TECHNICAL BULLETIN

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TRI 4011

Laser Applications on Cotton Textiles

CONTENTS

INTRODUCTION

Laser is an acronym for 'light amplification by stimulated emission of radiation.' Laser light has four fundamental characteristics:

- Monochromaticity
- Coherency
- Collimation
- Intensity

The monochromaticity of a laser is cause by the intrinsic features of the atom or molecule that is subjected to excitation. The light that is released as an electron in the atom, or molecule, drops from a high energy state to a lower energy state will have a specific wavelength. The monochromaticity of the laser contributes to the coherence of the laser as all photons are released with the same energy and are in phase with each other. Collimation describes waves of light which travel parallel to one another and are neither converging nor diverging. Collimation is achieved through the use of laser mirrors and by emitting the beam from a narrow aperture. The coherence of laser light makes collimation relatively easy to achieve. Laser light is intense because it is produced by energy that is highly organized, which allows a large amount of energy to be emitted from a small aperture. Optical lenses can also be used to focus the light and increase the intensity of a laser (Nayak and Padhye).

Lasers are classified based on their potential for causing injury. Seven laser classes have been established by the Laser Institute of America (LIA) and adopted into a standard by the American National Standards Institute (ANSI)

Table 1. Laser Classes as Defined by ANSI Z136.1-2007

Laser Class	Hazard Considerations	Control Measures
Class 1	Incapable of producing damaging radiation levels	Exempt
Class 1M	Incapable of producing damaging radiation levels unless viewed with an optical instrument	Exempt, other than to prevent optically aided viewing
Class 2	Emits visible light at 0.4-0.7µm	Eye protection is normally provided by an aversion response
Class 2M	Emits visible light at 0.4-0.7µm	Eye protection is normally provided by an aversion response. Can be hazardous if viewed with optical aides
Class 3R	May be hazardous to the eye if it is focused and stable, however risk of injury is small	Will not pose a fire hazard or diffuse reflection hazard
Class 3B	May be harzardous to the eye under direct and specular reflection	Does not normally pose a diffuse reflection or fire hazard
Class 4	Hazardous to the eye or skin from direct beam	May pose a diffuse refletion or fire hazard. Can produce laser generated air contaminants and hazardous plasma radiation

HISTORY

The earliest known conceptualization of lasers dates to 1916, when Albert Einstein theorized that atoms could release excess energy in the form of light. Einstein proposed that this phenomenon could occur spontaneously or as a result of stimulation (Einstein 1916). Lasers remained a theoretical concept until the 1950s, when Charles H. Townes proposed that coherent output could be produced at microwave frequencies by allowing stimulated emissions to oscillate in a resonant cavity. He demonstrated this concept in 1954 with the world's first 'maser' or microwave amplification by stimulated emission of radiation (Hecht).

Townes theorized that coherent output could be produced at other wavelengths and he discussed his ideas with a doctoral student named Gordon Gould in 1957. Townes and Gould both worked on this concept independently; Townes wrote research papers while Gould filed patents and coined the term 'laser.' The interaction between Townes and Gould led to decades of litigation as each had a credible claim as the inventor of the laser. The paper that Townes and his collaborator Arthur L. Schawlow published in 1958 titled "Infrared and Optical Masers" started a flurry of activity in laser research (Schawlow and Townes). Many researchers working in different universities, companies, and countries made discoveries and developed practical applications concurrently in the years 1960-61. Laser research continued at a rapid pace throughout the rest of the 1960s. However, the focus of that research diverged as researchers selected different laser media and sources of energy for their studies (Hecht).

The carbon dioxide (CO_2) laser was developed in 1964 by Kumar Patel while working at Bell Laboratories. By the following year, Patel had demonstrated continuous wave operation of a CO_2 laser at 200W and attracted commercial interest in manufacturing CO_2 lasers. Edward Gerry and Arthur Kantrowitz invented the gas dynamic laser while working at Avco Everrett Research Laboratory. The gas dynamic laser would eventually reach operation power of hundreds of kilowatts. This increase in power greatly expanded the potential commercial applications of CO_2 lasers.

