PERFORMANCE CHARACTERISTICS OF RAYON FROM BAMBOO IN BED SHEETS THROUGH LAUNDERING

by

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ABSTRACT

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Utah State University, 2012

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Department: Agriculture Systems Technology Education

Due to the recent production and popularity of the textile fabric rayon from bamboo, relatively little information is available regarding related performance characteristics. This thesis serves to evaluate the performance of rayon from bamboo in the bed sheet application. Three tests were conducted to determine dimensional stability, fabric hand, and weight, thickness, and density of the rayon from bamboo throughout twelve laundering cycles. Results indicate a lack of dimensional stability, superior hand, and acceptable changes in weight, thickness, and density.

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PUBLIC ABSTRACT

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In recent years, consumers have been encouraged to purchase bamboo fabric for various applications, including bed sheets. A variety of claims and marketing campaigns have stated that the benefits of rayon from bamboo result in this fiber being a suitable option for bed sheets and other clothing and household products. The purpose of this study was to test the performance characteristics of rayon from bamboo to determine if it is an appropriate textile for the bed sheet application. To identify the performance characteristics of this fiber, three tests were conducted (a) dimensional stability; (b) fabric hand; (c) the weight, thickness, and density of the fabric. Each factor was tested during various stages of the laundering process resulting in data that illustrated the performance of rayon from bamboo bed sheets compared to cotton throughout the life cycle of the product. The findings contribute to the literature and suggestions for future research are also discussed.

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CHAPTER 1

INTRODUCTION

Background for the Study

In 2002, the product rayon from bamboo was manufactured in China and distributed to companies worldwide (Erdumlu & Ozipek, 2008). With the release of the new product, false claims regarding positive characteristics were made. Environmental benefits, identity of the fiber, and the antimicrobial characteristics of the fiber were several of the false positives presented to consumers. While some claims were referenced in research-based articles, they were not based on valid and reliable findings referencing the actual performance characteristics of the fiber. To address the inaccuracies, research was conducted to examine original claims associated with the product performance characteristics (Erdumlu & Ozipek, 2008; Hardin, Wilson, Dhandapani, & Dhende, 2009; Lipp-Symonowicz, Sztajnowski, & Wojciechowska, 2011; Xu, Lu, & Tang, 2007). The results of the research conducted did not support the original claims made about rayon from bamboo. Gaps still exist in the literature documenting the positive characteristics of rayon from bamboo.

Multiple studies confirm classification of the fibers made from bamboo as rayon from bamboo, thus rejecting the notion that it is a unique fiber (Erdumlu & Ozipek, 2008; Hardin et al., 2009; Lipp-Symonowicz et al., 2011; Xu et al., 2007). Due to these findings, the properties of viscose rayon are examined to determine how the rayon from bamboo will perform in various aspects and situations. While there is a gap in research specific to rayon from bamboo, research has been conducted (Erdumlu & Ozipek, 2008;

Hardin et al., 2009; Lipp-Symonowicz et al., 2011; Xu et al., 2007) on the performance characteristics of viscose rayon and proven to be valid and reliable.

The American Association of Textile Chemists and Colorists (AATCC) published a technical manual outlining standardized tests for textile testing. While the AATCC is not the only source establishing standardized procedures for testing textiles, it is both prominent and reliable. From the AATCC technical manual, textile scientists can use valid and standardized tests to identify the performance characteristics of fibers. Tests included in the manual can be replicated and the original findings can be used to compare results of current and future tests. Since limited research exists, using the AATCC (2011) standardized tests for textile science research for the proposed study seeks to evaluate the performance characteristics of rayon from bamboo. Key characteristics that need to be identified are dimensional change of fabric made of rayon from bamboo, fabric hand, weight, thickness, and density of fabrics manufactured as rayon from bamboo after and through the laundering process.

Need for the Study

Bamboo is a relatively new, but a very popular fiber that has been manufactured and distributed worldwide. Consumers in general are unaware of the actual attributes of the rayon from bamboo fiber. False claims have been made concerning the actual identification of the fiber, the environmental impacts of the fiber, and the microbial characteristics of the fiber. Rayon from bamboo is not a bamboo fiber and it is in fact rayon from bamboo. False advertising has led to confusion regarding the actual performance characteristics of the respective products. Rayon from bamboo has been used in a large variety of products. While the rayon from bamboo fiber does have some versatility the fiber is not the best fiber for some end uses. It is essential for consumers to receive accurate and reliable information regarding the performance characteristics of rayon from bamboo. Because it is a relatively new fiber, the scientific tests that have been performed on the fiber are limited. Consequently, there is a large gap and need for additional research regarding the qualities and performance of rayon from bamboo fibers. The proposed study will provide needed information that can be used to accurately inform consumers of the performance characteristics of this popular fiber.

Specifically, consumers are encouraged to purchase household fabrics, such as bed sheets that are manufactured from rayon from bamboo. The results of the proposed research will identify the change in characteristics such as dimensional change, hand, fabric weight, thickness and density that occur during laundering. Rayon from bamboo sheets will be used and compared to cotton, a common fiber used for bedding. The qualities chosen relate specifically to the performance characteristics of sheets, and are thus relevant to consumers. If rayon from bamboo sheets cannot maintain relative quality during laundering it should not be considered a viable and effective fiber to be used in bedding.

Statement of the Problem

While rayon from bamboo is a relatively new fiber, false claims have led to misinformed consumers. The actual stability and performance of rayon from bamboo in sheets is relatively unknown in both the research community, and to the average consumer.

Purpose of the Study

The purpose of this study is to determine the performance characteristics of rayon from bamboo in relation to three tests conducted during laundering. The testing of the performance characteristics will consist of the following tests: dimensional change, fabric hand, and fabric weight, thickness, and density. Determining the effect of these characteristics during laundering will determine whether or not rayon from bamboo could be a suitable fiber for sheets.

Dimensional change will determine whether or not the fabric is able to remain the same length and width throughout laundering. If the fabric is not able to maintain relative dimensional stability it should not be considered suitable for sheets, because the specified sheets would no longer fit on a bed of corresponding size. Unlike cotton, rayon from bamboo may exhibit changes from progressive shrinkage during successive washings while cotton will shrink initially from relaxation shrinkage. The amount of shrinkage relative to initial measurements will determine whether or not the fabric is dimensionally stable.

The hand of rayon from bamboo is considered one of the greatest characteristics of the fiber. Due to superior hand, the feel of rayon from bamboo sheets is aesthetically pleasing. While hand includes many factors relating to the fabric, the two elements being tested in this study will be that of drape and softness. Drape will be tested on the Cusick Drape Tester yielding a drape coefficient giving a clear indication of the relative drape. Softness will be tested by a panel of people rating relative softness of fabrics compared to one another. Evaluations will be performed on new fabric, fabric washed once, washed six times and washed 12 times. This test will determine whether or not rayon from bamboo does in fact have superior hand compared to cotton, and whether the hand is altered through successive washings. If the hand is not maintained, then it cannot be considered advantageous over cotton in that respect.

The fabric weight, thickness, and density affect the quality of fabric. These measurements are important, because they affect other characteristics of fabric such as absorbency, cover, drape, warmth, etc. The weight of the fabric indicates relative quality of the fabric. The lower the fabric weight (oz./yd^2), the lower the quality of the fabric. Density plays an important role in moisture transport and air permeability, which contribute to the comfort and functionality of the respective sheets. By testing the change in fabric weight, thickness and density during successive washings it can be determined whether or not these fabric characteristics will remain constant through typical use.

Variables

Rayon from bamboo, and cotton sheets will be tested. Both samples will be tested when they are new, washed once, washed six times, and washed twelve times. Each test will evaluate both specimens at each of the specified washed times. Since a typical sheet may be washed approximately twice a month this will examine effects of laundering after the equivalent of 3 months and 6 months, respectively.

Research Questions

The following are proposed research questions to be addressed by this study.

1. Is rayon from bamboo suitable for the sheet application?

2. Will the laundering of rayon from bamboo have a significant effect on key characteristics of the fabric's performance?
3. Does the laundering of cotton have a significant effect on key characteristics of fabric performance?
4. Does the amount of laundering have an effect on the hand of rayon from bamboo and cotton fabrics?
5. Is rayon from bamboo or cotton fabric considered to have superior hand? Does this change throughout successive washings?
6. Will the fabric weight/thickness/density of rayon from bamboo decrease, increase, or remain the same throughout successive washings?
7. How much will the fabric weight/thickness/density of rayon change in comparison to the change of cotton?
8. Does the amount of laundering affect the dimensional stability of rayon from bamboo and cotton fabric?
9. Does rayon from bamboo or cotton fabric have more dimensional stability?

Hypotheses

1. While the reasons for dimensional change of rayon from bamboo and cotton may differ, after 12 successive washes rayon from bamboo will be affected significantly more than the dimensional changes undergone by cotton during similar 12 washes.

2. The fabric weight and thickness will increase more in cotton than in rayon from bamboo, because of the low wet modulus of rayon. The density will decrease as the fabric expands and relaxes throughout washing cycles.
3. While both the hand of the cotton and rayon from bamboo will change through the amount of laundering, the rayon will change more drastically. The initial hand of rayon from bamboo will be superior to that of cotton.

Definitions of Terms

Bast are soft, strong, woody fibers, for example, flax, hemp, jute, and ramie, obtained from the inner barm (the phloem, pericycle, or cortex) of dicotyledonous plants, usually by retting (Tortora & Merkel, 1996).

Dimensional change is a generic term for changes in length or width of a fabric specimen subjected to specified conditions. The change is usually expressed as a percentage of the initial dimension of the specimen (AATCC, 2011).

Laundering is a process intended to remove soils and/or stains by treatment (washing) with an aqueous detergent solution and normally including rinsing, extraction and drying (AATCC, 2011).

Surfactant is a soluble or dispersible material that reduces the surface tension of a liquid, usually water. The active ingredient in detergent, the surfactant is adsorbed on the surfaces of soil particles and aids in their removal (Tortora & Merkel, 1996).

Warp is a yarn that runs lengthwise in a woven fabric, parallel to the selvages. Warp ends interlace with the filling yarns in different patterns to form different weaves (Tortora & Merkel, 1996).

Filling, in a woven fabric, are the yarns that run from selvage to selvage at right angles to the warp (Tortora & Merkel, 1996).

Shrinkage is a dimensional change resulting in a decrease in the length or width of a specimen (AATCC, 2011).

Hand is the tactile sensations or impressions that arise when fabrics are touched, squeezed, rubbed, or otherwise handled (AATCC, 2011).

Drapability is a characteristic of fabric indicative of flexibility and suppleness. The degree to which a fabric falls into graceful folds when hung or arranged in different positions (Tortora & Merkel, 1996).

Absorbency is the propensity of a material to take in and retain a liquid, usually water, in the pores and interstices of the material (AATCC, 2011).

Ballast is the material used in procedures for processing or testing of textiles, to bring the total weight of textiles to a specified amount. It is also known as dummy load (Tortora & Merkel, 1996).

Relaxation is the relief of any strain present in fiber, yarn, or fabric resulting from various stages of processing. Relaxation is necessary to impart dimensional stability to the final textile material (Tortora & Merkel, 1996).

Detergent is a substance that cleanses, e.g., soap. In current usage, a detergent is a formulated cleaning agent containing one or more surfactants (lowers the surface tension of water) as active ingredients (Tortura & Merkel, 1996).

