose molecules could not shift their position easily and so the shape of fabric could be retained. Therefore, both AATCC Test Methods 124 and 128 have similar results.

In the AATCC Test Method 124 Smoothness Appearance of Fabrics after Repeated Home Laundering, it can be seen that with higher resin concentration, higher pick-up and higher drying temperature, the fabric samples have better performance in smoothness appearance grading. It is also shown that the effect of curing time on the smoothness appearance is limited. It may be because the fabric being studied in this project is thin and light in weight. 2 min is long enough for the resin to carry out crosslinking reaction at the high curing temperature.

3.4. Tearing Strength (BS EN ISO 13937-1)

The resin-treated 100% cotton light-weight woven fabric loses strength because of the strong acidic conditions and high temperature during processing. Even though wrinkle resistance is preferable for garments, the loss of tearing strength is not desired. Therefore, it is of great importance to control the loss of tearing strength due to the resin treatment.

The result for the Standard Testing BS EN ISO 13937-1 was generated according to the standard method. The tearing resistance of each of the ten specimens was calculated in warp and weft directions. For analyzing the result, all warp readings and weft readings were averaged separately.

3.4.1. Difference between Warp and Weft

Table 5 shows the difference between tearing strength in warp and weft direction of the fabric samples. It is shown that with the same drying temperature, resin concentration (30 g/L), pick-up and curing time, the warp direction has better tearing strength than the weft direction. This difference is seen in the untreated fabric also. Most of the resin-treated fabrics show similar results. Therefore, it can be concluded that the warp direction has a better tearing strength than the weft direction.

Table 5. Relationship between warp and weft in tearing strength.

Curing Time (Minutes)	Drying Temperature (°C)	Pick-Up (%)					
		60		70		80	
		Warp	Weft	Warp	Weft	Warp	Weft
2	110	6.4	4.9	5.7	4.7	6.2	4.9
	120	6.3	4.7	6.4	4.4	6.7	4.8
2.5	110	6.4	4.7	6.0	4.4	6.1	4.8
	120	6.2	5.1	6.0	4.8	6.8	5.2
3	110	6.4	4.7	5.9	4.7	6.4	4.3
	120	5.2	5.1	6.3	4.9	6.3	5.2

Remark: Untreated: Warp = 8.3 N; Weft = 6.2 N.

3.4.2. Effect of Drying Temperature

The differences between tearing strength of fabric samples dried at 110 °C and 120 °C are shown in Table 6. It is shown that when resin concentration (45 g/L), pick-up and curing time are the same, specimens dried at 120 °C have poorer tearing resistance than the specimens dried at 110 °C. There is a trend that a longer higher drying temperature leads to a lower tearing strength with the other treatment parameters being kept constant. It shows that drying temperature lowers the tearing strength of the 100% cotton light-weight woven fabric.

Table 6. Relationship between drying temperature, curing time, pick-up and tearing strength.

Curing Time (Minutes)	Drying Temperature (°C)	Pick-Up (%)					
		60		70		80	
		Warp	Weft	Warp	Weft	Warp	Weft
2	110	6.1	4.9	6.0	4.6	5.6	4.3
	120	5.7	4.5	5.5	4.2	5.4	3.9
2.5	110	5.9	4.7	5.8	4.5	5.5	4.2
	120	5.5	4.5	5.4	4.2	4.9	3.9
3	110	5.9	4.5	5.6	4.4	5.4	3.8
	120	5.4	4.1	5.0	4.0	4.7	3.6

Remark: Untreated: Warp = 8.3 N; Weft = 6.2 N.

3.4.3. Effect of Curing Time

Table 6 shows the differences between tearing strength due to the change of curing time. It is shown that with the same drying temperature, resin concentration (45 g/L) and pick-up, the tearing strength decreases when the curing time increases. There is a trend that a longer curing time means a lower tearing strength with the other parameters kept constant. The trend is a lot more remarkable when directly comparing the data of 2 min curing time with 3 min curing time. It shows that curing time can cause a decrease in tearing strength of the 100% cotton light-weight woven fabric.

3.4.4. Effect of Resin Concentration

The changes in tearing resistance due to the change of resin concentration are shown in Table 7 in which with the same drying temperature, curing time and pick-up (60%), the tearing strength decreases when the resin concentration increases. There is a general trend that a higher resin concentration results in lower tearing strength with the other parameters kept constant. It shows that resin concentration lowers the tearing strength of the 100% cotton light-weight woven fabric.