Laser finishing on denim garments was pioneered by Florida based Icon Laser Technologies. William J. Lockman and Frank J. Clayson filed a patent titled "Method for Marking and Fading Textiles with Lasers" on July 31, 1994. This patent focused on using neodymium-doped yttrium aluminum garnet (Nd:YAG) or CO_2 lasers to replicate stonewashing and acid washing on denim. By 1998 Icon Laser Technologies had licensed its technology to Levi Strauss and installed laser marking equipment in flagship retail stores in San Francisco and London. In addition to licensing technology to garment brands, Icon Laser Technologies collaborated with European textile machinery manufacturers. Icon shared information with Jeanologia and then licensed its technology to Tonello in 2003 (W. Lockman). Jeanologia and Tonello both exhibited laser-etched denim samples at ITMA in 2003 (Moser).

Jeanologia has established itself as an industry leader in promoting the use of laser technology for denim finishing. In addition to promoting the environmental advantages of laser finishing, they also focused on creating software with design tools to mirror the processes seen in traditional denim finishing. One of the major hurdles to early adoption of laser finishing for denim was the opinion that the process would result in goods that looked "inauthentic." In 2008, Jeanologia launched an exhibit called "Truth & Light" in Barcelona, Spain. This exhibit displayed original vintage denim garments alongside copies that were processed using laser technology. Denim industry experts were invited to view the exhibit and challenged to see if they could distinguish the original garments from the reproductions. The exhibit was well-received and went on to tour New York, Shanghai, Sao Paulo, Paris, and Munich.

The development and adoption of laser finishing on denim faced a major set-back in the 2010s. Much like the dispute between Townes and Gould in the 1950s, there was a conflict between patent holders and active users of the technology. On August 18, 2014 RevoLaze, LLC and Technolines, LLC filed a complaint to the U.S. International Trade Commission alleging that the import of laser abraded denim garments violated sections of the Tariff Act of 1930 by infringing on patents held by the complainants (O'Laughlin). The complaint targeted an assortment of well-known fashion brands. Some brands chose to resolve the dispute through a combination of settlements and licensing agreements, while others discontinued the use of laser technology.

TYPES OF LASERS

The classes of laser are defined by the hazards that they pose to human operators; the type of laser is defined by the lasing media. Lasing media are the substances in a laser system that are excited by energy input. The most effective lasing media are capable of existing in a metastable state. This is an excited energy state that can be maintained longer than a typical excited energy state. There are six general categories of lasers based on the lasing media.

- Gas
- Chemical
- Dye
- Metal Vapor
- Solid State
- Semiconductor

Different sources of energy are required for stimulation of different lasing media. The most common energy sources are electric discharge or electric current. Some lasers use other lasers as the energy source for stimulation. Chemical reactions are used as the energy source for chemical lasers.

Gaseous state lasers are activated by passing an electric current through a gas. Carbon dioxide (CO_2) and Helium-Neon (HeNe) are two of the more common lasing media used in gaseous state lasers.

USE OF LASERS ON TEXTILES

The lasers that are most commonly used for textile processing are Class 4 carbon dioxide lasers. Carbon dioxide lasers are high powered and relatively efficient compared to other lasing media. They are capable of operating as a continuous wave. The 10.6μm wavelength produced by carbon dioxide lasers is in the infrared region of the electromagnetic spectrum. The beam of energy is in the form of heat, which is used to burn away the surface of the material that it strikes. Carbon dioxide also has the advantage of being a readily available material that is relatively safe.

Lasers of this type often require a chiller to maintain steady operation and prevent overheating. Chillers circulate water or a mixture of water and ethylene glycol to cool the laser generator and optics.

Denim Applications

Laser etching has seen widespread adoption in the denim finishing industry. There is a great consumer demand for jeans that appear to be worn and faded at the point of purchase. Many of the traditional techniques used in denim finishing are not environmentally friendly and may pose a hazard to garment workers. Laser applications can be used to replicate some of these techniques including sandblasting, spraying with potassium permanganate, and using sandpaper to abrade the fabric surface by hand.

Sandblasting is a fast and low-cost process; factory workers spray jeans with abrasive sand under high pressure. Although brands, retailers, and countries have banned sandblasting because of its harmful effects on workers' health, it is still prevalent in denim finishing. Laser etching can easily replicate the look of sandblasted denim since both processes physically remove the indigo dyed surface of the yarns. Laser etching provides more consistent results through digital files while sandblasting relies on the skill of equipment operators.