Assumptions

While all variables and controls are being held constant, there are a few necessary assumptions in order to maintain the validity and the reliability of the study. First, relative humidity is kept constant. Because it is imperative to keep the relative humidity and temperature standard, the environment will be manipulated to attain relative humidity and temperature. The assumption is that relative humidity is kept constant throughout the duration of the tests. Fluctuating humidity could potentially alter test results. Further, it is assumed that a general representation of both cotton and rayon from bamboo are picked from the specimens being tested. While there are a wide variety of fabrics made from both rayon from bamboo and cotton, the specimens chosen for the current study represent a typical or standard fabric. Another assumption for the current study is that the evaluators used to assess the hand of the fabrics are equipped to make an educated decision. Each evaluator will be instructed on what is being evaluated and the meanings associated with each task, but a variety of perceptions contribute to some variance in this subjective test. All efforts will be made to ensure that evaluators will be sufficiently educated in order to make informed evaluations. Lastly, the assumption is made that the washing machine and dryer will perform the same during each wash. The exact conditions of the washing machine will be measured beforehand. It is a goal of the researcher to achieve consistent, exact conditions during each wash. Overall, the procedures associated with the current research study require the research to consider factors such relative humidity being kept constant, general representations of specimens selected, evaluators being equipped to make educated decisions, and both the washing machine and dryer performing the same throughout each cycle.

Limitations of the Study

While washing conditions in this test are controlled, it is important to acknowledge that test results performed by consumers at their own home could vary slightly depending on the settings and individual variations of the washer used. Factors that may have an effect, but have been controlled in this experiment would be factors such as water temperature, amount of agitation, water-to-fabric ratio, and detergent used.

Limitations can also result in the sample of rayon from bamboo fabric selected for use in the proposed study. First, it is difficult to know all the technical specifications of the fabric being used. While major specifications such as thread count are provided on the care label, it is impossible to know the exact fiber denier, production process, and finishes applied. These factors should not have significant effects on the tests performed, but it could account for slight variations. Second, the location on the bolt of fabric each sample originated from is unknown. Even though the exact location on the bolt is unknown, fabric specimens tested will be selected from different lengthwise and crosswise grains thus eliminating major bias. Due to the reliability and validity of the tests chosen for this study it is acceptable to conduct the test in this matter.

It is also important to note that while evaluating hand, every aspect of hand is not being evaluated. Testing is limited to the specific characteristics specified by the tests and will not be inclusive of all characteristics. While every characteristic is not being tested, the selected characteristics tested are some of the most relevant in reference to the end use of this textile product. Because the testing of hand is subjective in its very nature there is some degree of limitation in regards to this test. Results could vary based on the selected evaluators and their individual view, preferences, or perceptions.

A limitation presented by the dimensional change test is that the specific tightness of the weave could have an effect on the degree of shrinkage. This is important to acknowledge because if another test was done on the same fiber of different weave tightness dimensional change could vary slightly. To control for this reality, the thread counts of the specimens has been regulated, but slight differences could have a small effect on results.

Summary

Evidence suggests that the designed tests are necessary, applicable, reliable and significant. There is a need for this study as there is an obvious gap in research regarding rayon from bamboo as evidenced by limited research and circulation of faulty or questionable information regarding the fiber. Such research will not only benefit the research community, but will especially benefit the average consumer as they are enabled to make educated decisions regarding the specified products. The designated tests allow for standardized, reliable, and valid ways to determine the performance characteristics of rayon from bamboo related to the bed sheet product. The variables chosen will account for the short-term life of a sheet in relation to normal use, and will give valuable information regarding the changes throughout the life of the fabric. While limitations have been accounted for, the study will be completely reliable and valid as it represents the performance of rayon from bamboo as a whole in comparison to cotton. Tests used in the current study will produce accurate and relevant information to the examined research questions.

CHAPTER 2

REVIEW OF LITERATURE

Introduction

The literature review will examine the background information necessary for understanding implications and results for tests performed. First, bamboo as a fabric will be examined. Several of the false claims projected regarding bamboo from rayon will be evaluated. These include environmental friendliness, identification, and antimicrobial properties. Next, the properties of viscose rayon will be examined in order to better understand the performance of rayon from bamboo fabric. Finally, laundering, dimensional change, hand, and fabric weight, thickness, and density will be defined and examined to determine the effects and implications of the designed tests. While the information on rayon from bamboo is somewhat limited, there is sufficient information to perform the designated tests.

False Claims

One of the largest false claims made regarding rayon from bamboo is its high degree of environmental friendliness. Rayon from bamboo should not be considered a green fiber. This false claim stems from the fact that bamboo as a plant does contain positive characteristics. Bamboo is a tough, durable plant that is readily available. The bamboo plant is currently the fastest growing plant in the world with some species growing up to one meter per day (Lipp-Symonowicz et al., 2011). Not only is it the fastest growing plant in the world, but it’s also renewable, and degradable (Yueping et al., 2010). Additionally, bamboo can be grown with little or no pesticides and chemicals. The bamboo plant can absorb five times more CO_2 than an average tree and produce 35% more oxygen, which does have a positive effect on the environment. These collective characteristics lead one to believe that fabric derived from bamboo is environmentally friendly, but a closer look should be taken at the overall environmental impacts of the fiber (Lipp-Symonowicz et al., 2011).

The manufacturing of synthetic fibers is an energy–intensive process that requires large amounts of crude oil, and also releases emissions including volatile organic compounds, particulate matter, and acid gases such as hydrogen chloride. While the processing of natural fibers is not without a degree of environmental concern, the effects are minimal compared to those of manufactured fibers. Many of the textile manufacturing facilities are considered to be hazardous waste generators by the EPA (Claudio, 2007). The processing of the wood pulp into fiber uses large quantities of harsh chemicals, which contribute to air and water pollution. Although attempts have been made to reduce and recycle chemicals used, as well as reduce pollutant emissions, attempts have produced only minimal success (Chen & Burns, 2006).

While the conditions described apply to the production of manufactured fibers in general, rayon from bamboo, which is produced nearly identically to viscose rayon, holds its own unique set of environmental concerns. Carbon disulfide, a toxic chemical that is known as a human reproductive factor, is used as a solvent during processing. The effects endanger factory workers and pollute the environment through air emissions and wastewater. The significant issue with this solvent is that only 50% of the solvent is recovered by most viscose factories. The other half is released into the environment.

Sodium hydroxide and sulfuric acid are also potentially hazardous chemicals used in the process (Patagonia, 2009). The single largest environmental concern with rayon derived from bamboo is the waste produced. Furthermore, most rayon from bamboo is made in China where environmental controls and rare (Hardin et al., 2009). The environmental impacts of rayon from bamboo should be taken into consideration when considering the benefits and drawbacks of the fiber as a whole.

False claims have also been made concerning antimicrobial properties of rayon from bamboo. Antimicrobial “bamboo kun” is found in the bamboo plant and responsible for antibacterial and fungal resistance properties evidenced by bamboo. The protein dendocrin is specifically responsible for this characteristic (Lipp-Symonowicz et al., 2011). The kun leads to claims that fabric derived from bamboo is both antimicrobial and fungal resistant. The claim is not grounded. The AATCC performed a test to determine whether or not fabric derived from bamboo did in fact contain antimicrobial properties. A strain of bacteria was placed on seven different fabrics derived from bamboo. Bacterial colonies grew exactly where streaking had been done and no antimicrobial qualities were exhibited. To contrast these results, the same test was performed on antimicrobial-treated fabric that was several years old. These specimens showed a clear and distinct difference between effectiveness and no effectiveness at all (Hardin et al., 2009). Contrary to claims, fabric derived from bamboo holds no natural antimicrobial properties.

One of the most substantial false claims regarding rayon from bamboo involves the actual identity of the fabric. While such fabrics from bamboo have been labeled as “bamboo” fabric it is in fact rayon made from bamboo pulp. The AATCC conducted an experiment to determine the identity of marketed “bamboo” fabric. Seven fabric samples were tested using optical microscopy and SEM. The examined fibers were then compared to samples of rayon and bast fibers. The results showed that the “bamboo” fabric was identical to rayon, and is in fact rayon, made from purified cellulose isolated from bamboo pulp. The results showed no similarity to the characteristics of natural bast fibers (Hardin et al., 2009). Similar but separate tests conducted by Xu et al. (2007) confirmed that bamboo viscose is identical to conventional rayon in configuration. These tests were conducted using both SEM micrographs and wide angle X-ray diffraction (WAXR). SEM micrographs showed that ‘bamboo’ fabric displayed typical cellulose II pattern that is typical of rayon and not typical of bast fibers. The WAXR showed similar levels of crystallinity, and also confirmed via thermal analysis that the ‘bamboo’ fabrics showed typical cellulose II behavior (Xu et al., 2007). Further tests again confirm the identity of “bamboo” fabrics as rayon from bamboo as surface characteristics, cross-sections, longitudinal view, and similar crystallinities are tested (Lipp-Symonowicz et al., 2011). As shown repeatedly by studies, “bamboo” fabric is in fact viscose rayon derived from bamboo pulp. The rayon from bamboo fabric is comparable to viscose rayon in its structure and properties.

The identity of rayon derived from bamboo fabric can also be confirmed, as the process of the rayon from bamboo is identical to the viscose process. It differs in the respect that instead of cellulose pulp, bamboo pulp is used. The manufacturing process of regenerated bamboo fiber is a nine-step process. The first is preparation, which involves extracting and crushing the leaves and soft inner pith from the hard bamboo trunk. The second is steeping. The crushed bamboo cellulose is soaked in a solution of

15-20% sodium hydroxide at a temperature of 20-25˚C for 1 to 3 hours. The third step is pressing which involves the pressing of bamboo alkali cellulose in order to remove excess sodium hydroxide solution. The fourth step is shredding where a grinder, which increases surface area and makes cellulose easier to process, shreds alkali cellulose. Fifth, ageing involves leaving cellulose to dry for 24 hours while exposed to oxygen. During this stage the ageing degradation takes place, which allows chain lengths short enough to produce correct viscosities in the spinning solutions. The sixth is sulfurization where carbon disulfide is added causing the solution to gel. The seventh is xanthation where the remaining carbon disulfide is removed by evaporation and cellulose sodium xanthogenate results. Eighth is the dissolving process where a diluted solution of sodium hydroxide creating the viscose solution consisting of five percent sodium hydroxide and 7-15% bamboo fiber cellulose. The final process is the spinning process where bamboo cellulose is forced through the spinneret into diluted sulfuric acid solution, which causes it to harden. The fibers are then ready for further construction steps (Erdumlu & Ozipek, 2008). The fabric derived from bamboo is in fact rayon derived from bamboo as evidenced by identical processing.

Characteristics of Rayon from Bamboo

Despite false claims about fabric derived from bamboo, it is important to understand why the respective products are desirable. First, fabric derived from bamboo has a very soft hand, which is aesthetically preferred (Xu et al., 2007). Second, the moisture regain is relatively high which means that the transportation of moisture will be good. Erdumlu and Ozipek (2008) reported the moisture absorption of bamboo as high as 13% while cotton is reported about 7-8%. While these results may not be standard, and even somewhat biased, it is important to understand the moisture absorption is at least similar to that of cotton. Thermal analysis also confirms the fact that the fibers contain good water retention power due to surface characteristics (Xu et al., 2007). Rayon from bamboo fibers exhibits good dyeability, which contributes to the high colorfastness of the fabric (Erdumlu & Ozipek, 2008; Xu et al., 2007). Because it is a synthetic fiber, it lends itself to great versatility contrary to natural fibers. Versatility can lead to intentionally altered performance characteristics (Tortora & Collier, 1997; Wingate, 1964). Finally, the fiber can be produced economically. The blending of fibers with other fibers makes it especially marketable (Wingate, 1964). Rayon from bamboo does have some strong, marketable characteristics despite drawbacks.

Like any fiber, rayon from bamboo also has disadvantages. First, it is not environmentally friendly (Hardin et al., 2009). Second, it has a very low wet modulus strength resulting in a very weak fiber when wet. This may especially manifest itself during laundering. Similarly, it is relatively weak in dry strength (Johnson & Cohen, 2010). Third, the elasticity and resilience of the fibers is low resulting in poor shape retention and fabric stability. Finally, when untreated it is susceptible to acids, alkalis, mildew, silverfish, and sunlight (Elsasser, 2010; Tortora & Collier, 1997). While research is still being developed in relation to the rayon from bamboo fiber, a prediction of how rayon from bamboo will perform can be made based on the performance of viscose rayon.

