IOP Conf. Series: Materials Science and Engineering **254** (2017) 192009 doi:10.1088/1757-899X/254/19/192009

Hemp Fiber for Furnishing Applications

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Abstract. The primary objective of the study was to compare and contrast the performance characteristics of 100% woven cotton and 100% woven hemp fabrics for furnishing applications. Results obtained showed no difference between cotton and hemp fabrics in terms of colorfastness to crocking; oily stain release; flammability; tearing strength; breaking strength and elongation. For colorfastness to light, the hemp fabrics in this study exhibited noticeable color change. With regard to colorfastness to water, hemp fabrics performed satisfactorily indicating that steam cleaning of hemp furnishing fabrics in this study is not a concern. For abrasion resistance, the performance of hemp fabrics was slightly less than the cotton fabrics in the study. In conclusion, based on test results and benchmark comparisons, this study indicates that hemp is a viable fiber for use in furnishing applications.

1. Introduction

Refined resources such as petroleum, which are currently used for manufacturing synthetic fibers are rapidly depleting. It is estimated that the supply of fossil fuels such as crude oil are only expected to last for another 50-60 years, with world conventional oil production peaking between 2021 and 2112 [1]. Moreover, manufacture of synthetic fibers is not a closed loop process meaning that by-products cannot be processed back into the production cycle. During production of synthetic fibers such as nylon or polyester, volatile monomers and solvents that contribute to water and air pollution are released into the atmosphere [2]. It is imperative, therefore, that professionals in the textile industry begin to consider alternative resources for raw material used for fiber. It is doubly crucial that while considering alternative resources; sustainable, renewable and less polluting natural fibers be considered for uses hitherto dominated by synthetic fibers.

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A possible solution to the current dilemma is the bast fiber, hemp. Hemp is often praised as being an excellent rotational crop, requiring little use of pesticides, and has the reputation of purifying soil contaminated with heavy metals. The goal of this investigation was to bring awareness to the possibility of using hemp for furnishing applications by benchmarking the results of standardized tests against another natural fiber; cotton. The investigation was guided by ASTM International and AATCC (American Association of Textile Chemists and Colorists) standards [3]. ASTM Performance Specifications Designation D 3597 lists all specifications for woven upholstery fabric, which were the guidelines to test the performance characteristics of 100% woven hemp fabrics [4]. Specific objectives were to compare and contrast the performance characteristics of 100% woven cotton and 100% woven hemp fabrics of different weave structures with regard to colorfastness to crocking, colorfastness to light, soil release, colorfastness to water, flammability, abrasion resistance, tearing strength, breaking strength and elongation.

2. Materials and Methods

The hemp and cotton fabrics consisted of three different weave structures: plain, twill, and modified twills. The color of the plain weave cotton and hemp fabrics were black. The color of the cotton twill fabric was red and the color of the hemp twill fabric was brown. The modified twill cotton fabric was navy blue and the modified twill hemp fabric was un-dyed.

The colorfastness to crocking of wet and dry samples were tested using AATCC Test Method 8.

For testing colorfastness to light, fabric samples were exposed in an Atlas Suntest XLS+ Weatherometer chamber with the following parameters: Black Standard Temperature (BST): 63°C; Phase time: 300 minutes; Irradiance: 500 W/m^2; final dosage of 9,000 KJ/m^2. Each specimen was laid flat, side by side, parallel to the machine (warp direction), and mounted to a white cardstock backing. Samples were compared and evaluated under fluorescent light using the AATCC Gray Scale for Color Change. A grade of 5 represents negligible color change and Grade 1 represents the most drastic color change.

AATCC Test Method 130 was used to measure the ability of a fabric to release oily stains during cleaning (laundering) and AATCC Test Method 107 was used to test colorfastness to water.

ASTM Test Method D 6413 was used to guide the flammability test for the woven upholstery fabrics. For testing abrasion resistance, ASTM Test Method D 3884 was followed. ASTM Test Method D 2261 (single rip procedure) guided tearing strength tests of hemp and cotton fabrics. To test breaking strength and elongation of hemp and cotton fabrics, ASTM Test Method D 5034 was used. Both wet and dry tests were conducted. For wet testing, test specimens were immersed in distilled water for approximately 15 minutes and were tested immediately afterward.