Spraying the fabric with potassium permanganate at various concentrations achieves distressed appearances and whitening effects. However, potassium permanganate can irritate and burn workers' skin and eyes, and long-term exposure can cause lung damage. Potassium permanganate can also degrade the fabric when used at high concentrations and contribute to yellowing if it is not thoroughly neutralized. Residual manganese dioxide will appear as brown stains on the fabric if it is not thoroughly rinsed following neutralization. Laser etched materials can benefit from a simple rinse to remove the char for aesthetic reasons and to eliminate residual odors from burnt material. No neutralization step is needed for laser etching and the char is easily removed, but it will not damage the material if it is left on the fabric.

Hand sanding also exposes workers to dust and is labor-intensive. Laser finishing technology offers a more efficient and safer way to achieve the same distressed looks.

Figure 1. A series of sample garments produced by Soorty denim mills to demonstrate laser finishing techniques from unprocessed (left) to heavily altered (right).

The indigo dye and the heavy weight constructions used in denim contribute to its suitability for laser finishing. Indigo is a large molecule that does not readily penetrate a yarn bundle and is instead deposited on the surface. The laser removes the blue surface of the yarns to reveal the white center. The 3x1 twill construction that is most often used in denim is robust enough to handle this loss of material without losing its structural integrity. The indigo dye structure is also vulnerable to discharging by heat. This allows tonal looks to be achieved on indigo dyed fabrics that are made from finer yarns that do not have a white core.

Garment Handling

Laser etching machinery for the textile industry are typically equipped with flat tables of varying dimensions or with inflatable mannequins. Garments are most often manually aligned by an operator. A laser with a wavelength around 650nm is used to produce light in the visible region. This provides a bright red outline to use as a guide for positioning garments, prior to etching with the invisible 10.6µm infrared laser. Figure 2 illustrates using a visible laser as a guide for positioning a design on a back pocket.

Figure 2. Visible red laser outline for positioning garments.

Some new models of laser etching machinery use cameras and image processing software to align designs automatically. Figure 3 illustrates overlaying a digital design on a photo of a garment. The most advanced systems can track and mark garments on a moving conveyer belt.

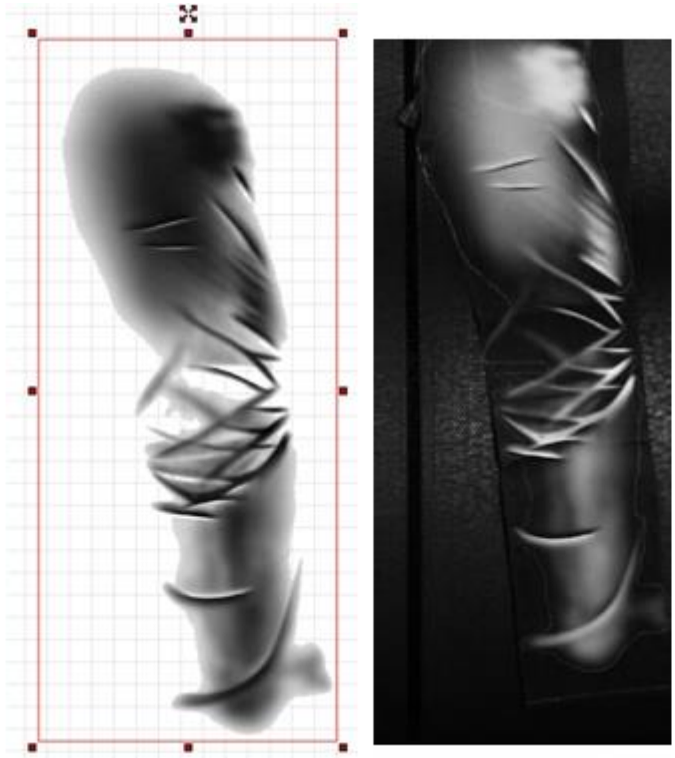

Figure 3. Greyscale bitmap design for laser etching (left). Inverted greyscale design, overlayed on a photo of jeans (right).

File Types

Bitmap images are rows and columns of square pixels. Each pixel is mapped and has a numerical color value. Laser marking software reads grey scale values to determine the intensity for marking each pixel. Pixel time is measured in microseconds (μs). The darker the pixel, the longer the laser will remain in that area. Grey scale values range from 0-255, with 0 being black and 255 being pure white. The threshold color for laser marking can be set lower than 255 to allow the software to ignore some portions of the bitmap data and streamline the marking process. Setting the threshold limit to 220 is common, but the appropriate limits for threshold color vary for each textile substrate and each laser.