Viscose Rayon

Understanding the positives and negatives of viscose rayon fabric will help develop an understanding of the performance characteristics of rayon from bamboo. Noting that the identity of the "bamboo fiber" is considered rayon from bamboo, looking at properties of viscose rayon provides a lot of insight.

Degradation of viscose rayon is relatively high. The amorphous molecular structure contributes to the susceptibility of acids especially concentrated acids such as sulfuric, hydrochloric and nitric acids. Cold, dilute mineral acids must be washed out at once or be neutralized (Elsasser, 2010; Tortora & Collier, 1997; Wingate, 1964). Comparatively, the effect is the same as on cotton or linen (Wingate, 1964). Similar to acids, alkalies also will also degrade the fiber (Elsasser, 2010). Viscose rayon is subject to damage from mildew, rot-producing bacteria, and silverfish (Elsasser, 2010; Tortora & Collier, 1997). Exposure to sunlight also deteriorates viscose rayon. Comparatively, the deterioration to sunlight is greater in viscose than to cotton. Although viscose products are used in products such as curtains and draperies, it is not satisfactory for these projects unless lined to protect from sunlight (Wingate, 1964). Age does not have a deleterious effect on viscose rayon if stored in clean and dry condition (Tortora & Collier, 1997).

One of the strongest appeals of viscose rayon fabric is the superior hand. Viscose fabrics can be surprisingly beautiful and soft. While the typical viscose fiber is flexible, the use of fine multifilament yarns will enhance both softness and drape (Elsasser, 2010; Tortora & Collier, 1997).

The versatility of fabric is also a great appeal. Viscose can be sheer as cobwebby silk crepe or voile and as heavy as any silk satin (Tortora & Collier, 1997). Because it is a synthetic fiber, other characteristics can also be manipulated. Typical viscose rayon will have a high luster, but can also be modified to have a low luster (Wingate, 1964). The diameter can also be controlled during the spinning process due to the varied spinnerets (Lewin & Pearce, 1998). When filament yarns are used the product is smooth which will feel cooler than spun yarns, which have a fuzzier texture. Spun viscose can adversely contribute to a relatively warm feel as it imitates the structure of a typical natural fiber such as cotton (Wingate, 1964). This characteristic of versatility is essentially unattainable by cotton fabrics because of its limitations in manufacturing characterized by the natural fiber characteristics.

Elasticity and resilience recovery of rayon is similar to that of cotton, but is less than that of a good-quality silk. Care should be taken to not fit or buy viscose garments that are too tight because of the splitting at points of strain. Poor shape retention is typical of viscose rayon fabric (Tortora & Collier, 1997; Wingate, 1964).

High heat will harm the viscose fibers. An ironing temperature of viscose is 250˚F and will scorch if too hot. This is relatively typical of a synthetic fiber, and much lower than that of a natural fiber. Long exposures to high temperatures will deteriorate the fiber (Tortora & Collier, 1997). Viscose rayon does burn similarly to cotton in the respect that when exposed to an open flame it will continue to burn until flame is removed. The smell will be similar to that of burning paper, and a soft, gray ash will remain after burning (Elsasser, 2010; Tortora & Collier, 1997).

The absorbency of viscose rayon is one of the most marketable characteristics. Although synthetic, the fiber does have good absorbability. While sources will vary slightly, the moisture regain for cotton is reported around 8.5% and viscose is reported around 11% (Johnson & Cohen, 2010). Because viscose has a high absorbency it is comfortable to wear as it allows for moisture and perspiration transportation (Elsasser, 2010). The absorbency also has an effect on its ability to accept and hold dye (Tortora & Collier, 1997).

Strength is one of the disadvantages of viscose rayon. Dry strength ranges from about 1.2 – 3.0 g/d while cotton comparatively is 3.0-5.0 g/d (Johnson & Cohen, 2010). One of the reasons for the lower strength is due to the amorphous inner structure of the viscose fiber. Low wet modulus strength is especially low for viscose rayon (Tortora & Collier, 1997). Viscose rayon loses approximately 30-50% of its strength when wet, while cotton is ten percent stronger when wet (Johnson & Cohen, 2010). Because of this it is important to handle viscose with care during laundering (Tortora & Collier, 1997).

Viscose rayon can be economical compared to other fibers and can be blended with more fibers such as wool to keep the price down (Wingate, 1964).

The environmental effect of rayon is extremely harmful as discussed previously.

Laundering

As defined by the AATCC (American Association of Textile Chemists and Colorists) laundering is a process intended to remove soils and/or stains by treatment (washing) with an aqueous detergent solution and normally including rinsing, extraction and drying (AATCC, 2011). The laundering process uses water as the solvent, which dissolves or suspends particulate soils, such as salts, sugar, dust clay and water-based spots and stains. When testing laundering effects on fabric it is important to launder the garment or textiles in accordance with the laundering care of its ultimate end use (Collier & Epps, 1999).

Several factors influence the effectiveness of laundering including the water quality, the type of cleanser used, the amount of agitation, the temperature, the material being cleaned, and the water-to-weight-of-fabric ratio. Agitation employs the mechanical action needed to loosen soils or dirt. Higher water temperatures are more effective in cleaning, but can negatively affect other properties such as dimensional change, colorfastness and fiber stability. The material being cleaned may react to laundering differently depending on fiber content and fabric construction. For example, while cotton is ten percent stronger when wet, viscose rayon is 30-50% weaker when wet, which will consequently influence factors during laundering. The water-to-weight-of-fabric ratio affects the amount of agitation received by the washed textile, and a lack of water will result in insufficient suspension of dirt or soil molecules resulting in redeposition on the fabric. When testing laundering techniques, it is important to standardize and account for these factors in order to eliminate excessive variables (Johnson & Cohen, 2010; Collier & Epps, 1999). Several ways to limit some of these laundering factors while testing would be to weigh the fabric beforehand so the agitation is standardized, put standardized detergent in the water, and measure the temperature and conditions of the washer and dryer in order to determine standardization.

Detergent is an organic composition produced by chemical synthesis. Detergents do not adversely affect textile fibers, which make them suitable for repetitive cleaning

(Johnson & Cohen, 2010). Detergents are surfactants meaning they alter water properties by lowering surface tension between molecules allowing the water to spread over more surfaces. In other words, the detergent surfactant allows water to get the fabric wetter. When combined with mechanical action, which is generally agitation in the washing machine, soils and dirt are loosened. The detergent will then surround loose soil particles and suspends them in wash water preventing redisposition on the textile (Collier & Epps, 1999; Humphries, 2009).

Dimensional Change

As defined by the AATCC dimensional change is a generic term for changes in length or width of a fabric specimen subjected to specific conditions. The change is usually expressed as a percentage of the initial dimension of the specimen (AATCC, 2011). While dimensional change could include the growth or shrinkage of a textile, the primary dimensional change seen when laundering is shrinkage, meaning a decrease in the fabric measurements. When reporting dimensional change the lengthwise and crosswise numbers should be differentiated. Factors such as water, heat and agitation cause a garment to shrink. There are two major forms of shrinkage: relaxation shrinkage, and progressive shrinkage (Johnson & Cohen, 2010; Collier & Epps, 1999).

Relaxation shrinkage is possible in any fiber content if there is tension between yarns that can relax in wet treatment or washing, and tumble drying (Humphries, 2009). The first wash is primarily where all relaxation shrinkage will be exhibited. The cause of relaxation shrinkage lies behind the manufacturing process. The warp yarns are stretched tight on the loom, and then the filling yarns are woven into the structure, resulting in much tighter yarns in the warp direction than in the weft direction. When the fibers absorb water they swell and relax. As the yarn relaxes it changes from a state of being pulled tight, to a more crimped state. Consequently, this pulls the yarns in closer together. Tight twist within the yarn may also relax to a more relaxed state. Looser weaves have little need for stress relief between yarns and will not have as much relaxation shrinkage as a tighter weave. Because the warp yarns are under more tension than the filling yarns they exhibit more shrinkage than the filling yarns due to their need of increased stress relief. Relaxation shrinkage happens more in hydrophilic fibers than hydrophobic fibers since the hydrophilic fibers will actually absorb the water and allow for swelling. Consequently hydrophilic fibers such as cotton and rayon will undergo more relaxation shrinkage than hydrophobic fibers such as polyester and nylon (Johnson & Cohen, 2010; Collier & Epps, 1999). While most sources agree that relaxation shrinkage happens after the first wash only, there are several sources claiming that it will continue for as long as ten laundering cycles. This would occur in a tightly woven fabric and is because the lattice structure of the fabric prevents the fiber from becoming fully swollen. This results in significant relaxation shrinkage through the first laundering cycle, but then residual shrinkage for as many ten of the following cycles. It should be acknowledged, that eventually the relaxation would cap at the same spot regardless of the weave, but it may take a tighter woven fabric longer to achieve the same state of full relaxation (Higgins, Anand, Holmes, Hall, & Underly, 2003).

Progressive shrinkage occurs at each laundering. Wool and rayon are the only major fibers subject to progressive shrinking action. Agitation plays an important role in progressive shrinkage. When the frictional forces between fibers are overcome through agitation the fibers are allowed to move. A low wet modulus contributes to the fibers easy extension when wet and retraction when dry. The fibers become entangled which then consolidates the structure. The more vigorous the agitation, the greater the shrinkage exhibited. Subsequently, when the fabric is tumble dried with heat the water is pulled out of swollen fibers causing them to collapse and leave room in the yarn and fabric structure for movement. Higher temperatures increase progressive shrinkage (Collier & Epps, 1999).

Shrinkage effects primarily hydrophilic fibers, as they are the ones that allow the water to soak into the fiber and swell, hydrophobic fibers will exhibit very little shrinkage. Cotton and rayon from bamboo are both hydrophilic fibers (Johnson & Cohen, 2010).

Fabric Hand

Hand includes a variety of factors related to the aesthetic or feel of the fabric interpreted by a person. Such factors would include flexibility, compressibility, extensibility, resilience, density, surface contour, surface friction, and thermal character. The interaction between all factors determines the overall hand or feel of the particular fabric. It is important to note that the desired properties of hand will vary depending on the application. While softness would be desirable in a product such as bed sheets, stiffness would be desirable in another context (Collier & Epps, 1999).

The hand of the fiber is affected by its shape, surface, configuration, yarn, construction, and finishing. The shapes of fibers vary and can include shapes such as round, flat, and multilobal. Round fibers tend to feel soft and smooth, while multilobal and flat fibers have a harsher hand (Johnson & Cohen, 2010; Elsasser, 2010). Similarly, filament fibers would contribute to a smoother hand then staple fibers would (Collier & Epps, 1999). While the shape of natural fibers cannot be altered, synthetic fibers are very versatile. Fiber surfaces also vary having attributes such as smooth, serrated, or scaly. Fiber configuration is either crimped or straight. Similarly, configuration of synthetic fibers can also be manipulated. The finishes, softeners, coatings and starches used on fabrics can influence the overall hand of a product (Collier & Epps, 1999). Terms such as soft, crispy, dry, silky, stiff, boardy, or harsh are just a few terms used to describe hand (Johnson & Cohen, 2010).

Drape is the ability for a fabric to bend and fold under its own weight. A high degree of drape would be related to a low bending resistance. While several factors affect drape, in general when rayon and cotton fabrics of similar thread counts are compared the rayon exhibits greater drape. As discussed with hand, the level of drape depends on the application. Wingate (1964) found that less drapable fabrics were desirable in the 1960s because prevailing fashions were primarily composed of geometric stiff fabrics. A similar study in 1990 showed that fabrics with more drape were desirable as fluid lines were the prevailing fashion trend. The specific application will affect the desired drape (Collier & Epps, 1999).