Table 7. Relationship between resin concentration and tearing strength.

Curing Time (Minutes)	Drying Temperature (°C)	Resin Concentration (g/L)					
		30		45		60	
		Warp	Weft	Warp	Weft	Warp	Weft
2	110	6.4	4.9	6.1	4.9	6.1	4.0
	120	6.3	4.7	5.7	4.5	5.2	3.6
2.5	110	6.4	4.7	5.9	4.7	5.2	4.3
	120	6.2	5.1	5.5	4.5	5.4	4.1
3	110	6.4	4.7	5.9	4.5	4.8	4.0
	120	5.2	5.1	5.4	4.1	5.4	4.0

Remark: Untreated: Warp = 8.3 N; Weft = 6.2 N.

3.4.5. Effect of Pick-Up

Table 6 shows the change in tearing strength due to the change of pick-up percentage. It showsthat with the same drying temperature, curing time and resin concentration (45 g/L), the tearing strength decreases when the pick-up increases. There is a general trend that a higher pick-up causes a lower tearing strength with the other parameters kept constant. It shows that pick-up lowers the tearing strength of the 100% cotton light-weight woven fabric.

3.4.6. Summary on Tearing Strength (BS EN ISO 13937-1)

Compared with the untreated fabric, all fabric samples treated by the resin were found to have a significant reduction of tearing strength. It is shown that resin treatment causes loss of tearing strength of 100% cotton light-weight woven fabric. Additionally and specifically, higher resin concentration, higher pick-up, higher drying temperature and longer curing time have adverse effects on tearing strength of 100% cotton light-weight woven fabric. Due to the crosslinking effect introduced by the resin, which restricts cellulose molecular chain moments, the flexibility of the 100% cotton light-weight woven fabric is weaker and thus the fabric becomes easy to be torn under the testing condition.

3.5. Dimensional Stability

Dimensional stability is the property that represents the ability of a fabric to retain the original dimension after certain processes such as laundering. The dimensional stability can be determined by the dimensional change. There are two types of dimensional changes, i.e., growth and shrinkage. Growth is the dimensional change because of an increase in length or width of the specimen. Shrinkage is the dimensional change because of a decrease in length or width of the specimen.

3.5.1. Effect of Warp and Weft

Table 8 shows the dimensional changes in percentage in the warp and weft directions after 5 washing cycles. It is shown that with same resin concentration (30 g/L), the same drying temperature, curing time and pick-up, there is an increase in dimension in the weft direction but a decrease in the warp direction. There is a trend that the warp direction has a negative dimensional change and the weft direction hasa positive dimensional change. It shows that there is a “Growth” effect in the weft direction and a “Shrinkage” effect in the warp direction. During the weaving process, the warp yarn is under tension because it has to be kept straight. However, though weft yarn is also straight when it is inserted, it crimps when it is beaten up. When wetted, the high-tension warp yarn relaxes and crimp. This is relaxation shrinkage. The yarns re-adjust themselves for this shrinkage. Therefore, the crimping shortens the fabric in the warp direction. There is also relaxation shrinkage on the weft yarn. However, the crimping effect is much smaller. As a result, after washing, there is a significant negative dimensional change in percentage in the warp direction.

Table 8. Relationship between warp and weft in dimensional change (%).

Curing Time (Minutes)	Drying Temperature (°C)	Pick-Up (%)					
		60		70		80	
		Warp	Weft	Warp	Weft	Warp	Weft
2	110	−1.6	1.3	−1.6	0.5	−1.3	0.5
	120	−0.8	0.5	−0.5	−0.5	−0.6	0.5
2.5	110	−1.3	1.2	−1.2	1.1	−1.5	0.6
	120	−0.7	0.6	−0.4	0.6	−0.5	0.5
3	110	−1.2	0.8	−1.3	0.8	−1.5	0.4
	120	−0.8	0.7	−0.5	0.8	−0.8	0.6

Remark: Untreated: Warp = −1.6%; Weft = 0.7%.

For the weft yarn, the relaxation shrinkage effect is much smaller. Therefore, the reduction in length is not significant. Meanwhile, the increase in length in the weft direction is because of the hygral expansion of the cotton fiber. This is a process in which the fiber swells when moisture is absorbed. The hygral expansion behavior depends largely on the magnitude of the weave crimp. The effect of weave construction on the fabric hygral expansion is very small at high moisture regains. At low regains, plain-weave fabrics tend to show slightly higher expansion than corresponding twill structures of similar crimp magnitude [27,28].