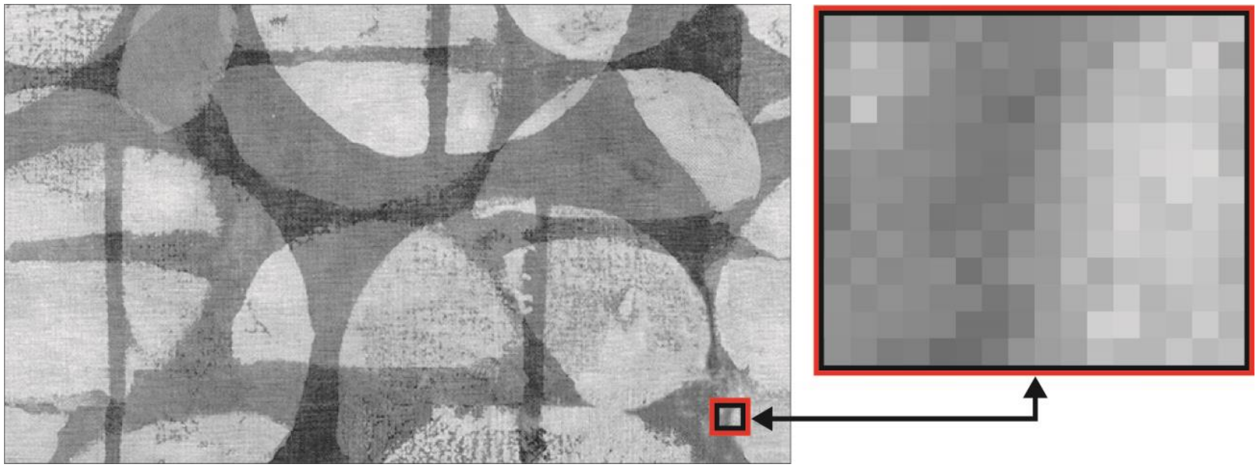

Figure 4. Enhanced view of pixels in a greyscale bitmap image

The point of contact for the laser beam has a dimension which is sometimes referred to as kerf. Kerf is a term borrowed from the woodworking industry; it describes the width of a saw blade. If the resolution in pixels per inch is finer than the kerf of the laser then the laser beam will make overlapping contact on the fabric surface. This can cause physical damage to the substrate and can even cause ignition if the marking intensity is high enough.

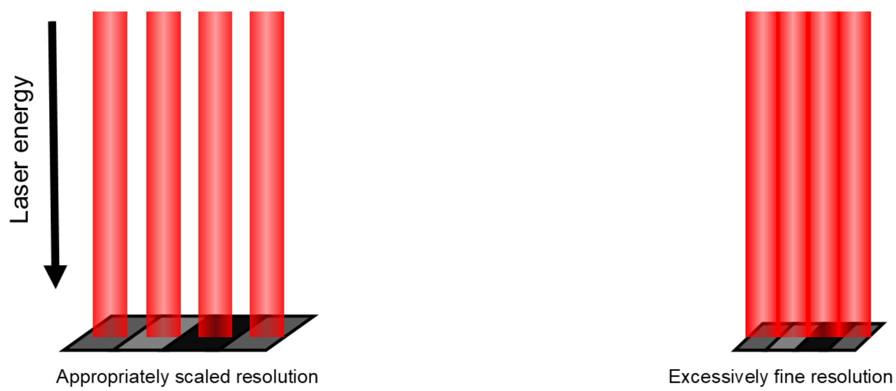

Figure 5. Representation of varing the resolution of a bitmap image while the laser kerf remains constant.

Vector graphics are made up of lines that have mathematically defined magnitude, direction, and position. The laser marks vector files by running continuously while tracing over solid lines. The intensity of the laser marking is determined by the duty cycle of the laser and the marking speed of the laser. Lowering the duty cycle percentage will reduce the amount of energy emitted from the laser. Slower marking speeds will etch or cut more deeply. Files for vector marking should be designed in a way that prevents lines from crossing. Re-marking a previously marked area is likely to damage the substrate and may cause ignition. Sharp changes in direction should be avoided for the same reason.