There are several factors that could influence and account for the degree of drape in a specific fiber. These factors would include the fiber, the yarn, the fabric structure, the construction and the finishing (Pant, 2010). While some fibers are more rigid, others will naturally be more prone to bending. Synthetic fibers definitely have greater variability and can be altered to achieve desired bending rigidity. Filament fibers will have more drape than staple fibers, and since all natural fibers except silk are filament fibers, they will generally exhibit less drape. The twist of the yarn will also affect drape. The lower the twist the higher drape will be. It is important to remember that filament fibers are not going to need the same amount of twist that a staple fiber would, and thus could be more prone to draping. Denier could also have an effect on the drapability of the yarns, and fabric (Johnson & Cohen, 2010; Pant, 2010). The weave will also affect draping. For example a satin weave would exhibit more drape than a plain weave because it has more floats, which lends itself to drape. Similarly, fabric tightness will also influence drape. Finally the construction and finishing will affect drape. Many of the finishes applied, especially resin based, will effect the drape of the fabric. In general, finishes lessen drape, but it does depend on the finish. Some finishes will have no effect on the drape of the fabric (Pant, 2010).

Prostrel discusses the importance of the aesthetic value of a product. The marketability of a product with positive aesthetic properties is significantly more than that of a product lacking aesthetic appeal (Prostrel, 2004). The value, appeal, and marketability of an aesthetic textile should not be underestimated or overlooked.

Fabric Weight, Thickness, and Density

Fabric thickness is measured by placing a fabric between two metal plates while standardized pressure is applied. The distance between the two plates is then measured and recorded (Collier & Epps, 1999). Taking several measurements throughout the fabric with different lengthwise and crosswise grains should be taken and then averaged for the most correct measurement (Johnson & Cohen, 2010). The thickness will influence the measurement of density and its corresponding characteristics.

The density of fabric is the weight relative to the thickness of the fabric. Density is figured in g/cm^3, which provides a standard for comparing density. A thick fabric that is lightweight will be warmer than a thinner fabric that is also lightweight (Collier & Epps, 1999). Density has an especially significant effect on the comfort aspects of moisture and heat transfer. Moisture can travel through a fabric via diffusion. This is facilitated through fabrics with interstices, or open spaces with in the fabric structure, and even the interstices between and in the yarn. As fabric interstices increase in number and size, moisture transport is enhanced. Dead air space facilitated through lower densities acts as an insulator towards outside temperatures, and contributes to thermal regulation, or heat transfer. The controlling of heat and moisture transfer contributes significantly to comfort characteristics. Density also influences the porosity, which is closely related to cover (Collier & Epps, 1999).

The weight of a fabric is taken on a scale in standard atmospheric conditions. If two fabrics of the types of fabrics are being compared the fabric that weighs more is considered superior. For example a heavier terry cloth is considered better quality than a lighter terry cloth. Fabric weight is also used in determining end use (Johnson & Cohen, 2010).

Summary

The literature review tells us a lot about rayon from bamboo, and can give indications of expected results from designated tests. Fiber made from bamboo is in fact rayon from bamboo. While a versatile and usable fiber, it is not environmentally friendly, or antimicrobial. By looking at the characteristics of viscose rayon a prediction can be made regarding rayon from bamboo. Understanding how the laundering process works provides a base understanding for what is being investigated for the research project. Understanding what dimensional change is and why it happens illustrates the effect that both rayon from bamboo, and cotton fibers may exhibit through the laundering process. Understanding hand provides base knowledge to judge the respective fabrics. The fabric weight, thickness and density can provide information on the specifics of the fabric. The literature review provided an adequate background to understand the implications of the tests.

CHAPTER 3

METHODOLOGY

Introduction

Three tests were conducted with correlating AATCC were used. Each test consisted of the rayon from bamboo sheet, and the cotton sheet specimen being tested when new, washed once, washed six times, and washed 12 times. Each wash cycle included the washing machine cycle, and the drying done in a tumble dryer. The first test measured the amount of dimensional change in the fabric determining whether or not the fabric can maintain relative dimensional stability. The second test determined the softness and drapability of the hand of the fabric, which gives insight into the aesthetic appeal of the fabric. Finally, the fabric weight, density and thickness were measured indicating the retention of fibers, which leads to multiple conclusions regarding additional performance characteristics. The compilation of these test results provided adequate information to determine whether or not the specified sheet application for rayon made from bamboo is suitable for the bed sheet application.

Laundering

The AATCC has released conditions to perform standardized home laundering tests (AATCC, 2011). The washer and dryer were checked to comply with set standards. Before each washing of the designated fabrics, the test specimens were weighed and enough ballast was be added to equal 1.8 ± .1 kg (4.00 ± .25 lb.). The fabric was weighed in standard temperature (70° ± 2° F) and relative humidity (65 ± 2). This controlled the amount of agitation during the washing cycle, ensuring that each fabric received equal agitation. Specified water level, temperature and rinse temperature were measured, confirming that they complied with AATCC standards. The washing machine was filled with 18 ± .5 gallons of water at the beginning of each cycle. 66.0 ± 1 g of 1993 AATCC Standard Reference Detergent was then added to each load. The water was agitated to dissolve detergent. The weighed test specimen and ballast were then added to the washer. Normal settings were selected, and the washer was allowed to run its cycle. Immediately after the end of the washing cycle, the specimens were moved to the tumble dryer and run on a normal cycle according to the AATCC guidelines. Fabrics were then placed back in standard temperature and humidity for a minimum of four hours until any testing of the specimen began.

Dimensional Change

Procedures

This testing was based on the AATCC Technical Manual outline of test method 135-2010. Before laundering, the fabrics were placed in standard temperature (70 ± 2°F) and relative humidity (65 ± 2%) for a minimum of 4 hours. Atmospheric temperatures were obtained and maintained through temperature (thermostat) and humidity controls (humidifiers). A thermometer measured the temperature and the humidity is measured by a hygrometer. In an effort to obtain comparable fabrics both the cotton and rayon from bamboo were confirmed to have a 300-thread count and a plain weave. With the entire specimen laying on a flat surface, three test specimens were marked. Marking was standardized to 250-mm squares taken from different lengthwise and crosswise yarns.

Both the rayon from bamboo and cotton bed sheets were marked with indelible ink. Fabrics were then washed according to the washing conditions stated above. After each specified wash cycle the specimens were placed back into the standard temperature and humidity for a minimum of 4 hours before any testing of the specimen was done. The fabric was then measured and data recorded.

Data Collection

While fabric is lying on a flat surface (in standard atmospheric temperatures) the dimensional changes for each specimen was measured to the nearest tenth of an inch. Both the warp and weft yarns were calculated and recorded separately. The following measurements were then figured to determine the average percent of dimensional change on the sets of specimens. Each set (1 wash, 6 washes, and 12 washes) were calculated and analyzed. Statistical analysis was performed to determine the significance of the measurements gathered.

a. Average % DC = 100(B-A)/A

    i. DC = Average dimensional change

    ii. A = original dimension

    iii. B = Average dimension after laundering.

Data Analysis

Comparisons between the numbers of washes, and the fabric type (rayon from bamboo vs. cotton) were analyzed against each other to determine the differences within washes, and the differences between fibers. The comparative change between rayon from bamboo and cotton fabric were analyzed to determine whether the change was identical, or whether there a significant difference existed.

Fabric Hand

Procedures

The fabric hand tests involved two parts. The first was the panel evaluation of the softness of the fabric, and the second was the figuring of drape coefficients via the Cusick Drape Tester. The evaluation of the softness of fabrics is generally outlined in the 2011 AATCC technical manual. The Cusick Drape Tester is standardized by the British Standard 5058: Method for the assessment of drape of fabrics (Pant, 2010). The specific outlined instructions are outlined in this paper.

The softness panel was done in accordance with AATCC testing procedures. The softness test was given to eleven different evaluators. Questions were asked to evaluators to ensure that the evaluator was relaxed and comfortable in a room free of distractions. The facilitator provided instructions about the elements of hand being evaluated, which was softness. The facilitator then provided instructions regarding the pairs of fabrics that the evaluator would be rating. The facilitator gave the evaluator two fabrics at a time and the evaluator was asked to determine which specimen was the softest. Comparisons were made between fabrics, which differed in their amount of wash. Every combination of fabrics was given totaling 16 evaluations. Ratings were communicated orally and recorded by the facilitator. Evaluators were free to close their eyes if desired. The entirety of the test did not take more than 15 minutes per evaluator. The specimen was placed on a smooth, nonmetallic surface. The evaluator first touched the specimen with their fingertips. While still on a flat surface, the evaluator held the fabric with one hand and stroke the fabric with the other. The fabric could then be touched or pressed with the fingers or palm of the hand. The evaluator was able to then pick up the fabric and rub it between the fingers and thumb of the hand. If desired, the fabric was crushed in the palm of the hand. The softness rating was verbally communicated to the facilitator where it was immediately recorded. The same person then repeated the test within 1-5 days. If the same results were not produced on the same set of fabric, that portion of their results was omitted from the report.

The Cusick Drape Meter was used to calculate drape. One of the major benefits of using the drape meter in place of an evaluation panel is the yielding of more concrete, less biased, and less subjective results than obtained from a panel. Samples of 24, 30, and 36 centimeters can be tested on the drape meter, and the selected size depends on the type of fabric. The three drape coefficients obtained from the various sizes of tested materials are not comparable; accordingly, a drape coefficient from a 36-cm ring is not comparable to that of a 24- or 30-cm ring. To determine the appropriate size of circle, a test was done using the 30-cm ring. If the drape coefficient is below 30% the 24-cm ring was to be used, and if the drape from the 30-cm ring is above 85% than the 36-cm ring was to be used (Saville, 1999). The test works as a circular fabric of designated dimensions is supported on a central disk, while the unsupported edges hang under its own weight. A light shines up through the test creating on a shadow on the standardized annular ring, which is on the unsupported fabric, creating a shadow in the draped area. After the shaded area has been traced it was cut out and used to figure the drape coefficient (Kenkari & May-Plumlee, 2005; Saville, 1999). The more shadowed area the stiffer the fabric, and the higher the drape coefficient. The test was performed as outlined and on the 30-cm ring, the first two drape percentages (on the cotton and rayon from bamboo) came out as 52.63% and 84.21%. The 30-cm was chosen to evaluate all of the ensuing samples. Each sample was cut from different lengthwise and crosswise grains of the fabric. Since the washing of the same samples would result in fraying which would distort the test, new samples were cut after each washing threshold. Three samples were cut and tested after each of the specified laundering cycles.

Data Collection

Results from the softness panel will be analyzed. If the answers of the evaluators were not identical for the two tests, then the differing answers would be omitted from the data. Results will not undergo any statistical analysis, but will be reported.

The drape coefficient will be figured by the following equation:

Drape Coefficient = Shaded area/Original ring

The three drape coefficients for each stage will be recorded for analysis. Statistical analysis will be done to determine whether or not there is a significant change at the various washings.

Data Analysis

The data analyses for the softness test and drapability test were handled differently. Given the subjective nature of the softness panel test, no statistical analysis was done. The numbers were reported and general trends were identified. Conversely, statistical analysis was done on the drapability test and significant differences were acknowledged. General trends in the data were identified. The comparability between the cotton and rayon from bamboo fabric, as well as the interaction between washes was analyzed. Results were reported accordingly. It can be assumed that if there were a significant change throughout the laundering cycles in the sheets that the drapability characteristic of hand is altered through the laundering of the fiber, whereas, no significance would illustrate little or no notable change.

Fabric Weight, Thickness, and Density

Procedures

The fabric samples were cut measuring 12 inches by 12 inches from different lengthwise and crosswise yarns. Fabrics were weighed in ounces after sitting for a minimum of four hours in the standard temperature and relative humidity. The weights were calculated in oz./yd^2 to give standardized and comparable numbers. A minimum of three fabric thickness tests will be done, averaged and recorded for every one sample. There were three total samples for each specified degree of laundry cycles. The fabric thickness measurements were recorded to the nearest tenth of a millimeter. Using both the weight and the thickness previously taken the density was calculated and recorded in g/cm^3.