3. Results and Discussion

3.1. Colorfastness to crocking

The ratings for dry and wet crocking tests are listed in Table 1. A grade of 5 indicates negligible or no color transfer and a grade of 1 is the lowest rating on the AATCC Chromatic Transference Scale. Each grade represents an average of 5 samples. According to ASTM specification requirements D 3597, fabrics must attain a minimum acceptable grade of 4 for the dry crocking test and a minimum grade of 3 for wet crocking in order to be deemed suitable for upholstery fabric. The black hemp plain weave fabric did not pass the minimum requirement with a rating of 2.3 for dry and wet tests. Similarly, the cotton plain weave (black) fabric did not meet the minimum requirements with a grade of 3.0 for the dry test and 1.5 for the wet test. The brown hemp twill fabric met the minimum requirement with a grade of 4 for both dry and wet tests. In contrast, the red cotton twill fabric passed the dry crocking test but failed the wet crocking

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test with grades of 4 and 2.5, respectively. The modified twill hemp fabric was undyed; a grade for color evaluation is not available.

Table 1. Colorfastness to Crocking

	Hemp		*Cotton*	
	Dry	**Wet**	**Dry**	**Wet**
Plain	2.3	2.3	3.0	1.5
Twill	4.0	4.0	4.0	2.5
Modified twill	n/a*	n/a*	4.0	3.8

*The modified twill hemp fabric was undyed; color evaluation is not available.

3.2. *Colorfastness to light*

Fabric specimens were exposed for five hours under an artificial light source simulated by the Xenon-Arc Lamp. Color change was evaluated under fluorescent light in a color assessment cabinet. Colorfastness to light ratings for hemp and cotton fabrics are given in Table 2. A grade of 5 indicates negligible or no color change and a grade of 1 is the lowest rating on the AATCC Gray Scale for Color Change. Each grade represents an average of 5 samples.

Table 2. Colorfastness to Light

	Hemp	*Cotton*
Plain	2	4
Twill	1-2	4-5
Modified twill	n/a*	4-5

*The modified twill hemp fabric was undyed; color evaluation is not available.

According to ASTM specification requirements D 3597, upholstery fabrics must attain a minimum grade of 4 for colorfastness to light in order to pass. The results of the colorfastness to light tests indicate that hemp performed poorly, with a grade of 2 or lower, suggesting that the dyes used on hemp are more prone to color change than cotton. In contrast, the cotton fabrics had grades of 4-5 or higher, suggesting that the dyes used for cotton were more resistant to light than hemp. The AATCC test method for Colorfastness to Light states that the total color difference can be assessed by measuring samples on a spectrophotometer and comparing the results to a reference (control) sample. To confirm the visual assessment of color change for hemp and cotton fabrics, the total color difference was calculated using CIELAB L*a*b* values. For the black cotton plain weave fabric, the average value of ΔE was 1.16 whereas for the black plain weave hemp fabric had a total color change (ΔE) of 2.87. The brown twill hemp fabric had ΔE of 3.90, which indicates that it had the greatest amount of color change among all the tested fabrics. Total color change (ΔE) for the red cotton twill fabric was 0.93. The navy blue cotton (modified twill) fabric had a total color change of 0.66, which indicates that this fabric performed the best of the three cotton fabrics. Spectrophotometric data confirmed the results of visual assessment.

3.3. *Soil Release*

The grades for soil release of hemp and cotton fabrics obtained by using the AATCC Stain Release Replica are listed in Table 3. Each grade represents an average of 5 samples. Each of the cotton plain weave, twill, and modified twill fabrics and the plain, and twill hemp fabrics had a grade of less than 3. This indicates that all of these fabrics have poor resistance to oil stains and stain spots would be visible on the upholstery even after laundering. Only the modified twill hemp fabric had a rating higher than 3 and displayed good stain resistance.