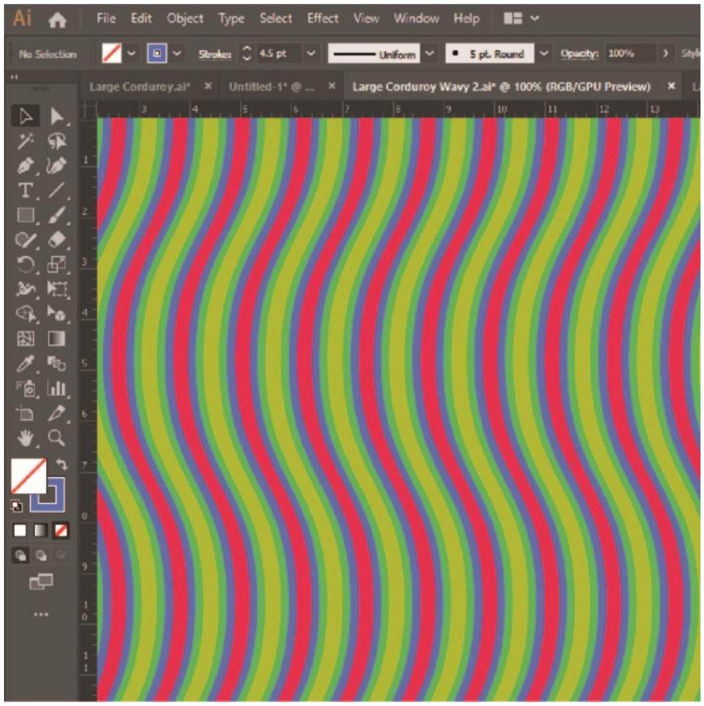

Figure 6. Representation of a vector design with color coded lines for variable marking speed.

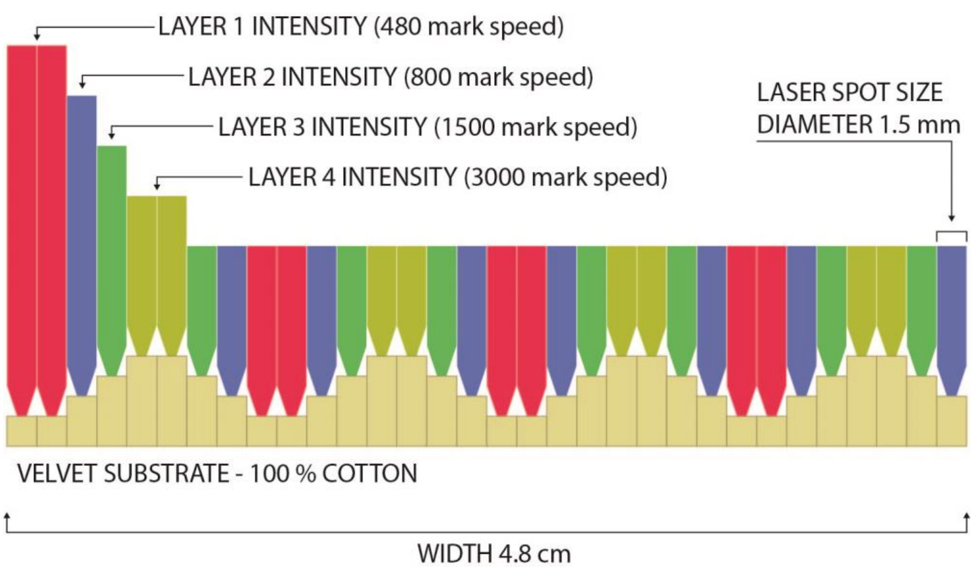

Figure 7. Cross section of the vector design in Figure 6.

Figures 6 and 7 illustrate the affect achieved by marking a vector design using variable speeds for adjacent lines. The curved lines are smooth and do not cross paths. The results of laser etching with this technique are displayed in Figure 12.

Laser Patterns

Patterns and photo realistic images can be marked with a laser. This is most often done using bitmap files. The number of distinctive grey scale values that can be produced by laser etching is limited by the characteristics of the fabric. Six to eight different shades can be reasonably expected on indigo ring dyed denim. It may be possible to achieve more variations in grey scale by separating the bitmap image into layers and using multiple passes of the laser.