Data Collection

Thickness data was collected using the thickness meter. The weight was taken with a scale. Standardized weight was recorded in oz/yd^2. The length and width of the fabric were taken with a ruler, and measured exactly 12 inches by 12 inches. The thickness was recorded in millimeters. Density values were calculated and recorded in g/cm^3. Three fabrics samples were tested at each laundry cycle benchmark, and each in standard atmospheric conditions.

Data Analysis

The weight, density, and thickness will provide a lot of valuable information about the fabric. The weight, density, and thickness will be compared when the sample is new, washed once, washed 6 times, and washed 12 times. Comparisons will be made between the rayon from bamboo and cotton fabrics as well as the changes within and between laundering cycles.

Weight is often an indicator of fabric quality. If the weight decreases significantly it can be determined that the actual quality of the fabric has decreased to a degree. While the moisture regain percentages are similar for both rayon from bamboo and cotton (Johnson & Cohen, 2010), the amount of fibers present will affect the absorbency of the fabric because it will change the amount of moisture it will be able to take up. If a fabric loses a significant amount of weight outside factors such as absorbency, and cover will be negatively affected. Loss of fibers could be attributed to the lint removed in the drying process, or the breaking of weak fibers. An increase in weight could be accounted for by shrinking of the fabric resulting in more yarns per inch and thus a larger weight. It is important to look at these measurements of the fabric because it is determining whether or not the quality of fabric is maintained through successive washings.

Two major factors that density contributes to include heat transfer and moisture transport. A decreasing density would result in more heat retention, as an increase in air pockets would allow more insulation between the body and the general atmosphere. An increasing density results in less heat transfer, and a poorer sheet quality in that respect. Moisture transport is affected similarly and would increase as the density decreases. Moisture transport is key in the functionality and effectiveness of sheets.

Summary

Three tests were performed on the two fabrics. First, dimensional change through the laundering process was measured. This gave an indication of whether or not the fabric is able to hold its shape through successive washes. The second test was the evaluation of hand throughout the laundering process. A panel of judges evaluated the softness aspect of hand, and the Cusick Drape meter was used to give an indication of drape. The third test measured thickness, density, and weight throughout the laundering process. After the third test was completed a determination of the retention of fibers, the comparative quality and the relation with other factors such as absorbency were performed. The applicable tests followed the AATCC guidelines in order to complete the comparison of rayon from bamboo and cotton in the bed sheet application.

CHAPTER 4

RESULTS AND DISCUSSION

Introduction

The purpose of this study was to determine the performance characteristics of rayon from bamboo in relation to three tests conducted during laundering. The testing of the performance characteristics consisted of the following tests: dimensional change, fabric hand, and fabric weight, thickness and density. Determining the effect of these characteristics during laundering resulted in rayon from bamboo being suitable for bed sheets in relation to hand, change in weight, thickness, and density. However, this fabric is not dimensionally stable after repeated laundering. The following chapter will discuss data analysis procedures and findings for the study. Quantitative data were analyzed using SPSS 20.0 (SPSS, Inc.). The strategies for data analysis and their justification in response to the research questions will be described at the beginning of each section.

Data Collection

Three tests with correlating AATCC guidelines were used to determine the performance characteristics of rayon from bamboo. Each test consisted of the rayon from bamboo sheet and the cotton sheet specimen being tested when new, washed once, washed six times, and washed twelve times. Each wash cycle included washing the fabrics using the machine cycle and drying in a tumble dryer. The first test measured the amount of dimensional change in the fabric determining whether or not the fabric is able to maintain relative dimensional stability. The second test determined the softness and drapability of the hand of the fabric, which gives insight to the aesthetic appeal of the fabric. Finally, the fabric weight, density and thickness were measured indicating the retention of fibers, which leads to multiple conclusions regarding additional performance characteristics.

Research Questions

The following research questions were addressed by this study:

1. Is rayon from bamboo suitable for the sheet application?
2. Will the laundering of rayon from bamboo have a significant effect on key characteristics of the fabric's performance?
3. Does the laundering of cotton have a significant effect on key characteristics of fabric performance?
4. Does the amount of laundering have an effect on the hand of rayon from bamboo and cotton fabrics?
5. Is rayon from bamboo or cotton fabric considered to have superior hand? Does this change throughout successive washings?
6. Will the fabric weight/thickness/density of rayon from bamboo decrease, increase, or remain the same throughout successive washings?
7. How much will the fabric weight/thickness/density of rayon change in comparison to the change of cotton?
8. Does the amount of laundering affect the dimensional stability of rayon from bamboo and cotton fabric?
9. Does rayon from bamboo or cotton fabric have more dimensional stability?

Data Analysis

Dimensional Stability

The dimensional stability test documents the shrinkage of the selected fibers. The warp (lengthwise) yarns, and the weft (crosswise) yarns are measured, figured, and analyzed separately. Results from the test are necessary in order to document the overall change of the fabric. Tables 1 and 2 provide the mean shrinkage percent for each washing cycle for the selected fibers. While the cotton warp and weft yarns shrunk approximately 8.75% and 3.92%, respectively, by the 12th wash, the rayon warp and weft yarns shrunk approximately 13.07% and 6.75%, respectively. These percentages clearly indicate that rayon from bamboo exhibited significantly more shrinkage than cotton in both the warp and weft direction. In conjunction with Table 1 and 2, Figure 1 illustrates the relative amount of change exhibited at each measured wash level. With the exception of the cotton warp yarns the most significant change was evidenced at the first wash. Shrinkage was evidenced at further washings, but to a lesser degree in both the cotton and rayon from bamboo yarns.

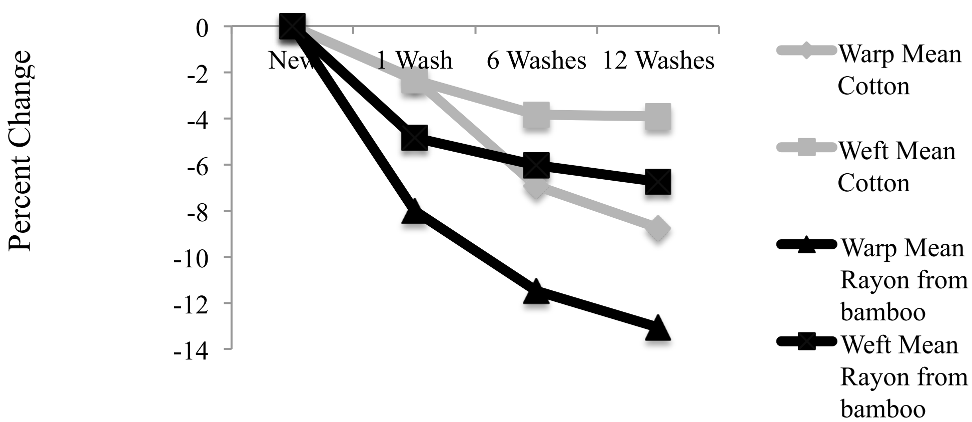

Figure 1. Warp and weft percentage change for dimensional stability.

Table 1

Cotton Descriptive Statistics of Warp and Weft Percent Change

Laundering cycle	Warp Mean	Warp Standard Deviation	Weft Mean	Weft Standard Deviation
New	.000000	.00000	.000000	.00000
One	-2.29167	1.678603	-2.33333	.288675
Six	-6.91667	.629153	-3.83333	.144338
Twelve	-8.75000	.00000	-3.91667	.144338

Note. Each sample was tested three times at each recorded laundering cycle

Table 2

Rayon Descriptive Statistics of Warp and Weft Percent Change

Laundering cycle	Warp Mean	Warp Standard Deviation	Weft Mean	Weft Standard Deviation
New	.00000	.00000	.00000	.00000
One	-8.0000	.00000	-4.83333	.288675
Six	-11.475	.34731	-6.04167	.36084
Twelve	-13.067	.11547	-6.7500	.433013

Note. Each sample was tested three times at each recorded laundering cycle

The calculated *p*-values confirm the significant statistical difference between the cotton sheet and the rayon from bamboo sheet in both the warp and weft directions (see Table 5). Referring back to Table 1, Figure 1, and looking at the mean difference listed in Table 5, it can be concluded that rayon from bamboo has less dimensional stability than cotton. Acceptable levels of shrinkage will be discussed in the conclusion.

Table 3

Tests of Between-Subjects Effects for Weft Percent Change

Source	Type II Sum of Squares	*df*	Mean Square	*F*	Sig. (P)	Partial Eta Squared
Corrected model	134.807	7	19.258	292.876	.000	.992
Intercept	287.907	1	287.907	4378.465	.000	.996
Material	21.329	1	21.329	324.366	.000	.953
Laundry cycle	106.075	3	35.358	537.726	.000	.990
Material by cycle	7.403	3	2.468	37.528	.000	.876
Error	1.052	16	.066			
Total	423.766	24				
Corrected total	135.859	23				

R Squared = .992 (Adjusted *R* Squared = .989)

While the *p*-values in Tables 3 and 4 indicated a significant difference in the wash cycles, individual changes occurred in a pairwise comparison between wash cycles within their respective fibers (see Table 6). All interactions between wash levels were significant, except the shrinkage between the sixth wash and the 12th wash in the weft direction for the cotton. Further, it can be concluded that both fabrics continued to shrink after each washing level was tested. Overall, the degree of shrinkage varied between the two fabrics. Specifically, the rate of shrinkage for the cotton fabric decrease between the sixth and twelfth laundry cycles and a maximum shrinkage of 8.75% in the warp direction occurred.

Table 4

Tests of Between-Subjects Effects for Warp Percent Change

Source	Type II Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Squared
Corrected model	531.860	7	75.980	181.580	.000	.988
Intercept	956.344	1	956.344	2285.512	.000	.993
Material	79.753	1	79.753	190.596	.000	.923
Laundry cycle	423.864	3	141.288	337.656	.000	.984
Material by cycle	28.243	3	9.414	22.499	.000	.808
Error	6.695	16	.418			
Total	1494.899	24				
Corrected total	538.555	23				

R Squared = .988 (Adjusted *R* Squared = .982)

Table 5

Fabric Significance of Warp and Weft Dimensional Stability Between Cotton and Rayon from Bamboo

	Mean Difference	Standard Error	Sig.
Warp	3.646	.264	.000
Weft	1.885	1.05	.000

Conversely, the rate of shrinkage for the weft yarns did not exhibit as dramatic a plateau resulting in a change not exceeding 4%. Evidence of the plateau trend in the cotton fabric is evidenced by the low standard deviation in the warp direction (.000000 standard deviation) and trace examples in the weft direction (.14438 standard deviation) indicating little variance in the reported results (see Table 1). No significance in the cotton weft direction between washes six and 12 (see Table 6) could further confirm theory that cotton fabric was reaching a plateau.

Table 6

Pairwise Comparisons of Material and Laundering Cycles of Percent Warp and Weft Change for Cotton

Laundry Cycle	Laundry Cycle	Warp Mean Difference	Standard Error	Sig.	Weft Mean Difference	Standard Error	Sig.
	1	2.292	.528	.001	2.333	.209	.000
New	6	6.917	.528	.000	3.833	.209	.000
	12	8.750	.528	.000	3.917	.209	.000
One	New	-2.292	.528	.001	-2.333	.209	.000
	6	4.625	.528	.000	1.500	.209	.000
	12	6.458	.528	.000	1.583	.209	.000
Six	New	882.169[d]	.528	.000	-3.833	.209	.000
	1	344.095	.528	.000	-1.500	.209	.000
	12	3936.494	.528	.003	.083	.209	.696
Twelve	New	615.032[e]	.528	.000	-3.917	.209	.000
	1	418.685	.528	.000	-1.583	.209	.000
	6	2936.004	.528	.003	-0.083	.209	.696

Further testing could determine whether or not the cotton would shrink past these specified levels during further washing or if they had reached their ultimate shrinkage. Rayon from bamboo had the most shrinkage initially, but continued to shrink through successive washings. The pattern exhibited in both the weft and warp directions for the rayon from bamboo was similar in the proportional amount of shrinkage that took place in relation to the shrinkage of cotton, but differed in the degree of shrinkage. The amount of shrinkage at every laundry cycle measured decreased in relation to the last.