Table 3. Soil Release: Oily Stain Release

	Hemp	*Cotton*
Plain	2.8	1.8
Twill	1.7	1.1
Modified twill	4.4	1.3

3.4. *Colorfastness to water*

For colorfastness to water evaluation, hemp and cotton fabrics were immersed in water for 15 minutes, passed once through a laboratory wringer, and stacked between plastic plates onto the perspiration tester. They were placed into a drying oven for 14 hours. Multi-fiber samples containing wool, rayon, silk, nylon, cotton, acetate, and polyester yarns were attached to each sample during wetting and drying. Color transfer was evaluated using the Gray Scale for Staining. A grade of 5 represents negligible or no color transfer and a grade of 1 is the most drastic color transfer. The grades reported in **Table 4** are the average of 5 samples. As shown in Table 4, the black hemp plain weave and brown hemp twill fabric had grades of 4 and higher on the Gray Scale for Staining. In contrast, the cotton fabrics had lower grades, particularly the red cotton twill fabric. The greatest amount of staining for the red cotton twill fabric occurred on rayon, cotton, and silk. Similarly, the navy blue cotton (modified twill) fabric had grades of 3 for staining on rayon and a grade of 3- 4 and 3 for staining on cotton. The black cotton plain weave fabric had grades of 4 or higher for staining on all fiber types with the exception of rayon, which received a grade of 3. Wool, acetate, and polyester were relatively unaffected by staining, with grades of 3-4 or higher for all hemp and cotton fabrics. It was duly noted that staining on all cotton fabrics, except for the red cotton twill, occurred in a spotted pattern as opposed to an even spread of color transfer.

Table 4. Colorfastness to Water

		Wool	**Rayon**	**Silk**	**Nylon**	**Cotton**	**Acetate**	**Polyester**
Hemp	Plain	4	4-5	4-5	4	4	4-5	4
	Twill	4-5	4-5	4	4-5	4-5	4-5	4
	Modified twill	n/a*	n/a*	n/a*	n/a*	n/a*	n/a*	n/a*
Cotton	Plain	4-5	3	4	4-5	4	4-5	5
	Twill	3-4	1-2	2-3	3-4	1-2	4	3-4
	Modified twill	4-5	3	4	4	3	4-5	4

*The modified twill hemp fabric was undyed; color evaluation is not available.

3.5. *Flammability*

Flammability of textiles refers to their burning behavior and particularly to the ease of ignition and continued burning after ignition. To compare the flame resistance of the hemp and cotton fabrics; the burn time, afterglow time and char length were determined by the vertical flame test method. The average burn times of the hemp and cotton fabrics in the warp and filling directions are listed in Table

5. Each value represents the average of 5 samples. Afterglow times are reported in Table 6. Afterglow times represent the amount of time that the fabric continued to glow after flame was removed.

Table 5. Burn time (in seconds) of cotton and hemp fabrics

	Warp	Filling	Warp	Filling
Plain	74	88	72	75
Twill	104	80	80	70
Modified twill	50	50	36	36

Table 6. Afterglow time (in seconds) of cotton and hemp fabrics

	Warp	Filling	Warp	Filling
Plain	122	156	213	168
Twill	121	114	77	71
Modified twill	139	113	101	139

According to the test standard, for a fabric to pass, the mean char length must not exceed seven inches. In addition, no single sample should have a char length of ten inches. The char length for all fabrics (cotton and hemp) was more than ten inches. Accordingly, none of the fabrics in this study passed the vertical flame test.

3.6. Abrasion resistance

Abrasion testing serves best to make comparisons between or among different fabrics for the same end use. For this study, the number of cycles until yarn rupture or an end-point of 500 cycles was recorded. Table 7 lists the average number of cycles for each fabric. Of the three different weave structures, the plain weave fabrics had the best abrasion resistance, suggesting that the higher number of interlacings and absence of floating yarns result in better abrasion resistance. The twill and modified twill fabrics have floating yarns that are more exposed and susceptible to abrasion.

Table 7. Average number of cycles until yarn rupture

	Hemp	*Cotton*
	Avg. number of cycles	**Avg. number of cycles**
Plain	397	500+*
Twill	78	127
Modified twill	34	61

The aesthetic appearance of fabrics before and after abrasion was also observed. Hemp fabrics

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exhibited highly noticeable frosting (color change due to flat localized abrasion) across all weave structures. For cotton fabrics, the plain weave and modified twill fabrics exhibited frosting the most whereas the twill fabric had the least amount of frosting. In addition to frosting, pilling was observed on several fabrics. Pilling occurred on both the cotton and hemp plain weave fabrics and to a lesser extent on the twill and modified twill fabrics.

3.7. Tearing strength

To measure the tearing strength of hemp and cotton fabrics, the single rip procedure at a constant rate of extension was used (ASTM D 2261). The results in Tables 8 and 9 represent the average of five samples in the warp and filling direction in dry and wet conditions respectively.