Figure 8. FABRICAST SK-2060-2A Marking an image with a laser on a medium weight indigo dyed knit

Laser patterns can also be marked on materials that were not dyed with indigo. Some reactive dyes can be discharged by laser etching though these materials usually achieve much less shade variation than indigo ring dyed goods. Unconventional dyeing techniques may improve the suitability for laser etching. Figure 9 displays a FABRICAST project dyed with dichlorotriazine reactive dyes where the alkali was added into the bath prior to adding the dyestuffs. This dyeing method encouraged a high strike rate on the surface of the fabric and prevented the dye from diffusing evenly through the material.

Figure 9. FABRICAST DK-2747-1L Marking an image with a laser on reactive dyed spacer knit.

Laser Cutting

Laser cutting is used extensively for soft signage and narrow-width synthetic goods. Laser cutting is favored for delicate fabric constructions because it is a non-contact method that will not distort the material (Nayak and Padhye). Laser cutting is not as common on cotton textiles because the laser does not have the added benefit of sealing the edges as it does with synthetic textiles. Figure 10 displays chambray fabric that was cut using the same digital file. A holographic foil was applied to 7014A with foil adhesive, prior to laser etching. The foil adhesive seals the cut edges and prevents the cotton yarns from fraying during the post laundering process producing a result similar to laser cutting on synthetic textiles. Contrast this with 7014B where the cut edges of the cotton chambray fabric frayed during laundering.

Figure 10. Foil adhesive seals cut edges and prevents fraying

Laser cutting can be precisely controlled to limit the depth of cuts on fabric. This technique can be used to cut through a single layer of a double cloth fabric, to carve 3-dimensional texture into a pile fabric, or to create texture on medium to heavy weight fabrics. Figure 11 demonstrates the difference in texture that results from etching the same vector file on the back versus the face of a broken twill fabric, selectively cutting either the fill or warp yarns.

Figure 11. Demonstration of the results achieved by scoring the back vs. the face of a fabric using a laser vector file

Figure 12 demonstrates the effect that is achieved by marking the face of a velvet fabric with a vector file while varying the marking speed of individual lines. Slower marking speeds cut the pile more deeply.

Figure 12. Demonstration of the results achieved by varying the marking speed of lines in laser vector files

Laser Curing

Some low temperature curable resins can be fixed using the heat from a laser. This can be used for curing some adhesives, pigment binders, and dye resist resins.

Figure 13. FABRICAST SK-2016-4 Curing of dye resist resins by laser marking

Figure 13is an image of a lightweight reverse slub jersey. This project was dyed a pale rose shade with reactive dyes. The fabric was then sprayed with resin and catalyst and dried at 70°C. The fabric was then laser etched with a floral pattern that cured the dye resist resin onto the fabric. The fabric was then overdyed a lavender color with reactive dyes and the uncured resin was rinsed away during the dyeing process.

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RESEARCH AND TECHNICAL SERVICES

Cotton Incorporated is a research and promotion company representing cotton worldwide. Through research and technical services, the company has the capability to develop, evaluate, and then commercialize the latest technology to benefit cotton.

- Agricultural research leads to improved agronomic practices, pest control, and fiber variants with properties required by the most modern textile processes and consumer preferences. Ginning development provides efficient and effective machines for preservation of fiber characteristics. Cottonseed value is enhanced with biotechnology research to improve nutritional qualities and expand the animal-food market.
- Research in fiber quality leads to improved fiber testing methodology and seasonal fiber analyses to bring better value both to growers and to mill customers.
- Computerized fiber management techniques result from in-depth fiber processing research.
- Product Development and Implementation operates programs leading to the commercialization of new finishes and improved energy- and water-conserving dyeing and finishing systems. New cotton fabrics are engineered — wovens, circular knits, warp knits, and nonwovens — that meet today's standards for performance.
- Technology Implementation provides comprehensive and customized professional assistance to the cotton industry and its customers — textile mills and manufacturers.
- A fiber-to-yarn pilot spinning center allows full exploration of alternative methods of producing yarn for various products from cotton with specific fiber profiles.
- The company operates its own dyeing and finishing laboratory, knitting laboratory, and laboratory for physical testing of yarn, fabric, and fiber properties, including high volume instrument testing capable of measuring micronaire, staple length, strength, uniformity, color, and trash content.

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