3.5.2. Effects of Repeated Laundering

Table 9 shows the percentage of area change after the 1st and the 5th laundering cycle. It shows that with the same resin concentration (30 g/L), same drying temperature, curing time and pick-up, there is a reduction in dimensional changes with the number of launderings. For fabric samples which have growth in the 1st laundering, the degree of growth reduces, or even becomes shrinkage. For fabric samples which have shrinkage in the 1st laundering, the degree of shrinkage increases further. It shows that repeated laundering causes a reduction in percentage of area change in the dimensional changes of the 100% cotton light-weight woven fabric. The results show there is progressive shrinkage of the fabric. Progressive shrinkage is shrinkage which increases with the number of laundering cycles.

3.5.3. Effect of Resin Concentration

Table 10 shows the percentage dimensional changes in area due to the change of resin concentration. It is shown that with the same drying temperature, curing time and pick-up (60%), the dimensional changes are smaller when the resin concentration increases. There is a trend that a higher resin concentration leads to a better dimensional stability with the other parameters kept constant. It shows that resin concentration improves the dimensional stability of the 100% cotton light-weight woven fabric [29].

Table 9. Relationship between number of laundering, pick-up, drying time, curing time and percentage of area change (%).

Curing Time (Minutes)	Drying Temperature (°C)	Pick-Up (%)					
		60		70		80	
		1 Washing Cycle	5 Washing Cycle	1 Washing Cycle	5 Washing Cycle	1 Washing Cycle	5 Washing Cycle
2	110	0	−0.3	0.2	−1.1	0.3	−0.8
	120	0.4	−0.3	0.5	0	0.4	−0.1
2.5	110	0	−0.2	0.1	−0.2	0.3	−0.8
	120	0.4	−0.1	0	0.2	0.3	0
3	110	0	−0.4	0.4	−0.5	0.6	−1.0
	120	0.4	−0.1	0.8	0.3	0	−0.2

Remark: Untreated: 1 washing cycle = −0.9%; 5 washing cycle = −1.5%.

Table 10. Relationship between resin concentration and dimensional change in area.

Curing Time (Minutes)	Drying Temperature (°C)	Resin Concentration (g/L)					
		30		45		60	
		1 Washing Cycle	5 Washing Cycle	1 Washing Cycle	5 Washing Cycle	1 Washing Cycle	5 Washing Cycle
2	110	0	−0.3	0.2	−0.2	−0.3	−0.2
	120	0.4	−0.3	0.1	0.1	−0.1	−0.4
2.5	110	0	−0.2	−0.2	−0.4	−0.1	0
	120	0.4	−0.1	−0.4	0	−0.3	−0.2
3	110	−0.1	−0.4	0.2	−0.7	−0.3	−0.2
	120	0.4	−0.1	−0.3	0.1	0.4	0.3

3.5.4. Effect of Pick-Up

Table 9 illustrates the percentage dimensional changes in area due to the change of pick-up. It shows that with the same drying temperature, curing time and resin concentration, the percentage dimensional changes can increase or decrease when pick-up increases. A higher pick-up may result in a better or lower performance in dimensional stability with other parameters kept constant. It shows that pick-up has limited effect on the dimensional stability of the 100% cotton light-weight woven fabric.

3.5.5. Effect of Drying Temperature

The percentage dimensional changes in area due to the change of drying temperature are shown in Table 9. It shows that with the same pick-up, curing time and resin concentration, the percentage dimensional changes are smaller when the drying temperature increases when compared with untreated fabric. There is a general trend that drying temperature helps a better performance in dimensional stability in general with other parameters kept constant. It shows that drying temperature improves the dimensional stability of the 100% cotton light-weight woven fabric.

3.5.6. Effect of Curing Time

The percentage dimensional change in area due to the change of curing time is shown in Table 9. It shows that with the same drying temperature, pick-up and resin concentration, the percentage dimensional changes increase or decrease when curing time increases. There is no trend showing that a longer curing time causes a better or worse performance in dimensional stability with other parameters kept constant. It shows that curing time has limited to no effect on dimensional stability of the 100% cotton light-weight woven fabric.

3.5.7. Summary on Dimensional Stability

Compared with the untreated fabric, all fabric samples with resin treatment under any parameters have a significance improvement in dimensional stability. It is shown that resin treatment can improve the dimensional stability of the 100% cotton light-weight woven fabric.