The warp standard deviation at twelve washes was low at .11547 (see Table 1), but the weft standard deviation at twelve washes was quite high at .433013 (see Table 1). Unlike cotton, these standard deviations, especially in the weft direction do not lead to the conclusion that the values had reached maximum shrinkage. Further testing could be done to determine how long and to what extent the rayon from bamboo would continue to shrink.

Table 7

Pairwise Comparisons of Material and Laundering Cycles to Percent Warp and Weft Change for Rayon from Bamboo

Laundry Cycle	Laundry Cycle	Warp Mean Difference	Standard Error	Sig.	Weft Mean Difference	Standard Error	Sig. (P)
	1	8.000	.528	.000	4.833	.209	.000
New	6	11.475	.528	.000	6.042	.209	.000
	12	13.067	.528	.000	6.750	.209	.000
One	New	-8.000	.528	.000	-4.833	.209	.000
	6	3.475	.528	.000	1.208	.209	.000
	12	5.067	.528	.000	1.917	.209	.000
Six	New	-11.475	.528	.000	-6.042	.209	.000
	1	-3.475	.528	.000	-1.208	.209	.000
	12	-1.592	.528	.000	.708	.209	.004
Twelve	New	-13.067	.528	.000	-6.750	.209	.000
	1	-5.067	.528	.000	-1.917	.209	.000
	6	-1.592	.528	.000	-.798	.209	.004

Fabric Hand

Fabric Softness

Data on fabric softness was gathered using a panel of evaluators who compared cotton and rayon from bamboo based on the number of laundry cycles completed. Table

8 and 9 include the data from the panel based on their individual preference for each fabric comparing the number of laundry cycles completed. As evidenced in Table 8 and 9, the majority of the responses were invalid.

Table 8

Softness Panel Results for Cotton

	Softness Preference					
Comparison of Laundry Cycle	Invalid Response	Same	New	One	Six	Twelve
New vs. One	5	3	0	3		
New vs. Six	6	1	1		3	
New vs. Twelve	2	0	1			8
One vs. Six	2	3		3	3	
One vs. Twelve	5	1		4		1
Six vs. Twelve	6	1			1	3

A recorded invalid response indicated that the evaluator was unable to give the same softness rating at two different test times. According to Table 8 there were 26 total invalid responses, which accounts for 39% of the total responses given for cotton. Table 9 indicates that 34 answers were invalid resulting in 52% of the total answers given regarding rayon from bamboo. Of the remaining valid answers given, a portion of those could be attributed to chance.

This leads to the conclusion that the results for the softness panel were altogether inconclusive. When looking at the valid responses that were given there don't seem to be any prevailing trends between laundry loads and the degree of softness within the fibers.

It cannot be concluded that the softness of either the cotton or the bamboo increased or decreased as a result of laundering. Further tests could be performed using a testing instrument that would be able to test to a finer degree.

Table 9

Softness Panel Results for Rayon from Bamboo

	Softness Preference					
Comparison of Laundry Cycle	Invalid Response	Same	New	One	Six	Twelve
New vs. One	6	0	0	5		
New vs. Six	5	0	3		3	
New vs. Twelve	4	0	4			3
One vs. Six	7	0		3	1	
One vs. Twelve	5	0		5		1
Six vs. Twelve	7	1			2	1

Fabric Drape

The Cusick Drape Tester was used to measure the drape coefficients of each fabric. Data in Table 10 and 11 present the mean values for the tested drape. The mean of cotton (.842100) was initially significantly higher than that of rayon from bamboo (.543833), indicating that the rayon from bamboo exhibited superior drape. By the conclusion of the twelfth cycle the cotton mean (.684200) remained higher than that of rayon from bamboo (.350867) indicating that rayon from bamboo was able to retain superior drape compared to cotton throughout the laundering cycles. Standard deviations for both fibers are low at each laundering cycle tested indicating little variance in the results.

Table 10

Descriptive Statistics of Drape Coefficients for Cotton

Laundering Cycle	Mean	Standard Deviation	# of Tests
New	.842100	.00000	3
One	.754333	.0303686	3
Six	.771933	.0304264	3
Twelve	.684200	.0303975	3

Table 11

Descriptive Statistics of Drape Coefficients for Rayon from Bamboo

Laundering Cycle	Mean	Standard Deviation	# of Tests
New	.543833	.0303686	3
One	.385967	.0304264	3
Six	.333300	.0303975	3
Twelve	.350867	.0303686	3

The *p*-values in Table 12 indicate a significant difference between the fabric type, laundering cycles, and the interaction between the laundering cycles within the fabric type, in regards to drape. For statistical analysis of the drape coefficients, a *p*-value of .05 or less was deemed to be sufficient to accept as statistically significant. Figure 2 compares the drape coefficient results of the two fibers illustrating the higher drape coefficient of cotton.

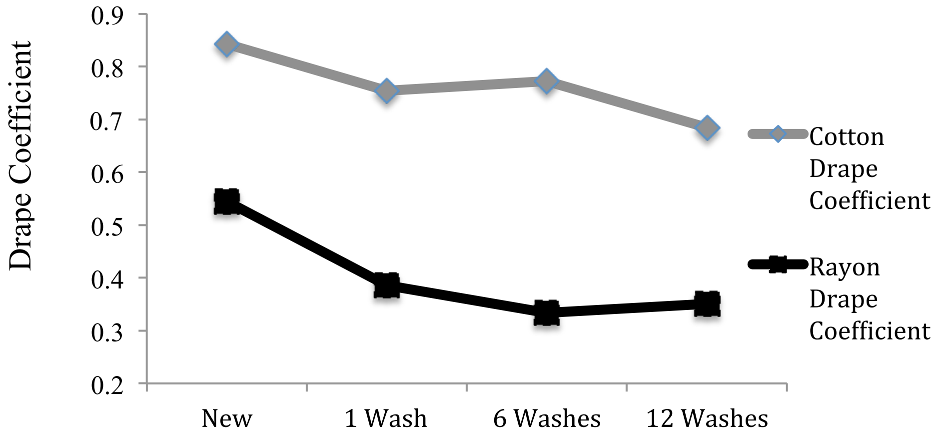

Figure 2. Drape coefficients of cotton and rayon from bamboo.

As evidenced by the data, an apparent gap between rayon from bamboo and cotton was exhibited in Tables 10 and 11 with a calculated *p*-value of .000. Further, Table 13 confirms that the mean difference between rayon from bamboo and cotton is significant. Rayon from bamboo had a lower drape coefficient than cotton at the end of each laundering cycle; therefore is considered to have a greater drapability.

While there is a distinct difference between the drape coefficients of rayon from bamboo and cotton, results between the levels of washing were not all significant. As evidenced by the *p*-value in the pairwise comparisons in Table 14, the cotton exhibits no significant difference between the first wash and the sixth wash. The rayon from bamboo (Table 15) did not exhibit a significant difference from the first to sixth wash, and the sixth to twelfth wash. This means that the twelfth wash showed no significant change between the two previous washes, and further meaning that the drape from the rayon from bamboo stayed largely the same.

Table 12

Tests of Between-Subjects Effects for Drape Coefficients

Source	Type II Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Squared
Corrected Model	.897	7	.128	184.977	.000	.988
Intercept	8.166	1	8.166	11787.460	.000	.999
Material	.776	1	.776	1120.241	.000	.986
Laundry Cycle	.105	3	.035	50.424	.000	.904
Material by Cycle	.016	3	.00	7.776	.002	.593
Error	.011	16	.001			
Total	9.074	24				
Corrected Total	.908	23				

R Squared = .988 (Adjusted *R* Squared = .982)

Both the cotton and the rayon from bamboo did show a significant change between the new fabric and first wash. So while it can determine that there was a significant difference between the two fibers as a whole, it cannot conclude that there was a significant difference between all levels of washing within the fibers. Further research could be conducted to determine whether or not changes would be exhibited after the 12th wash.

Table 13

Significance for Drape Coefficient Between Fabrics

Mean Difference	Standard Error	Sig.
.360	.011	.000

Table 14

Pairwise Comparisons of Cotton and Laundering Cycles Related to Drape Coefficients

Laundry Cycle	Laundry Cycle	Mean Difference	Standard Error	Sig.
New	1	.088	.021	.001
	6	.070	.021	.005
	12	.158	.021	.000
One	New	-.088	.021	.001
	6	-.018	.021	.425
	12	.070	.021	.005
Six	New	-.070	.021	.005
	1	.018	.021	.425
	12	.088	.021	.001
Twelve	New	-.158	.021	.000
	1	-.070	.021	.005
	6	-.088	.021	.001

Table 15

Pairwise Comparisons of Rayon from Bamboo and Laundering Cycles Related to Drape Coefficients

Laundry Cycle	Laundry Cycle	Mean Difference	Standard Error	Sig.
New	1	.158	.021	.000
	6	.211	.021	.000
	12	.193	.021	.000
One	New	-.158	.021	.000
	6	.053	.021	.026
	12	.035	.021	.122
Six	New	-.211	.021	.000
	1	-.053	.021	.026
	12	-.018	.021	.426
Twelve	New	-.193	.021	.000
	1	-.035	.021	.122
	6	-.018	.021	.426

Fabric Weight, Thickness, and Density

The weight of the fabric was taken on a scale in standardized conditions and measured in oz/yd^2. The thickness in millimeters was taken with a thickness tester that measured the fabric as they were placed between two metal plates. Due to the fact that density is a measure of mass in relation to volume, the density was figured taking both the fabric weight and thickness into account. Each tests was analyzed separately

Table 16 and 17 present the calculated mean scores for both the cotton and rayon from bamboo fibers, respectively. This allows for a comparison between the numbers of the two fibers, and the specific results at each wash. Using the given data in the mentioned tables, Figure 3 illustrates the clear gap between the weights of the fabrics at all washing levels. Rayon from bamboo was clearly the heavier fabric at all tested laundry level, while cotton was the lighter of the two. In both fibers the largest amount of weight gain took place after the first wash. Both fibers seemed to continually gain weight throughout the duration of the test.

Table 16

Descriptive Statistics for Fabric Weight Measured in oz/yd^2 for Cotton

Laundering Cycle	Mean	Standard Deviation	# of Tests
New	3.369600	.000000	3
One	3.611267	.0584278	3
Six	3.852000	.000000	3
Twelve	3.945000	.0259808	3

Table 17

Descriptive Statistics for Fabric Weight Measured in oz/yd^2 for Rayon from Bamboo

Laundering Cycle	Mean	Standard Deviation	# of Tests
New	3.585600	.0374123	3
One	4.117533	.0584856	3
Six	4.350000	.1039230	3
Twelve	4.665000	.0259808	3

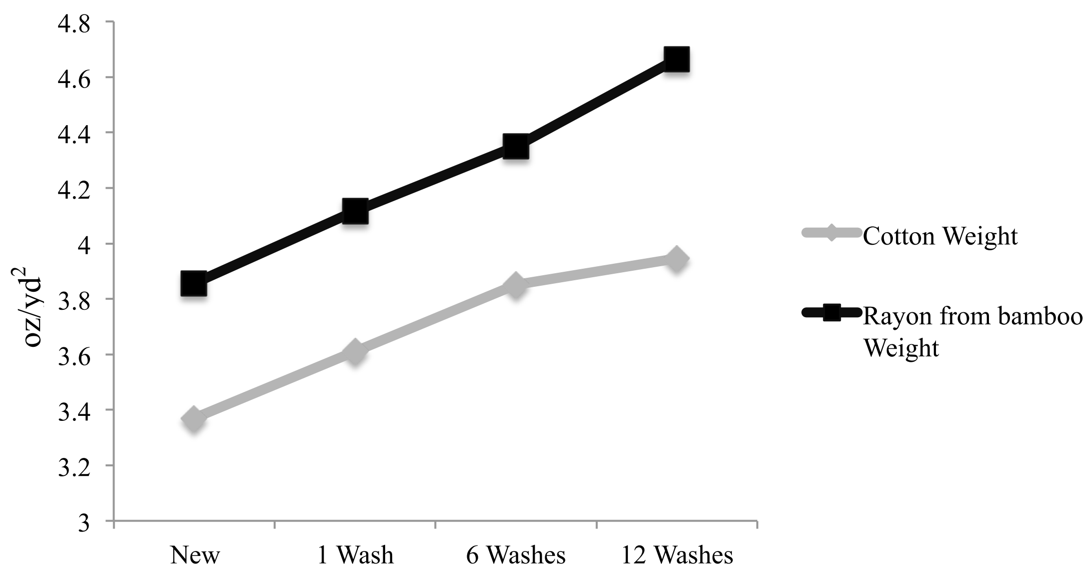

Figure 3. Weights of cotton and rayon from bamboo

The *p*-values in Table 18 present the significant difference between fabric types and differences between washing cycles using a univariate analysis. Table 19 confirms the significant difference in weights between the rayon from bamboo and cotton sheets as a whole. Based on the analyzed data, it is evident that while both fabrics increased weight during the laundering cycles, rayon from bamboo was clearly the heavier fabric at all stages of the laundering cycles.