Table 8. Dry tearing strength (lbf) of hemp and cotton fabrics

	Hemp		*Cotton*	
	Warp	**Filling**	**Warp**	**Filling**
Plain	9.9	9	11.4	8.4
Twill	36.8	33.2	10.4	8.2
Modified twill	40.1	40.5	8.2	6.4

Table 9. Wet tearing strength (lbf) of hemp and cotton fabrics

	Hemp		*Cotton*	
	Warp	**Filling**	**Warp**	**Filling**
Plain	16.1	14	16.6	13
Twill	50.6	29.4	11.6	7.4
Modified twill	42.4	31.4	12.9	8.2

As the data in the tables show, the hemp plain weave fabric had lower tearing strength in the dry test compared to the cotton plain weave fabric. The hemp twill and hemp modified twill fabric had higher tearing strength than the cotton twill and modified twill fabric in both directions for both dry and wet tests. To illuminate the results more, the GLM procedure for the least square means was done at a significance level of 0.05. The two-way interaction between fiber and structure did not show a significant difference between hemp and cotton plain weave fabrics with a p-value of 0.97. However, there was a significant statistical difference between the hemp and cotton twill fabrics and hemp and cotton modified twill fabrics with p-values < 0.0001. However, since the minimum requirement for tearing strength of upholstery fabric is 6 lbf, all fabrics in this study met the specification requirement and are acceptable for use in upholstery.

3.8. Breaking strength and elongation

For breaking strength tests, the average breaking force of five specimens for each weave structure of hemp and cotton was calculated. Results are reported in Tables 10 and 11. These values indicate the maximum breaking force exerted on the specimen. Results from breaking tests show that warp yarns had a higher breaking strength than filling yarns. In addition, it was also confirmed that for cellulosic fabrics the breaking strength of wet fabrics were greater than dry fabrics.

Table 10. Dry breaking strength (lbf) of hemp and cotton fabrics

	Hemp		*Cotton*	
	Warp	**Filling**	**Warp**	**Filling**
Plain	260.9	172.0	371.6	310.6
Twill	364.6	182.6	385.2	165.1
Modified twill	281.3	210.8	223.6	142.2

Table 11. Wet breaking strength (lbf) of hemp and cotton fabrics

	Hemp		*Cotton*	
	Warp	**Filling**	**Warp**	**Filling**
Plain	342.1	226.2	533.6	438.5
Twill	694.0	365.5	277.4	219.7
Modified twill	499.7	386.8	304.1	205.7

Statistical analysis at a significance level of 0.05 showed that the breaking strength of hemp and cotton fabrics were significantly different. The cotton plain weave fabric had higher breaking strength than the hemp plain weave fabric. Conversely, the hemp twill and modified twill fabrics displayed higher breaking strength that the comparable cotton fabrics. Since the minimum requirement for breaking strength of upholstery fabric is 50 lbf, all fabrics in this study met the specification requirement and are acceptable for use in upholstery.

Elongation of the hemp and cotton fabrics can be defined as the change in length due to stretching of the fabric. Hemp and cotton fabrics, unless blended with elastane or other elastic fiber, have no elastic recovery. Once elongated, the fabric does not return to its original length. Tables 12 and 13 list the elongation results of hemp and cotton fabrics.

Table 12. Dry elongation (inches) at the breaking point of hemp and cotton fabrics

	Hemp		*Cotton*	
	Warp	**Filling**	**Warp**	**Filling**
Plain	0.9	0.3	0.8	0.4
Twill	0.6	0.2	1.0	0.6
Modified twill	0.6	0.4	0.5	0.5

Table 13. Wet elongation (inches) at the breaking point of hemp and cotton fabrics

	Hemp		*Cotton*	
	Warp	**Filling**	**Warp**	**Filling**
Plain	0.9	0.4	1.2	0.6
Twill	0.9	0.3	0.7	0.7
Modified twill	0.7	0.5	0.9	0.7

Statistical analysis at a significance level of 0.05 indicated that the amount of elongation between hemp plain weave and cotton plain weave fabrics was not significantly different (p-value = 0.11). There was a significant difference (p-value = 0.003) in elongation between the hemp twill and cotton twill fabrics. Elongation of the hemp modified twill and cotton modified twill fabrics were not significantly different with a p-value of 0.10. There is no minimum or maximum elongation requirement for upholstery fabric according to ASTM performance specifications.

4. Results and Discussion

Based on the data obtained, it is concluded that the colorfastness to crocking was satisfactory in the case of both the hemp and cotton twill fabrics but unsatisfactory for the plain weave fabrics. The results from dry and wet crocking tests are influenced by the amount of dye penetration, proper selection of dyestuffs, and finishes present on the fabric.