The dimensional changes are small (most are smaller than 1%) and that is why the contrasts of results based on the change of the parameters is not strong. Therefore, some effects of changing of the treatment parameters are not as remarkable.

In the dimensional stability study, it has been shown that with higher resin concentration and higher drying temperature, the fabric samples have better performance. Meanwhile, the effect of pick-up on dimensional stability is limited. It is also shown that the effect of curing time on dimensional stability is limited. This may be because the fabric being studied is thin and light in weight. 2 min is long enough for the resin to carry out crosslinking reaction at a high curing temperature. With the use of resin in the treatment, the crosslinking effect introduced by the resin—which is restricting cellulose molecular chain moments and hence the molecular chains in the cotton fabric—has less significance under the testing conditions. Therefore, the dimensional stability improved.

4. Conclusions

In this study, effects of different resin treatment parameters including resin concentration, pick-up, drying temperature and curing time were explored. The results show that there are enhancements in wrinkle recovery, smoothness appearance and dimensional stability of the 100% cotton light-weight woven fabric after resin treatment. The results show that with higher resin concentration, higher pick-up and higher drying temperature, the fabric samples have better performance in terms of wrinkle recovery angle, smoothness appearance and dimensional stability. Nevertheless, the effect of curing time is insignificant for light-weight cotton fabric after resin treatment. On the other hand, compared with the untreated fabric, all fabric samples treated by the resin displayed a significant reduction in tearing strength. This may show that with higher resin concentration, higher pick-up, higher drying temperature and longer curing time, the 100% cotton light-weight woven fabric has poorer performance in terms of tearing strength.

For manufacturers, effectiveness and cost of the treatment are the main concerns. Lower usage of chemicals and energy minimizes the manufacturing cost. At the same time, customers look to purchase durable, easy-care shirts. Therefore, in balancing serviceability, production cost and durability of a shirting fabric, an optimum condition of wrinkle-resistant treatment should be studied further in the future.