Table 18

Tests of Between-Subjects Effects for Fabric Weight

Source	Type II Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Squared
Corrected Model	3.892	7	.556	218.185	.000	.990
Intercept	371.362	1	371.362	145745.959	.000	1.000
Material	1.451	1	1.451	569.583	.000	.973
Laundry Cycle	2.246	3	.749	293.836	.000	.982
Material by Cycle	.194	3	.065	25.403	.000	.826
Error	.041	16	.003			
Total	375.294	24				
Corrected Total	3.932	23				

R Squared = .990 (Adjusted *R* Squared = .985)

Table 19

Significance of Fabric Weight Between Cotton and Rayon from Bamboo

Mean Difference	Standard Error	Sig.
-.492	.021	.000

The *p*-values in Table 18 indicated that there were significant differences at individual laundering levels, but Tables 20 and 21 break down the specific levels in their respective fibers in a pairwise comparison. The pairwise comparison for both the cotton and rayon from bamboo prove significance at each level of laundering. While it is known that there was a significant increase of weight at each level, it should be acknowledged that the amount of increased weight was not equal at each laundering cycle measured.

The increase in weight slowed as the number of laundering cycles increased. An increase in the weight of the fabric can be largely attributed to the change of dimensional stability within the fabric, further research should be done to determine whether or not this trend in fabric weight would continue as the dimensional change in each fabric stopped.

Table 20

Pairwise Comparison of Cotton and Laundering Cycle in Relation to Fabric Weight

Laundry Cycle	Laundry Cycle	Mean Difference	Standard Error	Sig.
New	1	-.242	.041	.000
	6	-.455	.041	.000
	12	-.575	.041	.000
One	New	.242	.041	.000
	6	-.214	.041	.000
	12	-.334	.041	.000
Six	New	.455	.041	.000
	1	.214	.041	.000
	12	-.120	.041	.010
Twelve	New	.575	.041	.000
	1	.334	.041	.000
	6	.120	.041	.010

The thickness of both the rayon from bamboo and cotton fabrics increased throughout the wash cycles (see Tables 22, 23, and Figure 4). While cotton started out as the thicker fabric, after twelve washes both the rayon from bamboo and cotton had approximately the same thickness.

Table 21

Pairwise Comparison of Rayon from Bamboo and Laundering Cycle in Relation to Fabric Weight

Laundry Cycle	Laundry Cycle	Mean Difference	Standard Error	Sig.
New	1	-.532	.041	.000
	6	-.764	.041	.000
	12	-1.079	.041	.000
One	New	.532	.041	.000
	6	-.232	.041	.000
	12	-.547	.041	.000
Six	New	.764	.041	.000
	1	.232	.041	.000
	12	-.315	.041	.000
Twelve	New	1.079	.041	.000
	1	.547	.041	.000
	6	.315	.041	.000

Table 22

Descriptive Statistics of Fabric Thickness for Cotton in Millimeters

Laundering Cycle	Mean	Standard Deviation	# of Tests
New	.2867	.00577	3
One	.4167	.00577	3
Six	.5000	.01000	3
Twelve	.5200	.01000	3

For the bed sheet application, the desired thickness of a fabric can vary depending on the consumer's personal preference for warmth and environmental factors such as the weather.

Table 23

Descriptive Statistics of Fabric Thickness for Rayon from Bamboo in Millimeters

Laundering Cycle	Mean	Standard Deviation	# of Tests
New	.2533	.00577	3
One	.3800	.01000	3
Six	.4667	.01155	3
Twelve	.5267	.00577	3

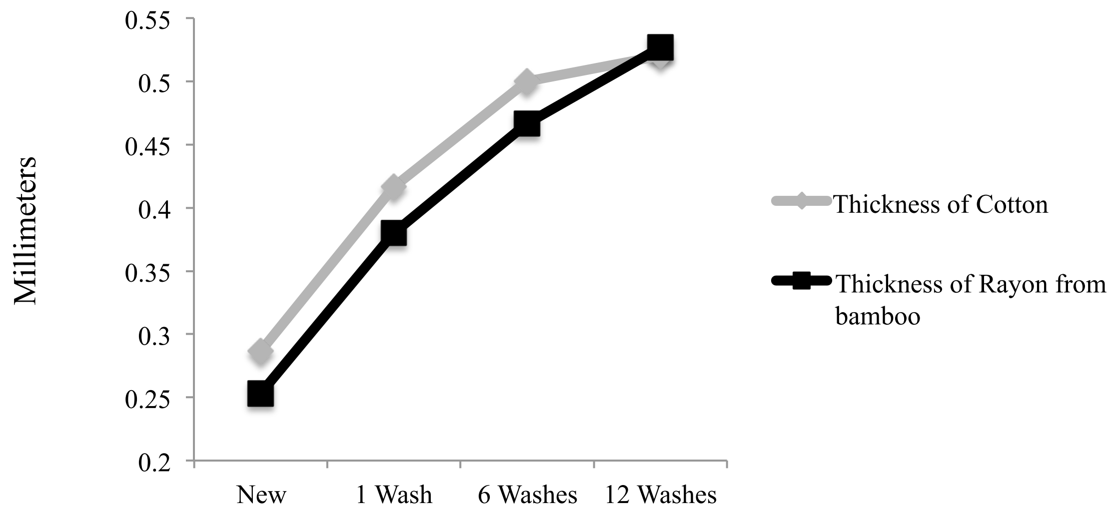

Figure 4. Thickness of cotton and rayon from bamboo.

The *p*-value of .000 in Table 24 referring to the material indicates that there is a significant difference between the two fabric types. This is further confirmed by the significant *p*-value in Table 25. Interestingly enough, the mean difference of .024 listed in Table 25 is quite low. Based on the findings it can be concluded that the difference in fabric thickness was significant, regardless of the fact that the difference between the two fabrics was relatively small.

Table 24

Tests of Between-Subjects Effects for Fabric Thickness

Source	Type II Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Squared
Corrected Model	.231	7	.033	466.546	.000	.995
Intercept	4.208	1	4.208	59413.235	.000	1.000
Material	.004	1	.004	49.471	.000	.756
Laundry Cycle	.226	3	.075	1063.118	.000	.995
Material by Cycle	.002	3	.001	9.000	.001	.628
Error	.001	16	7.083×10^{5}			
Total	4.441	24				
Corrected Total	.232	23				

R Squared = .995 (Adjusted *R* Squared = .993)

Table 25

Significance of Fabric Thickness Between Cotton and Rayon from Bamboo

Mean Difference	Standard Error	Sig.
.024	.003	.000

Table 24 also had a *p*-value of .001 when referring to material by laundering cycle indicating significance between the laundry levels within each material. The pairwise comparison in Tables 25 and 26 provided further insight regarding the significance of each laundry level within each fabric.

Table 26

Pairwise Comparison of Cotton and Laundering Cycles in Relation to Fabric Thickness

Laundry Cycle	Laundry Cycle	Mean Difference	Standard Error	Sig.
New	1	-.130	.007	.000
	6	-.213	.007	.000
	12	-.233	.007	.000
One	New	.130	.007	.000
	6	-.083	.007	.000
	12	-.103	.007	.000
Six	New	.213	.007	.000
	1	.083	.007	.000
	12	-.020	.007	.010
Twelve	New	.233	.007	.000
	1	.103	.007	.000
	6	.020	.007	.010

Table 27

Pairwise Comparison of Rayon from Bamboo and Laundering Cycles in Relation to Fabric Thickness

Laundry Cycle	Laundry Cycle	Mean Difference	Standard Error	Sig.
New	1	-.127	.007	.000
	6	-.213	.007	.000
	12	-.273	.007	.000
One	New	.127	.007	.000
	6	-.087	.007	.000
	12	-.147	.007	.000
Six	New	.213	.007	.000
	1	.087	.007	.000
	12	-.060	.007	.000
Twelve	New	.273	.007	.000
	1	.147	.007	.000
	6	.060	.007	.000

The pairwise comparisons for both the rayon from bamboo and cotton indicate significance at all levels of washing as evidenced by all listed *p*-values. It can be concluded that the increase in thickness between each load measured was substantial, even though the relative increase between levels was not equal.

Tables 28, 29, and Figure 5 present the calculated means for each laundering cycle in relation to the fabric density. While cotton began with a density of .4002 and ended with a density of .256733, rayon from bamboo began with a density of (.481367) and ended with a density of .299730.

Table 28

Descriptive Statistics of Fabric Density Measured for Cotton (g/cm^3)

Laundering Cycle	Mean	Standard Deviation	# of Tests
New	.400200	.0081406	3
One	.294533	.0007506	3
Six	.259867	.0062740	3
Twelve	.256733	.0062780	3

Table 29

Descriptive Statistics of Fabric Density Measured for Rayon from Bamboo (g/cm^3)

Laundering Cycle	Mean	Standard Deviation	# of Tests
New	.481367	.0038682	3
One	.369033	.0035726	3
Six	.315267	.0066154	3
Twelve	.299733	.0039954	3

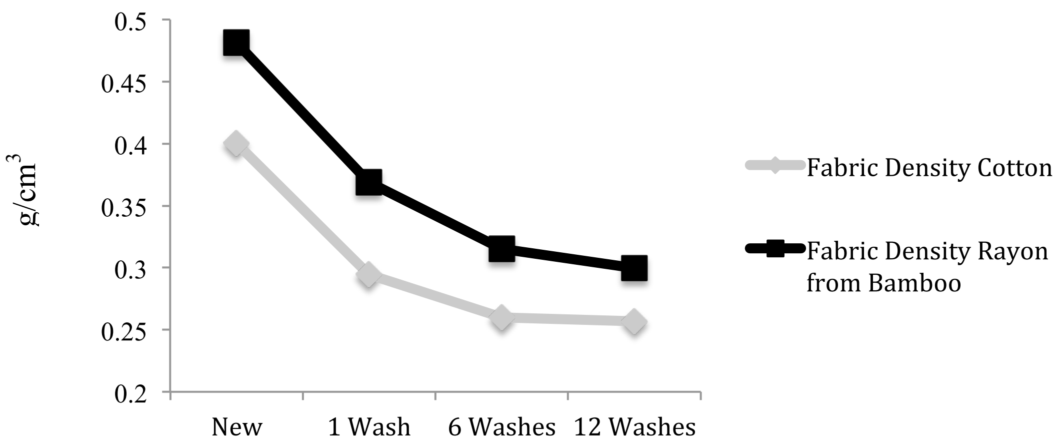

Figure 5. Fabric density of cotton and rayon from bamboo.

As evidenced by the reported numbers and Figure 5, rayon from bamboo maintained a higher density throughout the duration of the test.