Based on the total color difference (ΔE) values, the hemp fabrics had the greatest amount of color change on exposure to light. The results suggest that the use of hemp in home furnishings may be limited to indoor upholstery applications. Typically, indoor home furnishings are not exposed to a great amount of sunlight. However, in cases where hemp-upholstered furniture sits near an uncovered window, findings suggest that noticeable color change may occur within a short period of time. For indoor hemp-upholstered furniture that will be exposed to sunlight for prolonged periods, it is suggested that a treatment be applied that will provide resistance to color change caused by light.

Visual comparisons between specimens for oily stain release are subjective in nature. It was found that hemp fabrics had slightly higher grades than the cotton fabrics, particularly the modified twill and the plain weave fabrics. Cotton fabrics had grades of less than 2, which indicate poor stain removal compared to the hemp fabrics. The results from the oily stain release test suggest that none of the hemp and cotton fabrics had a soil or a stain release finish applied to them. Although the soil release test is not required for determining suitability for upholstery fabric, it demonstrates a fabric's propensity for staining due to oily substances. It is possible that the depth of color or lightness of the sample influenced higher grades for the hemp plain weave and hemp modified twill fabrics. Upholstered furniture serves as seating for everyday use or social gatherings, which can lead to incidence of spilled food or beverage containing oil or fatty substances. In this case, to prevent oil staining, a soil release finish should be applied to hemp- upholstered furniture in high-traffic areas.

According to AATCC Test Method 107, the colorfastness to water test measures the resistance to water of dyed, printed, or other colored textile yarns and fabrics. As a whole, the hemp fabrics that were tested performed well, while the cotton fabrics were graded lower and failed to pass the ASTM specification requirements for upholstery fabric. The multi-fiber sample exhibited the greatest amount of staining against the cotton fabrics. The hemp fabrics had negligible staining on the multi-fiber sample when exposed to water at 100°F, which indicates good colorfastness to water. The colorfastness to water test indicates how resistant a fabric is to cleaning. Dye loss and color transfer may be an issue when upholstery steam cleaners are used.

All hemp and cotton fabrics tested failed the flame resistance test by exceeding a maximum char length of 10 inches. The ease of ignition for hemp and cotton fabrics suggests that flame spread can be severe. This poses a serious threat of injury incurred by victims of an upholstery-related fire. Generally, fire is unpredictable and the flammability of upholstery fabric can be affected by other factors such as textile items in the immediate surrounding area. The test results indicate that both cotton and hemp fabrics have poor flame resistance without a proper flame resistant or flame retardant finish. The high amount of smoke and afterglow time indicates the hazard that untreated hemp and cotton fabrics pose when used for upholstery fabric.

The abrasion resistance of a fabric is subject to various factors, such as fiber content, yarn size, yarn twist, fabric construction, fabric count, fabric thickness, and weight. Abrasion is a crucial measure of durability of upholstery fabric as well as a factor in consumer satisfaction. If the development of holes, pilling, or frosting occurs as a result of abrasion in actual wear, the consumer is likely to be dissatisfied with a furniture item upholstered in that particular fabric. The number of cycles until yarn rupture is a subjective evaluation. However, since cotton lasted through a much higher number of cycles in all three different weave structures, it can be suggested that cotton has better abrasion resistance than hemp among the fabrics investigated in this study.

The tearing strength of upholstery fabric gauges how well the upholstery fabric behaves under stress, for example when seated on or when pulled at the seam. There was a not a significant difference in tearing strength between wet and dry tests. Additionally, all fabrics were acceptable according to ASTM specifications. It is also concluded that a hemp fabric with a twill or modified twill weave structure would be more ideal for upholstery use since their tearing strength values were significantly higher than plain weave fabrics.

There was no significant difference between hemp and cotton in terms of breaking strength. All the fabrics met the minimum ASTM specification requirement for breaking strength of upholstery fabric. It is further noted that twill or modified twill fabrics are more suitable for furniture applications. Also, both hemp and cotton fabrics have poor elastic recovery, meaning when they are stretched, they do not return to their original length or shape. Aesthetically, this can be problematic if upholstery on furniture becomes loose and stretched out due to stress on the fabric over time.

References

[1] Blackburn R S 2005 *Biodegradable and Sustainable fibres* (Cambridge, U.K.: Woodhead Publishing Ltd)

[2] Claudio L 2007 *Environmental Health Perspectives* 115 448-454

[3] American Association of Textile Chemists and Colorists 2009 AATCC Technical Manual (Research Triangle Park, North Carolina, USA: AATCC)

[4] ASTM International 2009 ASTM D3597, *Standard Performance Specification for Woven Upholstery Fabrics* (West Conshohocken, Pennsylvania, USA: ASTM International)