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References

1. Bakhodir, A.; Rustam, A.; Ashurovich, O.T.; Bakhtiyarovna, U.R. Changes in the physical and mechanical properties of shirt fabrics with different fiber content. In Proceeding of the International Conference on Research Innovation in Multidisciplinary Sciences, Online, 6–7 March 2021; pp. 227–232.
2. Nawab, Y. *Textile Engineering: An Introduction*; Nawab, Y., Ed.; De Gruyter Oldenbourg: Berlin, Germany, 2016.
3. Deshmukh, A.S.; Mohanty, A. Cotton mechanisation in India and across globe: A review. *Int. J. Adv. Res. Eng. Sci. Technol.* **2016**, *3*, 66.
4. Kan, C. *A Novel Green Treatment for Textiles: Plasma Treatment as a Sustainable Technology*; CRC Press: Boca Raton, FL, USA, 2015.
5. Jagadeesh, P.; Puttegowda, M.; Boonyasopon, P.; Rangappa, S.M.; Khan, A.; Siengchin, S. Recent developments and challenges in natural fiber composites: A review. *Polym. Compos.* **2022**, *43*, 2545–2561. [CrossRef]
6. Luo, X.; Cheng, P.; Wang, W.; Fu, J.; Gao, W. Established an eco-friendly cotton fabric treating process with enhancing anti-wrinkle performance. *J. Eng. Fibers Fabr.* **2021**, *16*, 15589250211003454. [CrossRef]
7. Hu, H.; Dong, X.; Zhao, Q.; Wu, R.; Meng, C.; Xu, J.; He, J. Novel Strategy to fabricate Antiwrinkle Cotton fabrics with 1, 2, 3, 4-Butanetetracarboxylic Acid under a Low Temperature. *ACS Omega* **2022**, *7*, 30093–30103. [CrossRef]
8. Wang, K.; Fu, C.; Wang, R.; Tao, G.; Xia, Z. High-resilience cotton base yarn for anti-wrinkle and durable heat-insulation fabric. *Compos. Part B Eng.* **2021**, *212*, 108663. [CrossRef]
9. Peng, H.; Zhang, P.; Xie, J.; Zhang, Z.; Cao, X. Properties of cotton fabrics treated by etherification and esterification and esterification/addition crosslinking with an amino-functional silicon softener. *Cellulose* **2021**, *28*, 7341–7354. [CrossRef]
10. Ibrahim, H.M. *Textiles: History, Properties and Performance and Applications*; Nova Science Publishers: Hauppauge, NY, USA, 2014.
11. Shahin, U.; Gursoy, N.; Hauser, P.; Smith, B. Optimization of ionic crosslinking process: An alternative to conventional durable press finishing. *Text. Res. J.* **2009**, *79*, 744–752. [CrossRef]
12. Lacasse, K.; Baumann, W. *Textile Chemicals: Environmental Data and Facts*; Springer: Berlin, Germany, 2004.
13. Bajaj, P. Finishing of textile materials. *J. Appl. Polym. Sci.* **2002**, *85*, 631–632. [CrossRef]
14. Andrews, B.; Simoneaux, J. Formaldehyde release and cellulose crosslinking with n-mathylol agents: A delicate balance. *Die Angew. Makromol. Chem.* **1983**, *115*, 115–117. [CrossRef]
15. Vali, S.; Arney, W. Reaction mechanisms of glyoxal-based durable-press resins with cotton. *Text. Res. J.* **1971**, *41*, 336–338. [CrossRef]
16. Ibrahim, N.A.; Abo-Shosh, M.; Elnagdy, E.; Gaffar, M. Eco-friendly durable press finishing of cellulose-containing fabrics. *J. Appl. Polym. Sci.* **2002**, *84*, 2243–2253. [CrossRef]
17. Dhiman, G.; Chakraborty, J.N. Assessment of durable press performance of cotton finished with modified DMDHEU and citric acid. *Fash. Text.* **2017**, *4*, 18. [CrossRef]
18. Huang, C.; Zhang, N.; Wang, Q.; Wang, P.; Yu, Y.; Zhou, M. Development of hydrophilic anti-crease finishing method for cotton fabric using alpha-Lipoic acid without causing strength loss and formaldehyde release problem. *Prog. Org. Coat.* **2021**, *151*, 106042. [CrossRef]
19. Eryuruk, S.H.; Kalaoğlu, F. The effect of weave construction on tear strength of woven fabrics. *Autex Res. J.* **2015**, *15*, 207–214. [CrossRef]
20. Sederavičiūtė, F.; Domskienė, J.; Jurgelionytė, L.; Sankauskaite, A.; Kimmer, D. Effect of DMDHEU treatment on properties of bacterial cellulose material. *Text. Res. J.* **2022**, *92*, 2580–2590. [CrossRef]
21. Koruycuc, A. Improving the breaking and tear strength of cotton fabric using BTCA and CA crosslinkers. *Çukurova Üniv. Mühendislik Fakültesi Derg.* **2021**, *36*, 1061–1072. [CrossRef]
22. Vimal, J.T.; Prakash, C.; Rajwin, A.J. Effect of weave parameters on the tear strength of woven fabrics. *J. Nat. Fibers* **2020**, *17*, 1239–1248. [CrossRef]
23. Hussain, T.; Ali, S.; Qaiser, F. Predicting the crease recovery performance and tear strength of cotton fabric treated with modified N-methylol dihydroxyethylene urea and polyethylene softener. *Color. Technol.* **2010**, *126*, 256–260. [CrossRef]
24. Tomasino, C. *Chemistry and Technology of Fabric Preparation and Finishing*; North Carolina State University: Raleigh, NC, USA, 1992.
25. Schindler, W.D.; Hauser, P.J. *Chemical Finishing of Textiles*; Elsevier: Amsterdam, The Netherlands, 2004.
26. Yan, Y.; Dong, Y.; Bian, L. Surface functionalization of cotton fabric with Ag_3PO_4 via citric acid modification using pad-dry-cure process for enhancing self-cleaning performance. *Cellulose* **2022**, *29*, 4203–4227. [CrossRef]
27. Dhingra, R.C.; Postle, R.; Mahar, T.J. Hygral expansion of woven wool fabrics. *Text. Res. J.* **1985**, *55*, 28–40. [CrossRef]
28. Fazal, M.Z.; Abbas, M.A.; Nawab, Y.; Younis, S. Machine learning approach for prediction of crimp in cotton woven fabrics. *Teh. Vjesn.* **2021**, *28*, 88–95.
29. Yang, R.H.; Kan, C.W. Investigation of wrinkle free treatment of 100% lightweight cotton plain fabric. *Ind. Text.* **2014**, *65*, 303–309.