Table 30

Tests of Between-Subjects Effects for Fabric Density

Source	Type II Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Squared
Corrected Model	.126	7	.018	615.983	.000	.996
Intercept	2.687	1	2.687	92226.880	.000	1.000
Material	.024	1	.024	830.888	.000	.7981
Laundry Cycle	.100	3	.033	1144.559	.000	.995
Material by Cycle	.001	3	.000	15.772	.000	.747
Error	.000	16	2.913×10^{-5}			
Total	2.813	24				
Corrected Total	.126	23				

R Squared = .996 (Adjusted *R* Squared = .995)

The *p*-value of .000 in Table 30 indicates significance between the two fabrics, and between laundry levels within the fabric. Table 31 confirms the significance between the fabric types. Using the significance from Tables 30 and 31 as well as the previous descriptive statistics regarding the density of the fabrics, it can be concluded that rayon from bamboo is significantly denser than a similar cotton fabric.

Table 31

Significance of Fabric Density Between Cotton and Rayon from Bamboo

Mean Difference	Standard Error	Sig.
-.064	.002	.000

Table 32

Pairwise Comparisons of Cotton and Laundering Cycles in Relation to Fabric Density

Laundry Cycle	Laundry Cycle	Mean Difference	Standard Error	Sig.
New	1	.106	.004	.000
	6	.140	.004	.000
	12	.143	.004	.000
One	New	-.106	.007	.000
	6	.035	.004	.000
	12	.038	.004	.000
Six	New	-.140	.004	.000
	1	-.035	.004	.000
	12	.003	.004	.487
Twelve	New	-.143	.004	.000
	1	-.038	.004	.000
	6	-.003	.004	.487

While Table 30 indicated a significant difference between laundry cycles, the pairwise comparisons in Tables 32 and 33 provide us with the specific significant interactions in both materials. Table 32 indicated that all levels were significant for cotton, except the densities between the 6th and 12th wash as the *p*-value was .487. In comparison with the findings on the dimensional stability test and the fabric weight test, this result supports the previous findings. Table 33 breaks down the interactions of the rayon from bamboo, and significant *p*-values are given for all tested interactions. Unlike cotton, rayon showed significance at the interaction between the 6th and 12th wash in both the dimensional stability test and the fabric weight test. Further analysis in the conclusions will further illustrate this phenomenon.

Table 33

Pairwise Comparisons of Rayon from Bamboo and Laundering Cycles in Relation to Fabric Density

Laundry Cycle	Laundry Cycle	Mean Difference	Standard Error	Sig.
New	1	.112	.004	.000
	6	.166	.004	.000
	12	.182	.004	.000
One	New	-.112	.004	.000
	6	.054	.004	.000
	12	.069	.004	.000
Six	New	-.166	.004	.000
	1	-.054	.004	.000
	12	.016	.004	.003
Twelve	New	-.182	.004	.000
	1	-.069	.004	.000
	6	-.016	.004	.003

Summary

The analysis of each test provided us with the trends and statistical significance between both the fibers, and washing cycles. In the dimensional stability test there was a significant difference between fibers. Rayon from bamboo shrunk significantly more than cotton. In the test of fabric hand there was a significant difference between the drapability of the fibers. Rayon from bamboo was the more drapable fabric. While the softness panel came out inconclusive, there was no evidence to prove an increase or decrease in the hand of the drape. Fabric weight, thickness and density proved to be significant between the two fibers. Rayon from bamboo was significantly heavier than cotton. The cotton was thicker than the rayon from bamboo, and finally the density was lower in the cotton fabric than in the rayon from bamboo fabric.

CHAPTER 5

CONCLUSIONS

Dimensional Stability

The shrinkage evidenced by these two fabrics was substantial and significant. The cotton fabric followed the model illustrated by (Higgins et al., 2003) where there was significant relaxation shrinkage on the first wash, but then residual shrinkage continued throughout the ensuing washes. According the research, the fabric should have reached its shrinking capacity by the 10th wash. When the cotton was measure at the twelfth wash both the warp and weft yarn seemed that they had plateaued at their current dimensions as evidenced by the low standard deviation for that wash. This finding is consistent with the trend of relaxation shrinkage, and could lead to the conclusion that shrinkage in the cotton fabric had concluded. Further testing would need to be done to confirm this theory. This type of shrinkage would be due to the tight lattice structure of the plain weave, which did not allow the yarns to fully swell resulting in partial relaxation shrinkage, which enabled shrinkage throughout successive washings (Higgins et al., 2003).

The type of shrinkage undergone by the rayon from bamboo may have differed from the cotton in several respects. While the cotton shrinkage was due to relaxation shrinkage, the rayon from bamboo fabric may have had a combination of relaxation and progressive shrinkage. Cotton is not affected by progressive shrinkage because of its high wet modulus strength, whereas rayon from bamboo exhibits low wet modulus strength and is thus extremely susceptible to progressive shrinkage. This test design cannot prove whether the dimensional change was due to relaxation or progressive shrinkage, but a combination of the two types of shrinkage could definitely be a plausible explanation for the dramatic shrinkage exhibited by the rayon from bamboo. Further research would have to be conducted to determine whether or not progressive shrinkage was a factor. The presence of progressive shrinkage could be evidenced by continuation of shrinking at further washing cycles.

ASTM Standard 5431 gives specifications for acceptable amounts of shrinkage for woven cotton sheeting (ASTM, 2004). According to the published standard (ASTM, 2004), woven cotton sheeting should not shrink more than 8% in the warp direction and 6% in the weft direction. According to the test results, the cotton sheet tested shrunk 8.75%, which is unacceptable according to the ASTM standards. The weft yarns shrunk 3.92% qualifying the weft shrinkage as acceptable. The rayon from bamboo warp and weft yarns showed shrinkage of 13.1%, and 6.75%, respectively. While there is no official standard published regarding acceptable shrinkage for rayon from bamboo fabrics, when comparing the amount of shrinkage in relation to cotton an unacceptable dimensional stability can be assumed.

The warp yarns shrunk significantly more in both the cotton and the rayon from bamboo fabrics. This can be largely attributed to the weaving process of the sheets as the warp yarns were pulled tighter than the weft yarns, and thus have further need and room for relaxing.

Fabric Hand

A number of factors contributed to the higher drapability of the rayon from bamboo than cotton. Rayon was made of filament fibers, while cotton was made from staple fibers. Because filament fibers do not need as much twist to hold them together structurally, drape is increased. Conversely, cotton is made out of staple fibers, which require a higher degree of twist resulting in a less drapable fabric. Another factor that could account for an increase in drapability would be an applied finish or finishes. Since the fabric treatments before the purchase are unknown, it cannot be proven that there is a direct relationship with an applied finish, but even a simple calendaring would have contributed to fabric drapability. Depending on the type of finish, it may wear off through the laundering cycle, thus improving drapability and altering our results at each laundered level. The structural change exhibited by the dimensional stability could also account for some change in drapability as the yarns were drawn closer together and the yarns per inch increased. The drapability of both the cotton and the rayon from bamboo increased, enhancing select aesthetic properties.

An increase in drape is beneficial to both the cotton and the rayon from bamboo. Specifically applied to bed sheets, an increase in drape allows the fabric to settle around the contours of the body. This could facilitate more effective moisture transport, because more surface area of the sheet is in direct contact with the skin. This facilitates absorption, and or wicking as the moisture is removed from the skin, affecting the overall comfort of the sheet. Since both fibers are hydrophilic and contain relatively high moisture regain percentages the moisture will transfer readily once in contact with the skin (Johnson & Cohen, 2010). While the physical touching of the skin does not account for all moisture transport such as the transport of insensible moisture, it does have a positive effect.

Because the hand of rayon from bamboo is often its strongest marketing point, it is significant that the fabric hand retained relative quality. While the softness panel came back inconclusive it did not indicate that the softness clearly degraded over time. Maintaining softness is acceptable, while the loss of softness would invalidate the softness claims, decreasing the overall performance of the fiber.

Compared to cotton, the rayon from bamboo had better drapability. The aesthetic appeal of a fabric is very influential in the marketing and salability of the fabric. Prostrel (2004) described the significant effect that aesthetic value has on consumers, and is often a primary motivator behind the purchase of a product. The aesthetic value of a product should not be overlooked, and rayon from bamboo has displayed a few very significant hand characteristics. Even if there are other drawbacks to the rayon from bamboo, a positive, durable, and substantial aesthetic appeal related to hand largely contributes to the marketing of the product.

Fabric Weight, Thickness, and Density

Both cotton and rayon from bamboo evidenced a significant change in weight. The shrinkage of the fabric through the laundry cycles was the primary reason for this phenomenon. Throughout shrinkage the yarns draw closer together resulting in more yarns per inch thus increasing the weight of the fabric. Similarly, the rayon from bamboo gained more proportional weight than the rayon, and the rayon also shrunk significantly more than the cotton. Factors such as lint or fiber loss did not seem to have a significant effect on the results.

Fabric weight is often used to identify the quality of fabric. In general a lower fabric weight would be graded as a lower quality. If either of the fabrics lost weight throughout the laundering cycle it would provide a concern regarding the overall quality of the fabric, but an increase in weight does not indicate degradation in fabric. In relation to fabric weight, bot the rayon from bamboo and cotton fabrics, while significantly different, maintained fabric quality through washing cycles. It should also be noted that the rayon from bamboo did exhibit a higher weight than that of cotton throughout the duration of the testing. This could lead to a conclusion that in regards to fabric weight, the rayon from bamboo was a superior grade.

The thickness of both fabrics also increased as the laundering cycles increased. The biggest addition of thickness was found at the first washing cycle, which makes sense when taking into account the changing fabric structure closely related to dimensional stability. As the warp yarns shrunk, the yarns were brought closer together. When the fabric was new the yarns were approximately in a linear pattern along both grains of the fabric, but as shrinkage occurred the yarns were brought closer together forcing them out of their linear position into a more variegated position. Through successive washings the thickness changed slowed in close proportion to the residual relaxation shrinkage that took place. Further tests could be conducted confirming the stabilization of fabric thickness during the stabilization of dimensional stability.

The density of a fabric is the measure of weight in relation to volume. Consequently, the mass of the fabric divided by the volume provides the density measurement for the fabric. Hence, both the weight and thickness measurements are essential in figuring density, and play a very large role in the effects that density has on the fabric as a whole.

The densities of both rayon from bamboo and cotton decreased during the washing cycles. A large contributing factor to this was due to the changing dimensional stability of the fabric as explained in relation to weight and thickness. Cotton began with a lower density and ended with a lower density, although the decrease of rayon from bamboo did seem relatively proportionate to that of cotton.

Two of the most prominent impacts that density has on a fabric are moisture transport and heat transfer. Both moisture transport and heat transfer are impacted in a positive manner by lower fabric densities. As the density in a fabric increases there is more dead space within the interstices of the fabric, which serves as a barrier to outside temperatures, and a type of insulator to the temperatures. The regulation of temperature is valuable in the bed sheet application due to consumer's desire to be warm during the winter months. Moisture transport is better facilitated through fabrics with the lower densities, as both the sensible and insensible vapors are allowed to pass through the dead air spaces of the fabric and into the outside environment. It is important to note that the density of the fabric would not have as much of an impact as the actual fiber, but it is a contributing factor. Both the moisture transport and the heat transfer are comfort properties desired by consumers when considering the purchase of bed sheets. The decrease in density in both fabrics leads to a positive influence on the overall comfort of the bed sheet.

Summary

Rayon from bamboo and cotton are significantly different from one another. On occasion some of the performance characteristics of each are the same, but as outlined by this completed research study variation exists. Rayon from bamboo is the heavier fabric, and exhibits greater hand in relation to drape and softness. However, rayon from bamboo is not dimensionally stable. Further testing involving more laundering cycles could be done to determine the final degree of shrinkage exhibited in bed sheets constructed with rayon made from bamboo. While the density of cotton is slightly lower than that of rayon, it is comparable. In relation to the dimensional stability of rayon from bamboo the findings of this research study conclude that rayon from bamboo is unsuitable for the application of a bed sheet. Transversely, findings from the other tests conducted (drapability, density, weight, and thickness) suggested that rayon from bamboo would be appropriate and suitable for the bed sheet application.

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